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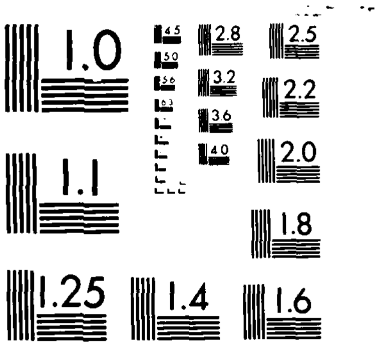

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AGGREGATING INDIVIDUAL PREFERENCES IN THE ANALYTIC HIERARCHY PROCESS APPLIED TO THE 1983 BATTELLE TAV STUDY

THESIS

Stalker E. Reed
Major, USAF

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This investigation showed that the Analytical Hierarchy Process (AHP) group priority vector was independent of three aggregation techniques: geometric mean input, arithmetic mean vector output, and majority rule output. The AHP consistency index was correlated (Kendall's Tau) with Kendall's Coefficient of Consistence when the AHP inputs were converted to a "voting" matrix - 0,½,1 for each pairwise comparison. Minor respondent dissatisfaction with the AHP priority vector suggested that the scale in surveys should be presented to reflect the ratio versus interval scale.

Eleven judges from the 1983 Trans-Atmospheric Vehicle (TAV) steering committee participated. They completed pairwise comparisons throughout a revised hierarchy of the 1983 Battelle TAV study. The study includes Apple Pascal computer codes to manipulate the input files.

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AGGREGATING INDIVIDUAL PREFERENCES IN THE ANALYTICAL HIERARCHY PROCESS APPLIED TO THE 1983 BATTELLE TAV STUDY

THESIS

Presented to the Faculty of the School of Engineering
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In Partial Fulfillment of the
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Stalker E. Reed, M.A.
Major, USAF

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Preface

The purpose of this study was to investigate the effect that different aggregation methods have on the group priority vector determined by the Analytical Hierarchy Process (AHP). Three aggregation methods were applied to a previously accomplished study to determine the rank order correlation for the respective priority vectors and consistency measures.

The previous study was the Battelle Columbus Laboratories' 1983 Trans Atmospheric Vehicle (TAV) feasibility analysis for the Aeronautical Systems Division of USAF Systems Command. The "revised" Battelle study provided a hierarchy of 32 criteria to evaluate 14 TAV design proposals. The judges were 11 of the original 13 TAV steering committee members who responded to Battelle's questionnaire to provide the top level objective weights.

The first aggregation technique determined the geometric mean of the 12 input comparisons prior to the calculation of eigenvector (priority vector). The second method determined the arithmetic mean of the judge's priority vectors. The third method converted the AHP input ratios to ordinal preferences and determined the group priority vector by the percentage of "votes" for each objective. The examination of the geometric mean of the priority vectors was not examined in this research.

The results showed that the three aggregation techniques produced correlated priority vectors. Also, the consistency measures for the ordinal matrices and the AHP matrices were highly correlated. Graphical analysis indicated that ratio "distance" may be preserved between preferences when ratio scale inputs are converted to ordinal preferences. However, this interpretation must consider the bias caused by creating the "voting" matrix directly from the AHP inputs, rather than rather than from an independent survey. Further study will be necessary to determine the number of judges and the number of criteria necessary for this preservation of distance.

In performing the surveys and writing this thesis I have had a great deal of help from others. I am indebted to my faculty advisor, LtCol Mark Mekaru, and my reader, Major Ken Feldman for their insight and lifting spirits. I also wish to thank members of the TAV steering committee for their expeditious assistance in this endeavor, with particular thanks to Dr. Eric Rice and Dr. Jerry Arnett for their invaluable information and advice. Finally, I wish to thank my wife Gerry for maintaining an even keel during these stormy six monthes.

Stalker E. Reed, III

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Abstract

This study showed that Analytical Hierarchy Process (AHP) group priority vector was independent of the three aggregation techniques examined. Also, the (AHP) consistency index was correlated with Kendall's Coefficient of Consistence. The study applied the AHP to Battelle Columbus Laboratories 1983 TAV study using 11 of the original members of the 1983 TAV steering committee.

The first aggregation technique used the geometric mean of the 12 input comparisons to calculate the group priority vector. The second method used the arithmetic mean of the judges' priority vectors to calculate the group priority vector. The third method converted the AHP input ratios to ordinal preferences and used the percentage of preferences for each objective to determine the group priority vector.

The analysis used Apple Pascal computer code for manipulating the AHP input files. Kendall's correlation coefficient, tau, showed significant rank order correlation between the three group vectors. Also, graphical analysis indicated that strength of preference was preserved when converting from a ratio to ordinal scale. Minor dissatisfaction with the priority vectors suggests that when administering the AHP by survey, the comparison scale should be displayed to reflect the logarithmic nature of the input ratios.

different aggregation methods. The examination of the statistical properties of the Kemeny and Snell correlation is outside the realm of this study. However, the Kemeny and Snell correlation's similarity to tau supports the use of tau as a statistical evaluation in this thesis. The discussion on tau as a correlation measure between two rank orders will be in chapter IV, Methodology.

Opinion Elicitation. Robert Fallon showed in "Subjective Assessment of Uncertainty" that biases in a person's background affect his prediction of future events. He showed how current availability, anchoring, and representativeness distort one's assessment of uncertainty in probabilistic terms (Quade, 1970:287). Although there is little one can do to diminish this bias, the analyst must be aware that despite perfect consensus among undisputed experts, there are inherent biases that may distort the entire prediction. An example would be the error in predicting the cost of 1982 petroleum during the 1973 oil embargo.

Saakman criticizes the entire process of eliciting expert opinions. Directed at the Delphi technique, the criticisms apply equally well to any of the elicitation methods discussed in this thesis. Saakman points out the following weaknesses in soliciting opinions from experts:

> The questionnaires should be administered under rigorously controlled conditions.

chapter.

Distance Functions. In 1962 Kemeny and Snell began a research thrust in priority vectors achieved by ranking. They proposed that committee rankings be viewed in terms of a "distance" measure. Such a measure relative to a pair of rankings would be an indicator of the degree of correlation between rankings. They established a set of axioms which any such measure should satisfy, and proved its existence and uniqueness. Their set of axioms is similar to Arrow's axioms, except the former does not require the "irrelevant alternatives" condition (Kemeny and Snell, 1962).

Kemeny and Snell used their distance function to propose the median and mean rankings as acceptable forms of consensus. Bogart, however, showed that in the general setting Kemeny and Snell's means and medians were not necessarily unique. It would be necessary to restrict the orderings to an odd number to achieve uniqueness (Bogart, 1973:65).

Bogart showed that in the case of linear orderings, the Kemeny and Snell correlation measure was the same as Kendall's tau (Bogart 1973:44). However, for partial orderings (indifference) its value diverges from tau. Bogart suggests further study of the properties of this statistic in the cases in which it differs from tau.

This research does not address Bogart's suggested study because the focus is on comparing priority vectors derived by decision maker, be she the group itself through an interactive process, or a benevolent dictator, to weight the inputs of the individuals. That is, the supra may give twice the weight to Joe's opinions over Fred's opinions because Joe has 30 more years of experience. This process to combine individual values into a group value is more fully discussed under Value Theory, this chapter. This research will attempt to apply interpersonal value comparisons to achieve "more rational" (transitive) group decisions, as explained in Chapter IV, Methodology.

Arrow showed that group decisions may be intransitive and Keeney showed that the intransitivity may be reduced by interpersonal value comparisons. The critical issue is the degree of intransitivity of the group decision. The more intransitive the group decision is, the less it reflects the individual opinions which leads to a lack of confidence in the results.

This thesis will apply interpersonal value comparisons to reduce the intransitivity of the group decision. In addition, this thesis will apply two aggregation techniques that measure the intransitivity in a series of pairwise comparisons. Saaty's Analytical Hierarchic Process (AHP) measures the consistency in the strength of preferences by the consistency index (CI). Kendall's coefficient of consistence, zeta, measures the intransitivity of voting matrices. Both of these methods are explored in the next impossible. Arrow's conditions are summarized by Blin:

> 1) Any amalgamation method must define a unique order (rationality).
>
> 2) If one alternative rises or remains stationary in order of every individual, then it must not fall in the joint order (positive association).
>
> 3) The addition or removal of an alternative, which results in no change in any individual order of the remaining alternatives, must not cause a change in the order of the remaining alternatives of the joint order (independence of irrelevant alternatives).
>
> 4) The joint order is a function of the individual orders and must not be imposed by some outside influence (citizen's sovereignty, or pareto optimality).
>
> 5) The joint order must not be arbitrarily defined by the order of one individual without consideration of the other individual orders (non-dictatorship).
>
> (Blin and Satterthwaite, 1978:252)

Arrow proved that there is no rule for combining the individual's rankings that is consistent with the seemingly innocuous conditions. That is, there is no procedure that can combine several individuals' rankings of alternatives that will satisfy the five conditions above.

Arrow's Impossibility Theorem implies there is no procedure for combining individual rankings into a personal comparison of preferences (Keeney and Raiffa, 1976:524). Keeney, however, reports that group decisions can be transitive if there is an additional condition: interpersonal value comparisons are allowed (Keeney and Raiffa, 1976:145).

Interpersonal value comparisons allow the "supra"

Chapter II. Literature Review

Introduction

A survey of recent literature reveals numerous methods for soliciting individual opinion and aggregating it into a group consensus. This review will divide the studies in three broad categories: 1) General: includes Arrow's impossiblity theorem and the mechanics of elicitation - rankings, ratings, and pairwise comparisons, 2) Value Theory: includes an explanation of the AHP and fuzzy set theory, and 3) Group aspects: includes dynamics of groups, individual emphasis, and an explanation of Delphi and variations.

General

Arrow. Kenneth Arrow first axiomized majority rule group decisions in 1951 (Arrow, 1963:12). He proved that the aggregation of rational judges results in an irrational group decision. Arrow's "Impossibility Theorem" showed that when the rational conditions of economic social choice were defined, they gave inconsistent group priority rankings. That is, the aggregate choice of transitive judges would be intransitive (Blin and Satterthwaite, 1978:260).

Many theoretical writers responded to Arrow's conditions first published in 1951. Responding to their criticisms, Arrow strengthened three of the five conditions (1,2, and 5), but still showed that a rational group decision was the literature review of pertinent articles and texts that reference the topics under evaluation, with particular emphasis on Delphi, Value Theory, and the AHP. Chapter Three relates the aspects of soliciting and aggregating opinions in the AHP. Chapter Four discusses the methodology used in this thesis and chapter Six interprets the results and dicusses the insights gained, along with a few follow on research ideas.

FIGURE 2

Revised Hierarchy

1		Rapid Response	REQUIREMENTS
2		Flexible Basing	
3		Horizontal TO/Landing	
4		Adverse Weather Ops	
5		Fully Reusable	
6		Single Stage	
7		20,000 lbs Orbit	
8		Sortie Operations	
9		Payload Mass	PERFORMANCE
10		Payload Volume	
11		Trajectory Flexibility	
12			COSTS
13		Propulsion	RISK
14		Structure	
15		Mass Fraction	
16	Amount	Propellant Supply	LOGISTICS
17	# Types		
18	Cyro or Store		
19		Facilities	
20	# Jets	Maintainability	
21	# Rockets		
22	TPS Type		
23	# Elements		
24		Atmosphere/Space Loiter	SURVIVABILITY
25		Mobile Launch	
26		Base Escape	
27		Dispersal Range	
28		Laser Hardness	
29		Radar Cross Size	
30	Space	Maneuverability	
31	Aero		
32	Powered		

priority vectors and consistency measures. Related side issues will be explored, such as discovering the effect that applying Delphi has on the AHP weights and determining the relationship between Saaty's measure of ratio consistency and Kendall's measure of ordinal consistency (transitivity).

The framework used in this study was the Battelle hierarchy. The number of criteria in the Battelle heirarchy was reduced from 47 to 32 as a result of insight gained from the Battelle study and to eliminate redundant criteria. The following elements were changed in the "revised hierarchy," as seen in Figure 2:

Goals and Requirements were combined because of the similar attributes and weighting.

Environmental Impact was deleted because of the low weighting.

Manned Flight was dropped because it failed to distinguish between any alternative (All TAV designs were capable).

5 Minute Launch and 2 Missions per Day were dropped because it failed to distinguish between any alternative (All TAV designs were capable).

Global Range and Number of Expendables were dropped because its attributes were the same as single stage.

Few Orbits was dropped because its attributes were redundant with Loiter capability.

Multiple Dispersal Sites was dropped because its attributes were redundant with Mobile Launch (runway length required).

Overview

This thesis is divided into six chapters. Chapter Two is few studies on how to aggregate multiple decision makers using the AHP. Several questions surface, such as: How effective are aggregation methods that use feedback, such as Delphi, when they are applied with the AHP? How does the priority vector change if the mean is taken of the pairwise comparisons, rather than the mean of the priority vectors? How do these "before" and "after" aggregated AHP vectors compare with established aggregation techniques, such as majority rule?

A related question is to determine the relationship between the different measures of consistency. The ordinal consistency, that is the degree of intransitivity, of voting matrices may be measured by Kendall's coefficient of consistence (zeta). Zeta is a count of the number of circular triads. The interval or ratio consistency is measured by the AHP consistency index (CI). The CI measures the divergence of the individual comparison ratios from the corresponding priority vector ratios. This study will examine the relationship between zeta and CI; their correlation as a function of matrix size, judge identifier, and variance between judges.

Research Objectives

This thesis will make a critical examination of the AHP applied to group decision making using the 1983 Batelle study of the TAV feasibility. The main objective is to measure the effect that different aggregation techniques have on the is likely the decision makers would make different ratings if they knew the attributes that Battelle defined for the study. For example, Battelle determined that "runway length required" would be the driving attribute for "survivability," but the author doubts that the experts used this attribute when making their assessment of "survivability."

The source of the variance between objective ratings is obscured as a result of the judges not using the same attributes. That is, it is difficult to determine if the variance between the judges' ratings came "artificially" from different assumed attributes, or "honestly" from different evaluations of the same attributes. The resulting priority vectors cannot be summed and averaged because the judges may not have used the same attribute definition.

One method to insure the judges are using the same attributes is to ask them to evaluate the lower objectives prior to comparing the next higher level objectives. This will insure that each judge is aware of the subobjectives that make up the next higher level objective. The analytical hierarchy process, applied from the bottom level up, accomplishes this goal. Each judge is asked to compare clusters of objectives regarding their importance to the next level objective.

Research Problem

Despite the fact that the AHP is gaining widespread acceptance as a method to solicit priorities, there has been

Battelle used equal weights for all but three criteria: propellant logistics, and structural risk, and payload performance. These criteria were weighted by a factor of two.

Battelle sent their questionnaire to the 18 member TAV steering committee to elicit their ratings of the eight top level objectives (on a scale from 1 to 10). They received 13 responses as shown in Table 1. The poll was administered once and the arithmetic mean for each objective rating was normalized to obtain the weighting factors. The judges gave their ratings before Battelle had determined the attributes to measure these objectives.

TABLE I

Top Level Complete Battelle Ratings

	Judge													
Obj	1	2	3	4	6	7	8	9	10	11	12	13	14	Ave
1	10	10	10	10	10	10	10	7	10	10	10	10	10	9.7
2	6	8	7	6	6	9	5	5	10	7	8	7	9	7.2
3	6	8	8	10	8	8	10	9	6	8	7	7	10	8.1
4	8	9	10	10	7	5	8	9	4	6	10	8	7	7.8
5	6	5	10	7	5	7	6	9	6	6	8	8	8	7.0
6	8	5	6	7	7	6	10	8	8	7	9	8	9	7.5
7	8	5	9	8	8	10	8	7	7	6	4	9	8	7.5
8	5	1	5	5	2	5	5	4	3	2	3	5	3	3.7

(Battelle, 1983:6-2)

Note:
Judge #13 and 14 not used for subsequent surveys.

The problem with this approach was that the judges did not know the ranges of attributes that made up the criteria (Keeney, 1977:286). Decision makers must not only know the ranges of the attributes, but also they must use the same attributes before comparable assessments can be elicited. It criteria from their in-house experts. As seen in Figure 1,

Figure 1

Original Battelle Hierarchy

1		Manned Flight	REQUIREMENTS
2		Sortie Operations	
3		Global Range	
4		Rapid Response	
5		Flexible Basing	
6		Horizontal TO/Landing	
7		Adverse Weather Ops	
8		Launch 5 Minutes	GOALS
9		2 Missions/Day	
10		Fully Reusable	
11		Single Stage	
12		20,000 lbs Orbit	
13		Few Orbits	
14		Payload Mass (X2)	PERFORMANCE
15		Payload Volume	
16		Trajectory Flexibility	
17			COSTS
18		Propulsion	RISK
19		Structure (X2)	
20		Mass Fraction	
21	Amount (X2)	Propellant Supply	LOGISTICS
22	# Types		
23	Cyro or Store		
24		Facilities	
25	# Jets	Maintainability	
26	# Rockets		
27	TPS Type		
28	# Elements		
29	# Expendables		
30		Atmosphere/Space Loiter	SURVIVABILITY
31		Mobile Launch	
32		Base Escape	
33		Dispersal Range	
34		Multiple Dispersal Sites	
35		Laser Hardness	
36		Radar Cross Size	
37	Space	Maneuverability	
38	Aero		
39	Powered		
40		Troposhere Quality	ENVIRONMENT
41		Upper Atmos Qual	
42		Noise (Launch, Sonic)	
43		Debris/Spent Hardware	
44		Water Quality	
45		Resource Use	
46		Socio Economic	
47		Accidents	

determine the expert's priority vector. Despite the strengths of the AHP, it is a difficult tool to aggregate judges' assessments because of the enormous effort required to achieve a group consensus of the numerous comparisons. This effort is even more cumbersome when applied by mailed survey, as in this study.

This study will examine different techniques to aggregate the preferences derived from the AHP, including versions of Delphi to reduce spurious variance between judges, self expertise evaluations for individual weightings, and various mathmatical aggregation methods to derive the "means." The vehicle used to compare these different methods will be the 1983 Battelle study.

Battelle Study

Battelle sought to determine the feasibility of the TAV concept and to identify which designs were worth pursuing. They evaluated the effectiveness of 14 TAV designs using the following weighted objectives: Requirements, Goals, Performance, Costs, Technological Risks, Survivability, Logistics, and Environmental Impact.

These "top level" objectives were broken into 49 criteria as seen in Figure 1. The entire hierarchy was established by Battelle except the criteria that made up requirements and goals. The requirements and goals criteria were established by Mission Area Analysis at Wright Patterson AFB (ASD/XRS). Battelle determined the attributes for these

Various authors have studied the problem of combining individual preferences into a group choice or consensus. Problems of this nature arise frequently in a variety of areas: marketing of new products, allocation of priorities to R & D projects, etc. In most of these cases, an individual's preference is expressed in terms of ranking available alternatives. The objective in each case is to combine the individual preferences into a group consensus (Cook and Seiford, 1978:1721).

There are two fundamental problems with gathering group opinions: 1) How does one elicit the true individual opinion? and 2) How does one aggregate them to accurately represent the group? Every analysis which uses expert opinions must confront and answer these problems.

In 1983 Battelle Corporation confronted these problems in a feasibility study of the Trans - Atmospheric Vehicle (TAV) for the Aeronautical Systems Division (ASD) of the United States Air Force. They elicited expert ratings to establish the weights for the top level criteria. They asked each respondent to rate each criterion on a scale of 1 to 10. Battelle aggregated the ratings by taking the arithmetic average for each criterion.

This thesis will explore the methods used to solicit and aggregate expert opinions. The focus will be on the Analytical Hierarchy Process (AHP) to solicit expert weights. The AHP uses pairwise comparisons between the objectives to

AGGREGATING INDIVIDUAL PREFERENCES IN THE ANALYTIC HIERARCHY PROCESS APPLIED TO THE 1983 BATTELLE TAV STUDY

Chapter 1: Background

Introduction

Expert judgment must often be used to choose among several alternate courses of action. An expert's presumed intuitive insight provides answers to complex questions that today's quantitative approaches are often unable to answer.

There are several methods to elicit the expert's opionions. Ranking and rating are often used in situations which do not allow a structured decision approach. Such problems are usually characterized by lack of measurable objectives and reliable information (Baas, 1977:47). The decision maker's insight, based on background knowledge and sensitivity to its relevance, is substituted for the "structured decision approach."

Often many experts are consulted because the problems are too broad for one individual. Even in narrow problems, the investment may be too large to rely on a single decision maker to derive all the priorities (Brown, 1968:13). A consensus of these experts is needed to present a unified "group" judgement.

> How the test items were derived should be explained.
>
> What pilot procedures were used for item analysis to prune down the original pool to the final set used for the study.
>
> What psychometric scaling approach was selected?
>
> How were the experts choosen - selective or random?
>
> Are the experts related to objectively defined populations with measureable parameters?
>
> What are expected statistics regarding the precision of results for the sample size and dispersion results?
>
> (Saakman, 1975:59)

Saakman's point was that many methods for eliciting expert weights were unsystematic opinion surveys. Opinion surveys should follow the American Psychology Association (APA) standards of rigorous test development and validation (Saakman, 1975:48). If needed, analysts should seek pyschologist consultants to develop the tests they require to elicit these opinions. Otherwise, the "objective" surveys they apply may, in fact, bias the results more than the interacting group they are trying to avoid.

Experimental Comparison. Analysts however, can increase the validity of their findings by reducing the bias that originates in the actual solicitation. Eckenrode studied variations of three basic mechanics of soliciting weights from individual decision makers: ranking, rating, and pairwise comparison. His study provides an excellent overview to these three general methods. He used Kendall's Coefficient of Concordance to measure agreement among the sets of weights produced by the various methods, as well as the agreement among the decision makers. He found that the methods established very similar weights for the three experiments using factual data, general data, and predictive data. That is, he found that ranking, rating, and pairwise comparison produced essentially the same ordering of weights over a wide range of data types (Eckenrode, 1965:185).

Eckenrode found that rating the objectives produced the greatest variance and the narrowest range between weights. Eckenrode considered small ranges and wide variance to be undesirable characteristics for a method to be used in weighting multiple criteria because of lessoned discrimination. As expected, he found that the degree of agreement appeared to decrease as one moved from a relatively specific system to a more general problem (Eckenrode, 1965:187).

Saaty reported about an experimental test of the AHP by Schoemaker and Waid in 1978 to compare AHP with the multiple regression approach, the multi - attribute utility approach of Keeney and Raifa and simple direct assessment. These four methods differ in several ways: (1) They require different types of judgements, (2) They require different response measures (ordinal, interval, and ratio), and finally, (3), each method can be applied in areas in which the others would be limited (Saaty, 1980:246).

In the experiment, subjects (33) were asked to evaluate hypothetical admissions candidates (20 pairs), in pairwise comparisons, using four attributes only: quantitative SAT, verbal SAT, high school cumulative average, and an index of extra-curricular activity. Their choices between these 20 pairs of candidates was considered the "correct" list to compare four different methods of "automated" decision making functions: the AHP, Regression, Multi Attribute Utility, and Direct Assessment.

To derive these functions the subjects were asked for further judgements (such as comparing the attributes directly) and four linear additive representations were constructed. Below are the correct predictions and Pearson product-moment correlations between the predicted and observed strengths of preference:

	Correct	Correlation
AHP.	84%	.72
Regression	57%	.19
Multi-Attribute Utility. . . .	86%	.75
Direct Assessment.	84%	.77

(Saaty, 1980:246)

The advantages of each method determine its appropriateness for a given application. Eckenrode found that direct assessment required the least amount of time (Eckenrode, 1965:186). Subjects are just asked to rank or rate a single column of criteria. So when time is a critical element and there are simple relationships between the criteria, direct assessment may be the appropriate methodolgy. While it is also likely that an expert can estimate the situation directly and may not do better with the AHP approach, the AHP gives a measure of consistency which is not available in direct methods (Saaty, 1980:64)

Consistency (transitivity) is not required among preferences in the AHP, while the construction of a utility function by multi-attribute utility theory (MAUT) requires a transitive preference relation. Both of these methods deal with the subjective bias of expert judgement. The judgement in terms of a single subcriterion affects the measures of other "independent" criteria. This results in a vector that has bias between its components, sometimes double counting the importance of a subcriterion (Saaty, 1980:237).

One of MAUT's strongest advantages is that it has a well developed methodology for handling situations with risk and encompasses utility functions that are not linear (Keeney and Raiffa, 1976:34). The main disadvantage of MAUT is that the elicitation process is laborious. For repetitious decision making, MAUT, with its "standard" utility function would be more advantageous. However, in practice the utility function changes often and requires constant revisions. Coty explained that:

> MAUT gives a complete orderings of alternatives but at some cost in time spent establishing the functional relationhips among performance indices. The temporal nature of some state vector elements may also cause some difficulty.
>
> (Coty, 1980:AA-15)

Thus, operationally, MAUT looses its advantage over AHP because of its "detailed elicitation to establish form and constituents of scaler social choice function" (DeWispleare and Sage, 1981:16). AHP, on the other hand, can perturb judgments within the hierarchy to get a new set of priorites, without reconstructing the utility function for each period of time. (Saaty, 1980:246).

The regression techniques are strongest in well defined situations that have precise measures. However, in such areas as technology forecasting, these measures are often elusive, and the application of regression is inappropriate and gives distorted results. Saaty was critical of regression techniques (and equal weighting) because they either ignore relevance by using arbitrary statistical objectives, or focus on other subcriteria rather than the global criterion (Saaty, 1980:237). MAUT and AHP are better tools for these "fuzzy" applications.

These results apply directly to this thesis. The original Battelle survey used direct ratings to elicit the experts' opinions. Eckenrode criticized ratings as a poor discrimating tool because of the resulting small range and wide variance between judges. This thesis uses pairwise comparisons to elicit the opinions. Eckenrode found this method more satisfactory because of the smaller variance between judges and wider range of the priority vector.

Value Theory. The overall scores in the AHP can be considered as the valuations of an additive value function (Kamenetzky, 1982:705). Because the AHP's foundation is elicitation of additive value functions, more discussion is necessary on the concepts involved.

Value theory establishes the fundamental conditions for construction of order preserving representation of values on a set of alternatives. There is a distinct line between value functions and utility functions. Preference representation under certainty is referred to as a value function, and preference representation under uncertainty is referred to as a utility function (Keeney and Raiffa, 1976). This research focuses on value functions because decision under certainty is the underlying assumption in the application of the AHP.

A value function relates the value of given attributes. It says that if attribute b is preferred to attribute c then the value of b is greater than the value of c, and vice versa. This relationship can be represented functionally:

$$b \succ c \iff V(b) > V(c)$$

Value functions are classified in two general forms: multiplicative and additive. The additive form of a value function has more restrictive conditions and is the type of value function assumed in the AHP. It allows the value of a given objective to be the sum of the values of its attributes. For the single decision maker the additive form can be expressed:

$$V(X1,X2,\ldots,Xn) = \sum Vi(Xi)$$

(Keeney and Raiffa, 1976:116)

It can be shown that if the V is bounded, this equation can be rewritten:

$$V(X1,X2,\ldots,Xn) = \sum_i WiVi(Xi)$$

Where:

Vi, $i = 1,\ldots,n$ is scaled from zero to one

$\sum_i Wi = 1$

(Kamenetzky, 1982:705)

An additive value function for a group is comparable to the additive value function for an individual. The difference is that the attributes for the group decision maker are the values the individual members ascribe to a given set of attributes. The group decision maker will be referred to as the supra decision maker, and she may be benevolent dictator or the group itself through interaction. The additive group value function, Vg, may be expressed:

$$Vg(X1,X2,\ldots,Xn) = \sum_i Vgi[Vi(Xi)]$$

Where:

Vg = Supra's Value Function
Vgi = Supra's Value of Individual i's Values

(Keeney and Raiffa, 1976:525)

A necessary and sufficient condition for an additive value function is mutual preferential independence (MPI). MPI is implied if every pair of attributes is preferentially independent of its complement (PPI). For a group value function, the attributes $\{Vi,V_j\}$ are preferentially independent of their complement $\underline{V}_{ij}$, for all $i = j$, $n \geq 3$ (Keeney and Raiffa, 1976:524).

Preferential independence implies for any two individuals, i and j, i=j, if all other n-2 individuals are indifferent between a pair of consequences, then the group preference depends only on the preferences of individuals i and j. In particular, the group value function should not depend on the level of preferences of the other individuals (Keeney and Raiffa, 1976:525).

For example, consider a three person group and start with the consequences, X' and X". Now suppose V(X') = V(X") by individual 3. Preferential independence implies that the group preference of X' relative to X" should not depend on whether individual 3 considers X' and X" good or bad. The group ranking of X' and X" should depend only on the opinions of individuals 1 and 2.

If the values of the attributes are not independent, then they cannot be added together. Their representation is limited to the ordinal: >, <, =, scale:

> 1) Utilities experienced on the set of alternatives allow for numerical representations on the ordinal scale.
>
> 2) Additive representation implies independence of the utilities involved.
>
> (Baas and Kwakernaak, 1977:47)

Therefore, attributes must be MPI to have an additive value function, otherwise the preference representation is ordinal. This requirement is not made clear in derivation of the AHP. One of the reasons may be that establishing MPI would eliminate the advantage that the AHP has over MAUT and MAVT - the burdensome elicitation process.

<u>Critique/Comparison.</u> Saaty noted that the scores are independent, but the requirement for preferential independence has not received a "passing mention" in most applications of the AHP (Kamenetzky, 1982:705). Kamenetzky compared the AHP with two other methods that more rigorously establish MPI: the midvalue splitting technique and the lock-step procedure.

In the lock step procedure, the decision maker is asked to identify points in the consequence space among which he is indifferent. By equating the value of these points and arbitrarily assigning the unit of measurement, the unidimensional value functions and the overall value functions are assessed simultaneously. The resulting value function is measured on an ordinal scale.

In the midvalue splitting technique, as in the AHP, the single attribute value functions are assessed independently. Also, like the AHP, this technique consists of two separate steps: (1) assessment of the unidimensional value functions and (2) assessment of the weighting constants (Kamenetzky, 1982:706).

In each of these two steps, there are some perceived advantages and disadvantages of the midvalue splitting technique compared to the AHP. The midvalue method assumes that the decision maker can order the differences in the strength of preference among alternatives. In contrast, the AHP assumes that the decision maker's preferences can be measured on a ratio scale.

Kamenetzky favors the AHP when there are a small number of alternatives for the estimation of the value functions, W_j/i or $Vi(X_ji)$, for the following reasons:

> 1) Pairwise comparison judgments are easy to elicit.
>
> 2) The weights W_j/i synthesize the information contained in all possible pairwise comparisons among the m alternative actions with respect to the criterion Ki. The redundancy of the information contained in these $m(m-1)/2$ pairwise comparisons contributes to the robustness of the estimates.
>
> 3) The AHP allows for inconsistency of the pairwise judgments and provides a measure of such inconsistency.
>
> (Kamenetzky, 1982:706)

Kamenetzky favors the midvalue splitting technique with regard to assessing the weights of the criteria for the following reasons:

> 1) The assumption of mutually independent attributes is made explicit and its validity is tested.
>
> 2) The question asked in the AHP for the elicitation of the scaling constants is too vague:
>
> "What is the relative importance of criterion Ki with respect to criterion Kk?"
>
> (Kamenetzky, 1982:707)

The ratio Wi/Wk is the marginal rate of substitution of Wj/i for Wj/k, which depends on the scale on which the Wj/i and Wj/k are measured. As a result, a better question would be:

> "Considering that the Wj/i are scaled such that the sum of all Wj/i = 1, what is the ratio of the increase in Wj/i that would be necessary to compensate for a given decrease in Wj/k to the given decrease in Wj/k?"
>
> (Kamenetzky, 1982:709)

Kamenetzky found contradictory opinions asserting whether decision makers will provide the same answers to either of the above questions. For example, Garielli and Von Winterfeldt's results showed the weight estimates were insensitive to changes in the range of the attributes (Kamenetzky, 1982:710).

They hypothesized that people can assign importance to attributes without specified alternatives and ranges because they have some plausible set of alternatives and ranges in mind, when judging importance. Perhaps, Kamenetzky argues, this is why another study found no difference among seven different methods of collecting attribute weights, with five of the methods assessing weights for linear additive models with no reference to individual attribute ranges (Kamenetzky, 1982:707).

Keeney, however, warns that questions need to have attribute ranges. "A common error made in many studies is to ask which of several attributes is most important, independent of their ranges" (Keeney, 1977:286).

Saaty believes the phrasing should reflect the proper relationship between elements in one level with the property in the next higher level. He gave the following example:

> If the elements are dominated by the property rather than vice versa, ask how much more strongly the element is dominated, affected by, and so on , this property. In projecting an outcome, ask which element is more likely to be decisive or to result in the outcome.
>
> (Saaty, 1982:77)

Kamenetzky inclines toward Keeney's view. He feels Saaty's question is so vague that the weights Wi obtained by asking this question may not reflect the decision maker's preferences accurately. This is not true in the midvalue splitting method because the way in which the weights are estimated insures that the resulting value function will be consistent with at least some of the decision maker's preferences, i.e., those involving the carefully chosen n-1 pairs of alternatives (Kamenetzky, 1982:708).

AHP-Midvalue Combination. Kamenetzky suggests combining the best of the midvalue splitting technique and the best of the AHP in four steps:

> 1) Check whether attributes are mutually preferentially independent and if there are sufficient conditions satisfied for the existence of a measurable value function. The attributes must be mutually preferentially independent in order to apply any of these techniques. If there is not a measurable value function, it cannot be asserted that the preferences of the decision maker can be represented by an interval scaled additive value

function. Consequently, neither can it be asserted that they can be represented by ratio scaled units.

2) Obtain the relative standing of each action with respect to each criterion W_j/i by the midvalue splitting technique.

3) Obtain a new set of weights S_j/i, by scaling the W_j/i so that $\max(j) S_j/i = 1$, and $\min(j) S_j/i = 0$ by using the transformation:

$$S_j/i = (W_j/i - \min(j) W_j/i) \, / \, (\max(j) W_j/i - \min(j) W_j/i)$$

$$j = 1, \ldots, m, \quad i = 1, \ldots, p.$$

(Kamenetzky, 1982:709)

If the denominator above equals zero, attribute K_i should not be considered because it does not discriminate among the alternatives being considered. The S_j/i obtained from this transformation will not be expressed on a ratio scale anymore, but they will still constitute the valuations of p unidimensional value functions. Since a ratio scale has all the properties of an interval scale and an interval scale is unique up to a linear transformation, these value functions can be given a strength of preference interpretation.

The transformed weights for the actions are then used to define the value function, $V_i(X_j) = S_j/i$ which is weighted and summed over all the criteria. The criterion weights are determined by making pairwise comparisons between these value functions using the AHP. The normalized eigenvector establishes the weights. Kamenetzky covers an alternative method to establishing the weights by "restricting the use of the additive form to a smaller region of the consequence space," that is, he reduces the number of comparisons to be evaluated.

Kamenetzky does not claim that the overall measure of preference obtained by this hybrid method is ratio-scaled, as it is in the AHP. This measure is intended to be used as an ordinal measure of preference in order to facilitate the process of eliciting single attribute preferences and scaling constants. It is assumed that the decision maker can provide judgments of preference on a ratio scale. Consequently, to be rigorous, it should be checked that it meets the sufficient conditions for a ratio scaled additive value function. Although the conditions for an interval scaled additive value function have been listed (Dyer and Sarin, 1979:810), no one has determined the sufficient conditions for the existence of a ratio scaled additive value function (Kamenetzky, 1982:712).

Kamenetzky summarizes the differences in his hybrid AHP from the standard AHP:

> 1. The assumption of mutual preferential independence of the attributes is made explicit and its validity is tested. Also, it is tested whether the sufficient conditions for the existence of an interval scaled additive value function are satisfied.
>
> 2. The question "What is the relative importance of criterion Kk with respect to criterion Kh?" is replaced by a more specific question concerning the relative preferability of two well defined alternatives.
>
> 3. The W_j/i are scaled from zero to one [used as value functions of actions] (Kamenetzky, 1982:712)

requiring the outliers to do extra work (Saakman, 1975:45). Helmer explains that requiring respondents to justify "outlier" opinions helps to solidify the multi-peaked characteristic of Delphi rather than force an artificial consensus:

> The effect of placing the onus of justifying relatively extreme responses on the respondents had the effect of causing those without strong conviction to move their estimate closer to the median, while those who felt they had good argument for a deviationist opinion tended to retain their original estimate and defend it.
> (Wheelwright, 1980:282)

Saakman also critiqued the insufficient reliability, the sensitivity to the ambiguity in questions, and the difficulty in assessing the degree of expertise to determine the "decision makers." Although these complaints are valid criticisms, they are relative to the entire field - the Delphi method should be judged in terms of the available alternatives. The same objections apply even more critically to the less systematic methods of forecasting (Wheelwright, 1980:280).

The author shares E.S. Quade's biggest criticism. Delphi is cumbersome. It requires several weeks to receive responses and the iterative questionnaires can be tedious (Quade, 1968:324). This may be one of the reasons the feedback results were very difficult to ascertain in this research; the subjects were all high level defense experts who were impatient to repetitive surveys.

Saaty compared the Delphi approach to the AHP and found the following differences:

1) Anonymous versus operating group discussion.

2) Adjustment in a series of rounds versus dynamic discussion.

3) Questionnaire versus hierarchy structure as a basis for judgments.

4) Statistical and quantitative analysis versus qualitative analysis.

(Saaty, 1980:69)

Both processes improve the quality of judgments, but Saaty says the AHP better fits the human cognitive style because it breaks the judgment into its elements. Saaty further claims that the group has better confidence in the relevance of their judgments because the group determines the important set of variables (Saaty, 1980:70).

Delphi Criticism. Not all the research has been positive regarding feedback. Gustafson found that written feedback appeared to lead to a reduction in the quality of estimates in his experiment about estimating population heights. He speculated that written feedback without clarification may lead to distortion and recommended further experimentation on the effects of unelaborated feedback on judgemental tasks (Gustafson and others, 1973:280).

Saakman has criticized the Delphi method on several accounts, particularly for what he considers the artificial consensus brought about by the "bandwagon appeal" and iteration, including the first. The group is then "fed back" the reasons but not the statistics (median, etc). The process is repeated until the individual judgments stabilize.

QFC is particularly appropriate to the AHP questionnaire because the reasons for the individual's priority vector can be collected beginning on the second iteration (after the vectors have been computed from the comparison matrix). The number of reasons would be well within reason and could be assimilated into the decision maker's thought processes as he revises his comparison matrix.

Press explained the responses of the group members as a function of the feedback. The student-t distribution was used to show the systematic convergence of the reasons (Press, 1979c:3). He found that the QFC judgements were more systematic and stable than the control group which received no feedback. Since the feedback is "qualitative," Press claims the procedure does not induce an artificial consensus on the group (Press, 1979b:1).

AHP-Delphi. Saaty mentions that it is possible to elicit the hierarchy and judgements by questionnaire (Saaty, 1980:35). If he were to do this using anonymity, controlled feedback, and statistical group responses, he would be applying the Delphi technique to the AHP. The Delphi technique is a well established methodology to collect opinions remotely, such as mailed questionnaires. Many researchers consider it better than interacting groups.

> is multi-peaked, rather than single-peaked. Most cases Delphi methods have been applied to in the past are these single-peaked straight forwardly factual issues, a prospect more than likely in many spheres of the value area.
>
> (Rescher, 1969:6)

Feedback. There are many variations of the Delphi approach, primarily varying the type of feedback given to the respondents. As long as the feedback involves some relatively precise summary of the previous round, the form of feedback does not have much affect on the variance between judges (Dalkey and others, 1970:28).

One version of Delphi returns only the percentile score to each participant. Thus, the respondent only knows the general direction of the group consensus, rather than the actual mean or median. Dalkey's experiments showed, however, that percentile feedback appeared to be slightly less effective with respect to average error, than medians and quartiles (Dalkey and others, 1970:28,3).

Quality Feedback Control. James Press proposed a Delphi variant which he called Quality Feedback Control (QFC) to help elicit the value judgements and recommended decisions of groups (Press, 1979b:1). The method shares two distinctions of Delphi: anonymity and controlled feedback. QFC differs from Delphi in that it does not return statistical group responses. While Delphi collects reasons for deviant responses on the second and subsequent iterations, QFC collects reasons for each answer on every

Delphi avoids the dysfunctional group interactions. The separation of the participants helps to insure that their judgements will not be influenced by social pressure towards conformity or other aspects of small group behavior, such as dominant individuals or irrelevant communication (Dalkey, 1969b:5). The approach is broken into the following phases:

1. The experts are asked for their judgements on a series of mailed questions.

2. The median and quartile scores for each question are returned to the respondents. On those items on which there is no general agreement,the experts are asked to state their reasons for their divergent estimates.

3. Process 2 is repeated 1-3 times with the explanations for the outliers. This reduces the quartile range without pressuring the respondents.

Delphi's focus is the methodology to collect these opinions. Unlike many forecasting methods, Delphi does not have to produce a single answer as its output. Instead of reaching a consensus, the Delphi approach can leave a spread of opinions, since there is no particular attempt to get unanimity. Rescher reports this feature makes Delphi more appropriate for exploring group examination of values, rather than Delphi's traditional role to assess expert opinion about factual questions:

> Rather than serving as a tool for discovering or forging a group consensus, Delphi can provide a technique for discovering subgroups of variant opinion in a group - when the pattern of responses

surveys are also becoming more responsive. It is foreseeable that in the not so distant future, a national/worldwide computer network will link everyone, and surveys will have the same response time as interactive groups.

There have been few studies on applying the AHP by survey. This study will apply the AHP via mailed questionnaires to examine this aspect of the AHP. The process used to solicit the opinions will be a version of the Delphi technique first developed by Rand Corporation in the 1950s.

Discussion. The Delphi approach is among the most common methods for qualitative forecasting (Wheelwright, 1980:298). It is a solicitation method that iteratively uses surveys and statistical feedback to achieve a group decision.

Both Delphi and the AHP improve the quality of judgments, but Saaty claims thatthe AHP better fits the human cognitive style because it breaks the judgment into its elements. Saaty also claims that the group has better confidence in the relevance of their judgments because the group determines the important set of variables (Saaty, 1980:70).

Saaty sees the Delphi approach as the end product. It is not. It is a technique identified by the following three aspects which would be an excellent tool to apply the AHP by survey:

1) Anonymous response.
2) Iterative and controlled feedback.
3) Statistical group response.

(Dalkey, 1969b:v)

amount (Rowse, 1974:280). This was the result that Battelle found when they performed a sensitivity analysis on the top level weights. The weights could change by a factor of four and still have negligible effect on the results (Rice, 1983:2-86).

With regard to weights on individual opinions, one is not necessarily seeking a change in the results, only that the results are more representative of the group. Keeney insists that weights are necessary to avoid intransitive results and Rowse found that personal weights resulted in more accurate group responses than interacting groups. Therefore, this study will pursue weighting individuals to achieve a more valid representation of the group opinion.

Delphi. Saaty maintains that in "seeking consensus," it is preferable that the judges interact" (Saaty, 1980:68). He considers the single input of interacting judges preferable over deriving a mathematical mean input (Saaty, 1980:32). The aggregation methods that require all the decision makers to be physically collocated are common for small sample sizes or homogeneous groups. However, the decision makers who have the diverse backgrounds necessary for research and development questions are often dispersed across wide regions. Requiring them to interact physically would restrict the sample size and the caliber of "expert decision maker" solicited.

Besides allowing a wider dispersion of participants, individual inputs (Saaty, 1980:68).

Rowse performed an experiment where he evaluated the accuracy of group decisions as a function of different weighting schemes. Interacting group responses were compared to five weighting schemes. The five schemes were equal weights, peer assigned weights, self assigned weights, group assigned weights (a combination of peer and self weights), and average peer and self weights. All his methods used the mean response after weighting. He measured the accuracy of the group answers by the least squared error from the real answer and the group reliability by the variance of the estimates across methods and averaged over five questions.

He found no differences between the five weighting methods, but all the weighting methods did better than interacting groups. Perhaps the fact that all the techniques were reliable across similar questions may mean that it is possible to effectively predict the optimal range of expertise. This would be a very difficult task for the supra decision maker to determine the optimal range of expertise of his staff. This estimate of the difficulty was pointed out by Keeney when he was referring to interpersonal value comparisons by either the "benevolent dictator" or the group itself evaluating the weights for its own members.

Another reason there were no differences between the weighting methods may be that the weights do not have enough affect on the estimates for changing the range a significant

1968:342).

Dobbins reported that the quality of a rank-ordered priority aggregation can be significantly influenced by the variation in each judge's knowledge of each alternative he chooses to rank (Dobbins, 1980a:60). Dalkey also found these self ratings statistically improved the accuracy of group estimates of historical facts (Dalkey, 1969c:2). In Dobbin's research, he restricted the self-ratings between zero (worse) and one (best). Dobbins multiplied this self-expertise rating by the alternative scores for the judge's decision matrix as if the self-rating were a multiplicative weight (Dobbins, 1980:60).

There have been several applications of using interpersonal weights to help accurately amalgamate group decisions. The "soundness" may be measured by relative intelligence, years of experience, past record, personal involvement in the issue at stake, personal evaluation, etc (Saaty, 1980:68). Dobbins used self assessments between 0 and 1 which he directly applied to the individual's inputs to weight them (Dobbins, 1980a:65). Similarly, Horsky and Rao corrected for the judges' differential familiarity with various alternatives by having the judge state his confidence in his judgement for each pair of comparisons (Horsky and Rao, 1984:808). Saaty gave more weight when he had high confidence in the judgement of a particular individual expert. When he had low confidence he used the mean of the that the dictator determine the best and worst value from each individual. Then he must superimpose his own value structure about the relative desirability of the change in the value from 0 to 1 for individual A versus the change in value from 0 to 1 for individual B, etc.

> We make no pretense that interpersonal utility comparisons are easy, but they are often implicitly made in group decisions...Not only does the decision maker have to scale intensities of preferences for each of the individuals, but the process requires interlinking the scales of the individuals and hence it involves extraneous interpersonal comparisons."
>
> (Keeney, 1976:145)

The same type of thinking must be followed in the participating group decision model by each of the individuals in the group. However, they must also arrive at a consensus for the constant weighting factors. Sometimes this may not be possible and thus the model could not be used as intended. There have been several experiments to investigate the factors involved in interpersonal comparisons.

Applications of Weighting Individuals.

Experiments have shown that if the experts are asked to grade themselves on competence, the estimates they give are fairly reliable. On the basis of this information, it may be possible to obtain better results by using as the group consensus, not the median of all responses to a question, but the median of the fraction who declared themselves most knowledgable with regard to that question (Quade and Boucher, influences are at least partially overcome by mathmatically aggregating individual estimates. Rowse stated that mathmatical consensus should "be chosen over behavioral consensus for the entire range of likelihood ratios" (Rowse and others, 1974:283). This is very beneficial for solicitation by survey, as in this study, but contrasts sharply with Saaty's emphasis on interacting groups to achieve a consensus.

Emphasizing Individuals. Keeney adds an additional condition to Arrow's five conditions to insure the group value function is transitive. He requires interpersonal comparisons of preferences (Keeney and Raiffa, 1976:526). Keeney gives two sources that are able to make these assessments: a benevolent dictator and the group itself - as a participating model (Keeney, 1976:144). The group priority vector is then a linear combination of the individual priority vectors.

Saaty calls this linear combination a "synthesis" of the individuals:

> When each of several individuals does his own evaluation, the separate results may be compared from standpoints of individual utilities to obtain a synthesis performed by an outside party of what the individuals would do jointly.
> (Saaty, 1980:9)

Assessing the interpersonal comparisons is a difficult task. Keeney's system to determine scaling constants requires

Group Interactions

Introduction. There have been several studies to show the deleterious effects of interacting groups and the quality of the final "group" decision. Huber found that although there is less variability when there is some group discussion prior to data collection, the move toward conformity was temporary and the result of social pressures. He found the rate and extent of convergence of expressed outlook would vary considerably from one organization to another (Huber, 1968:488).

In another study, VandeVen looked at the different group types and found the heterogeneous groups (low correlations in personality profiles) produced a higher proportion of high quality - high acceptance solutions than the homogeneous groups (VandeVen, 1971:208). The TAV steering committee used in this research would be labeled as heterogeneous because of the diverse specialties represented.

Perhaps most significant was Dalkey's finding that more often than not, face to face discussion tended to make the group estimate less accurate; whereas more often than not, the anonymously controlled feedback procedures made the group estimate more accurate (Dalkey, 1969b:v).

One of the reasons for the inaccurate face to face group decisions is that group influences are dysfunctional as an aggregation tool (Rowse and others, 1974:283). These

The AHP does not require linear value attributes, but it does require that all the comparisons in a given matrix be within an order of magnitude of value of each other, so that the input comparisons will remain representative of the relative values. Any objective whose value exceeds the other values in the matrix by more than the scale allows (1..9), should be removed from that matrix, otherwise, the AHP assessment is inappropriate.

This hybrid procedure relies on the AHP to build the unidimensional value functions. It combines elements of both the AHP and the midvalue splitting method to determine the weighting constants. It uses the eigenvector from the AHP to measure the preference function and the midvalue splitting technique to compare hypothetical alternatives selected.

Worth Assessment. Another elicitation technique that requires additive value functions is worth assessment. It has an additional restriction on top of that required by the AHP in that it requires linear value attributes. The similarity with the AHP requirements can be seen in the definition of worth independence:

> 1) The relative importance of satisfying separate performance criteria does not depend on the degree to which each criterion has in fact been satisfied.
>
> 2) The rate at which increased satisfaction of any given criterion contributes to the overall worth is independent of the levels of satisfaction already achieved on that and other criteria.
>
> 3) The rate at which decision makers would be willing to trade off decreased satisfaction on one criterion for increased satisfaction on other criteria so as to preserve the same overall worth is independent of the levels of satisfaction already achieved by any and all of the criteria.
> (Sage, 1977:359)

These three statements imply that the decision maker's value curves are linear. If, at the boundaries of decision space, the curves lose their linearity, then worth assessment would no longer be an appropriate method to elicit weights.

Summary Group Interactions. The entire point of Delphi's feedback and Saaty's interacting groups, is to derive a group decision free from spurious variance. Large variances tend to cancel out individual inputs and that objective receives less emphasis. As reported below, there is less support for the group decision:

> If an area is important to our needs, but there is disagreement on implementation, we would have to withhold action until people develop a better appreciation for the need and can induce more cohesive action...Where there is disagreement, people will tend to be dissatisfied because they don't see realization of their judgments. Otherwise, with agreement there is greater satisfaction. (Saaty, 1980:30)

Throughout the discussion of variance reduction and achieving consensus, it is important to remember that group consensus is not a goal in itself. Siegal emphasizes this point in his statistics text when he explains the Kendall coefficient of concordance, which is one measure of consensus between rank orders:

> It should be emphasized that a high or significant value of concordance does not mean that the orderings observed are correct. In fact, they may all be incorrect with respect to some external criterion.... It is possible that a variety of judges can agree in ordering objects because all employ the "wrong" criterion....A high degree of agreement about an order does not necessarily mean that the order which was agreed upon is the "objective" one. In the behavioral sciences, especially in psychology, "objective" orderings and "consensual" orderings are often incorrectly thought to be synonymous.
>
> (Siegal, 1956:338)

Saaty emphasizes that the top level weights are the most important and require additional attention. The Delphi and QFC examination in this thesis will be applied to the top level.

> One must prioritize very carefully the highest level of the hierarchy because it is there that consensus is most needed since these priorities drive the rest of the hierarchy.
> (Saaty, 1980:30)

Majority Rule

Introduction. When individual preferences are given in terms of ordinal rankings, the simplest form of group consensus is majority rule (Cook and Seiford, 1978:1722). Majority rule (MR) determines the group ranking by the number of "votes" received by each objective. This thesis will extend the concept and determine the cardinal rankings, that is, the priority vector from the number of "votes" received for each objective. A survey of the literature exhibits several pertinent studies regarding majority rule.

Discussion. Kendall reported that the best method associated with the least squares is to rank the sums of ranks allotted to individuals. The sums of squares of differences between what the totals are and what they should be if all rankings were alike is a minimum when this method is used to estimate ranks. Furthermore, if the ranking arrived at by this method is correlated by Spearman's rho with the actual observed rankings, the mean rho obtained is larger than for any other estimated rankings (Kendall, 1955:100). Kendall broke tie scores by ordering the tied scores by their variance. That is, if there were three tied objective scores, the one with the smallest variance between judges would be ranked ahead of the others (Kendall, 1955:100, Cook and Seiford, 1982:621).

Fishburn explains the method to establish a priority vector with this approach by using value theory. Instead of votes he adds the continuum of values. Assuming that the value of the whole equals the sum of the value of the parts, one may write:

$$U(X_{ij}) = X_{ij}/(\sum^{ij} X_{ij})$$

where $U(X_{ij})$ is the group value of objective ij
X_{ij} is the individual value of objective ij
(Saaty, 1980:238)

This thesis extends Fishburn's technique to the voting matrix to calculate an alternative aggregation method. The inputs are preferences with no strengths (0,1,1/2). Dobbin's reports that the appealing advantage of this aggregation method for voting matrices is that intransitive rank orders appear only as indifferent alternatives (Dobbins, 1980a:43). For example, one judge votes the objectives: A>B>C, and another judge votes the objectives: B>A>C. Their aggregate order will be A=B>C. The greater the number of judges, the more likely there will be no tie scores because of the finer discrimination between elements. For each n-matrix the total votes cast is equal to (number of judges)(n)(n-1)/2. The priority vector derived from ordinal ranks becomes more continuous with more judges, or increasing n, and better reflects the group priority vector.

This study begins with the AHP ratio comparisons and converts them into ordinal preference relations in order to apply majority rule. There are many majority rule methods that use slightly different techniques to aggregate ordered ranks of preferences. Dobbins compared the following majority rule techniques:

1) Borda's Method of Marks
2) Adjusted Borda Method of Marks
3) Condorcet's Criterion
4) Black's Simple Majority Procedure
5) Dodgson's Method of inversion
6) Copeland's Majority Rule
7) Shannon and Svestka's Majority Rule
8) Black's Single Peaked Preference

(Dobbins, 1980a:25)

Dobbins found that the Shannon method allowed him to complete the most of the following requirements for his computer model.

1. Accepts Ordinal or Cardinal Data
2. Accepts Intransitive Rank Orders
3. Accepts Partial orders
4. Accepts Weak rank orders
5. Accepts An odd or even number of judges
6. Majority winner is ranked in first place
7. Method will balance A>B in an individuals preference ordering by B>A in some other individuals ordering as long as there are no other alternatives between A and B in either ordering.

(Dobbins, 1980a:28)

This study will also use the Shannon Majority Rule method for the same reasons that Dobbins lists above. This thesis will extend the Shannon Majority Rule method one step and interpret the ordinal output ranks as cardinal ranks to compare them to the vectors derived by the AHP.

Ellsburg noted that a transformation of value numbers to the ordered rank would not, in general, "preserve the equality or give inequalities among differences between utility numbers" (Ellsburg, 1954:272). This will be examined in this thesis by comparing the priority vectors derived by both the AHP ratio scale and the voting matrix ordinal scale.

Transitivity. Many studies have been directed toward determining the probability of achieving an intransitive aggregate rank order through a majority rule method, and what conditions are required for a usable majority rule decision. Dobbins describes two of the conditions which are actually restatements of Arrow's properties:

> 1) Scoring constants should logically be 1,0,-1, have autonomy, be non-reversed, and have non-dictatorship.
> 2) The social welfare function [group priority vector] should exhibit monotonicity and faithfulness.
>
> (Dobbins, 1980a:20)

An accepted limitation of the unrestricted use of many majority rule methods is that the aggregated results are intransitive. Dobbins examined the efforts to develop decision rules to avoid intransitive results. Generally he found the authors had to restrict the characteristics of the individual rank orders, such as not allowing tied ranks (Dobbins, 1980a:20).

An example of one of these restricted inputs is Bowman and Colantoni's report. If the majority rule problem has transitivity constraints on the input voting, then it can be solved with integer programming models (Bowman and Colantoni, 1973).

Chapter III: The Analytical Hierarchy Process

Introduction

Besides the ease of application of the AHP, this thesis chose to examine the AHP because it was a more appropriate tool to provide discrimination. One of the goals of the Battelle study was to discriminate between alternatives. Although MAUT also discriminates well, it is not as easily applied in survey form, nor does MAUT allow for intransitive rankings. The AHP incorporates intransitive rankings in its measure of consistency which can be used as a figure of merit for the different aggregation methods. Finally, this thesis saw the need for research on the effect different aggregation methods have on the AHP results.

Principles

The analytical hierarchy process uses pairwise comparisons between elements of the same level in a decision hierarchy to arrive at a priority vector for these elements (Saaty, 1982:35). Saaty describes the three principles of the AHP:

> 1) Hierarchic representation and decomposition - breaking the problem down into separate elements.
> 2) Priority setting - ranking the elements by relative importance.
> 3) Logical Consistency - insuring that elements are grouped logically and ranked consistently according to a logical criterion.
> (Saaty, 1982:26)

The elements of the hierarchy are clustered into homogeneous groups of five to nine so they can be meaningfully compared to elements in the next higher level. The only restriction on the hierarchy is that any element in the next higher level must serve as a criterion for assessing the relative impact of elements in the level below (Saaty, 1982:36). A hierarchy can be divided into sub-hierarchies sharing only a common top most element. This is seen in this thesis hierarchy, Figure 1. The clusters of subobjectives for the third level are not related between clusters except through the top goal: "TAV Effectiveness." Also, the interrelationship within clusters is limited to the "parent" objective in the level above them.

Kamenetzky breaks the AHP into two phases. The first phase of the AHP is to determine the relative importance of the objectives. Every objective is assumed to have an unknown measure of relative importance denoted Wi, i = 1,...,p. If these weights Wi, are known and a matrix C with elements $C_{ij} = W_i/W_j$ is constructed, this matrix satisfies the equation:

$$CW = pW$$

Where: p = order of the matrix
C = matrix of relative importance
W = (W1, W2, ..., Wp)
(Kamenetzky, 1982:700)

The decision maker is asked to provide an estimate of the matrix C' by answering the following question: "What is the relative importance of objective i with respect to objective j?" Saaty has shown (1982) that an estimate, W', of the true vector of weights W satisfies the equation:

$$C'W' = (\text{lambda max})W'$$

where:[lambda max is the maximum eigenvalue of C']

Weighting or setting the priorities requires the objectives in each level be compared among themselves in relation to the next objective "up the chain." These in turn are prioritized with respect to the objective of the next higher level, and so on. Finally, each of these priority vectors is multiplied by the "parent" element in the next higher level to obtain overall priorities. This is done by coming down the hierarchy and weighting the priorities measured in a level with respect to an objective in the next higher level with the weight of that objective.

The second phase of the AHP that Kamenetzky describes is to determine the relative standing of each alternative with respect to each objective. There may be as many as p pairwise comparison matrices (one for each objective) for each level of the hierarchy. The overall score of each alternative is then determined by simply summing the weighted valuations of the alternatives.

One of the weaknesses of AHP is that it has few axioms for rigorous derivations of its validity. Saaty admits to not making a "serious attempt" to axiomatize the AHP, but lists the following assumptions that must be made prior to applying the AHP:

> 1. A system can be decomposed into comparable classes.
> 2. Elements in each class may be compared with respect to some or all the elements in an adjacent class.
> 3. Comparisons can be made in terms of an absolute numerical scale to form ratios.
> 4. The pairwise comparisons utilize reciprocal matrices (optional).
> 5. Intransitivity is allowed and its effect on the consistency of the outcome measured.
> 6. The priority of an element is derived through a weighting principle.
> 7. Any element which appears in the hierarchy is considered relevant, although its priority may be low. It does not make sense to speak of "irrelevant alternatives" introduced into the hierarchy to test for independence from them.
> 8. The expressed preferences are assumed to be deterministic rather than probabalistic. Thus a preference remains fixed and is not contingent upon other factors not included in the problem.
>
> (Saaty, 1980:9,248)

The assumptions that concern this thesis are 2 and 8: individuals can make comparisons using the ratio scale and the elements are deterministic.

Scale. The inputs to the AHP can be considered a type of "score" for that particular objective. Kraweic lists the following advantages of scoring methods:

> - They are the only methods specifically designed to incorporate noneconomic criteria.
> - They use input data in the form of subjective estimates provided by knowledgeable persons in the form of point or interval statistical estimates.
> - They use subjective "guesses" overtly, where other methods generally require a more costly and quantified form of the same guess.
> - The subjective probability assessment can be the conceptual and analytical framework of the scoring method to produce an efficient portfolio of R&D projects.
> - The scoring methods produce results that are, on an average, 90% rank order consistent with economic and constrained models.
>
> (Kraweic, 1984:22)

TABLE II
AHP Pairwise Comparison Scale

INTENSITY OF IMPORTANCE	DEFINITION	EXPLANATION
1	Equal importance in both elements.	Two elements contribute equally to the property
3	Weak importance of one element over another	Experience and judgement slightly favor one element over another
5	Strong importance of one element over another	Experience and judgement strongly favor one element over another
7	Demonstrated importance of one element	An element's dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of the highest order of affirmation
2,4,6,8	Intermediate values between two judgements	Compromise is needed between two judgements

Reciprocals: If activity i has one of the preceding numbers assigned to it when compared with activity j, then j has the reciprocal value when compared to i. (Saaty, 1982:78)

The scoring function in the AHP has a unique scale shown in Table II. The -9 to +9 ratio scale used in the pairwise comparisons is based on Saaty's tests to maximize man's ability to discriminate between alternatives. Judges range their comparisons based from absolutely more important (9), through equally important (1), to absolutely less important

(-9). The scale, however, is surrounded with the controversy between ratio-interval-ordinal scales and the requirements to establish these measures in value theory (see Value Theory in Chapter 2).

The AHP scoring function and hierarchic representation enables decision makers to represent the simultaneous interaction of many factors in complex, unstructured situations. It helps them to identify and set priorities on the basis of their objectives and their knowledge and experience of each problem. Saaty suggests that one's feelings and intuitive judgments are probably more representative of our thinking and behavior than are our verbalizations of them (Saaty, 1982:12). Perhaps this is the reason Gear found that managers readily accepted the AHP (Gear, p18).

Saaty lists the following advantages of the AHP:

> Unity: Provides a single, easily understood, flexible model for a wide range of unstructured problems.
>
> Process Repetition: Enables people to refine their definition of a problem and to improve their judgment and understanding through repetition.
>
> Complexity: integrates deductive and systems approaches in solving complex problems.
>
> Judgment and Consensus: Does not insist on consensus but synthesizes a representative outcome from diverse judgments.
>
> Interdependence: Can deal with the interdependence of elements in a system and does not insist on linear thinking.
>
> Tradeoffs: Takes into consideration the relative priorities of factors in a system and enables people to select the best alternative based on their goals.
>
> Hierarchic Structuring: The AHP reflects the

> natural tendency of the mind to sort elements of a system into different levels and to group like elements in each level.
>
> Synthesis: Leads to an overall estimate of the desirability of each alternative.
>
> Measurement: Provides a scale for measuring intangibles and a method for establishing priorities.
>
> Consistency: Tracks the logical consistency of judgments used in determining priorities.
>
> (Saaty, 1982:23)

Consistency

Introduction. The last advantage Saaty lists is consistency. The AHP measures the "consistency" in the judgements. Humans are seldom perfectly consistent in making comparative judgements, particularly when dealing with intangibles where there are no scales to use. However, consistency is an important criterion as a necessary condition to valid scalings of reality (Saaty, 1980:228) Rather than creating axioms requiring only consistent comparisons, the AHP accepts inconsistency and measures the amount. This ratio consistency is best illustrated with an example. If car A costs 3 times more than car B, and that car B costs 2 times more than car C, to be perfectly consistent the decision maker must say that car A costs 6 times more than car C. Note that the consistency will drop if he says car A costs 5 times more than car C, even though his ordinal ranking remains the same.

Groups also exhibit inconsistency. Several authors show that groups in general cannot make decisions in the same rational straight forward manner that an individual can. One way to look at group decisions is to compare it to a pairwise comparison matrix. Each row would represent one member's inputs, whether they are ordinal ranks or direct assessment ratings. There would inevitably be inconsistencies between rows (judges) in the group. This would be an indication of the group inconsistency.

Group decisions are neither rational nor straight forward according to group decision properties that Arrow postulated in 1951, as examined in the literature review (Blin and Satterthwaite, 1978:257). The crux of Arrow's impossibility theorem is that intransitivity is generic to group decisions that comply with his logical conditions.

The participants will have more confidence in the final decision if they see their inputs reflected in the group output vector. Because intransitve ranks between judges tend to cancel each other, the fewer the "inconsistencies," the more likely the participants will be satisfied with the group priority vector. From this approach, one may consider the minimum group intransitivity as a valid objective in aggregating individual opinions.

AHP. The AHP derives a consistency index by taking the ratio: (lambda max - n) / (n-1), where lambda max is the trace of the comparison matrix and n is the number of criteria. Saaty explains the reasoning behind CI in the following manner. If the comparisons are estimated precisely, then $X_{ij} = W_i/W_j$ and each main diagonal element would be divided into two sections: a single page Battelle questionnaire (Delphi iteration), and a 16 page instrument applying the AHP.

The "Delphi" application included statistical group feedback (mean and standard deviation) from Battelle's first questionaire along with the particular respondent's original rating. He was asked if he wished to update his ratings based on his current knowledge (feedback + experience). In particular, he was asked to explain his ratings that remained outside one standard deviation of the initial group average. The Delphi approach sometimes requires several iterations to reduce the variance between respondents. Dalkey showed that the variance between respondents has the most dramatic reduction after the second Delphi iteration (Dalkey, 1970:10), so this effort will be limited to two iterations of the survey.

The second section of the first survey solicited 132 pairwise comparisons for the criteria in the revised Battelle study. The judges were also asked to rate their own qualifications associated with the comparisons. The purpose was to have a basis to weight the opinions of the more knowledgeable judges. Dalkey found these self ratings statistically improved the accuracy of group estimates of historical facts (Dalkey, 1969c:2).

The second survey (Appendix B) returned the judges' pairwise matrices and the corresponding priority vectors so

Process. The process to achieve these objectives will be twofold. First, the initial Battelle direct assessent survey will be returned to the judges with the group results to allow the judges to "update" their original inputs. The returned AHP survey will also have the explanations that individuals gave on the initial survey for exceeding one standard deviation of the group mean. The final collected surveys will be used for the determination of the priority vectors.

The second part of the process is to calculate the AHP priority vectors and the majority rule (MR) priority vector. Kendall's tau will measure the correlation between the resultant priority vectors. The Kendall's coefficient of consistence (zeta) will be calculated for each of the MR matrices and will be compared to CI (AHP consistency index).

Finally, as an ancillary thesis effort, these new priority vector will be applied to the original Battelle study to see the effect that the AHP has on the outcome. That is, the weights will be applied to the attribute values used by Battelle to achieve a scaler measure of the TAV "feasibility" for each of the original proposals.

Survey

Appendix A shows the 18 page pamphlet that was sent to each of the original 13 members of the TAV steering committee. The cover page explained the purpose of the study and explained how to complete the survey. The survey was

Chapter IV. Methodology

Overview

Objectives. This thesis will apply the AHP to solicit weights throughout the 1983 "Batelle" study of the TAV feasibility. There are two main objectives: I) Measure the effect that feedback has on the rank of the top level weights between the AHP and direct assessment techniques, and II) Measure the effect that different aggregation techniques have on the priority vectors and consistency measures.

Alternative Approaches. The Delphi approach is an iterative loop to achieve consensus through controlled feedback. The Delphi approach (or versions) should be the first step in all aggregation techniques applied to group decision making through surveys. The three mathematical approaches emphasized in this study of the AHP are: 1) taking the geometric mean of the judge's inputs before calculating the eigenvector, 2) taking the arithmetic mean of the 12 judges' eigenvectors, and 3) converting the pairwise comparisons to a voting matrix and applying majority rule.

Measures of Effectiveness. The effect of feedback will be evaluated by the variance between elements of the judges' priority vectors (criteria weights), before and after feedback. The effect of different aggregation rules will be evaluated by the change in consistency.

comparison between the different methods. The majority rule vector will be referred to as VoteM, for vote mean.

Aggregation Summary. The vector mean is the most widely used technique of all those available (Cook and Seiford, 1978:1722). This average vector, when it is derived from a voting matrix, is also the method recommended by Kendall to *minimize the mean square error* (Kendall, 1955:100). The question is to determine the relationship between these vectors in terms of their consistency and their rank correlation.

Note that the arithmetic mean input is inappropriate with ratio inputs. This is clear with an example. If one were to take the simple arithmetic mean, he would arrive at (a + 1/a)/2, rather than one, which is the correct ratio mean between two opposite ratings.

Besides the priority vector derived from the average input, this study looked at the priority vector derived from the average output. The arithmetic mean priority vector was determined between judges, rather than the geometric mean priority vector. The reason was that the arithmetic mean preserves the restriction that the sum of the vector elements equal one. The geometric mean vector would require an additional normalization before it would satisfy this restriction. A superficial examination showed that the normalized geometric mean vector and the arithmetic mean vector were related, but the extent of this relationship was not examined in this study.

Majority Rule. The final aggregation technique examined will be to convert the AHP inputs into ordinal "votes" and sum across the rows of the comparison matrix. These row totals will be summed across judges to arrive at the Shannon Majority Rule priority rankings as explained in the literature review. The interval between the resulting ranks will be the difference in the number of votes. This conversion to an interval scale priority vector will allow consistency index (CI). The AHP consistency index provides a convenient measure of the consistency of pairwise preferences, but it does not indicate the social intricacies of group interactions, such as dominant individuals. Saaty suggests that one of the most promising contributions of the hierarchical analysis is to structure the problem from the start with interacting groups (Saaty, 1980:69).

Aggregation Methods. The point of the aggregation method is to accurately reflect the true "group" priority vector. This thesis will look at two of the many methods for aggregating individual opinions into one opinion: 1) taking the mean of the inputs/outputs for the AHP, and 2) converting the inputs into an ordinal scale and using majority rule. In addition two techniques to reduce the variance and intransitivity between priority vectors will be examined: emphasizing inputs of certain individuals and using Delphi to elicit the weights.

Mean. The inputs to the AHP matrix are ratios between the values of two objectives. The geometric mean is the preferred input rating when determining the group average input. This is the same as the arithmetic mean of the input logarithms. That is, the nth root of the product of n inputs is equal to the sum of n input logarithms divided by n. For example, if one person assigns the value a and another assigns the value 1/a, the mean would be:

$$[(1/a)(a)]\exp(1/2) = \text{antilog}[(\log(1/a) + \log(a))/2]$$

$$1 = 1$$

Aggregation

Introduction. Saaty described the AHP as providing a new method to incorporate judgements of several people and resolve conflicts among them (Saaty, 1982:25). The drawback is how to accomplish this amalgamation:

> How to represent group judgement in a satisfactory way when people's experiences and judgments differ, and whose opinions should be taken more seriously and why, is a major problem in social study and conflict analysis.
>
> (Saaty, 1980:69)

Unfortunately, this "major problem" does not have an easy solution with the AHP. Saaty defines consensus as improving confidence in the priority vector by using several judges to bring the results in line with majority preferences (Saaty, 1980:66). For large matrices, trying to achieve a consensus via survey becomes intractable because of the enormous amount of feedback required for the n(n-1)/2 comparisons. The more direct approach would be to seek consensus for the derived priority vectors. The judges would then reexamine their comparisons in light of the feedback for the n-element priority vector.

Saaty assumes that the input comparisons to the AHP are either individual inputs or the aggregated group inputs. However, there has been no study examining the effect that different aggregation methods have on the results of the AHP.

The AHP results include the priority vector and the zeta when the same matrix is converted to ordinal comparisons. This is because the ratio may change between equivalent comparisons but the ordinal relationship remains the same. This research will examine the relationship between CI and zeta as a function of the size of the matrix and the judge making the comparisons to more fully understand the interaction between them.

at n = 8, the calculated zeta must be lower than .60 to reject that zeta=1 (Dobbins, 1980a:32-35). Another way to look at it is that the more objectives the judge is voting on, the more circular triads he can have and still be considered consistent.

The null hypothesis will be that there is perfect disagreement between the judges (there is no concordance between methods). Kendall developed methods and special small N value (# judges) probability tables to evaluate W between zero and one (Appendix E). Kendall does not explain how he calculated the distribution of d (or zeta), other than to say that the "distributions are rather troublesome to obtain" (Kendall, 1970:147).

Summary. For the single judge, pairwise comparisons provide an additional measure of consistency that is not available in direct assessment (interval scale) or ranking (ordinal scale). The consistency measure for the continuous scale is the AHP consistency index (CI) and for the ordinal scale it is Kendall's zeta.

CI can be thought of as the amount of divergence each comparison is from the equivalent "average" comparison computed from the eigen vector. Zeta can be thought of as the count of the number of circular triads over the maximum number of circular triads possible.

It is believed that a matrix with ratio scale (AHP) may show inconsistency with CI but remain transitive according to and the ranking is more inconsistent. The actual formulas for zeta's calculation are discussed in the next chapter, Methodology.

Note that it is possible to have circular polyads greater than three. The circular three ranks (triad), however is always present in a larger "n-ad." Kendall points out that a circular n-ad must contain at least n-2 circular triads(Kendall, 1970:145).

The fact that it contains circular triads does not imply that it is itself circular. For example, suppose that ABCD is circular. Then either A>C or C>A. In the first case ACD is circular, in the second case ABC is circular. Similarly either ABD or BCD is circular. Thus the tetrad must contain at least two circular triads. Kendall ignored the more ambiguous criteria based on larger polyads and based zeta on circular triads which comprise the elementary inconsistencies (Kendall, 1970:146).

Kendall insists that the data can be ranked only if zeta = 1, i.e., there are no triads (Kendall, 1970:147). Kendall determines statistically when zeta=1 by establishing a distribution zeta would have if all the preferences were allotted at random. The distribution is dependent on n. For a given significance level, the calculated zeta value that rejects the null hypothesis that zeta=1 slowly drops (Appendix E). That is, at .05 significance, when n = 3, any calculated zeta different from 1 will reject zeta=1; whereas scale (1 to 9 scale for the AHP) or by an ordinal scale (-1,0,1 or 0,1/2,1) such as in ranking. This thought is more clearly brought out by Klahr.

Klahr found that information about transitivity is lost in rank ordering (single judge). He thought paired comparisons were better than ranking in the sense that equal preference in ranking may be the result of intransitivities in pairwise comparisons. A distinction that may be important (Klahr, 1969:319). That is, if A>B>C in one line of comparisons and B>A>C in another line, then the end result will be A=B>C. Ranking, on the other hand only has one line; it is a single dimensional vector which assumes perfect transitivity for the individual judge.

Voting Matrix. The index which determines the amount of intransitivity in the ordinal pairwise comparison matrix, or "voting matrix," is called Kendall's coefficient of consistence, or "Zeta." Three ranks would be intransitive (inconsistent) if it circled back on itself: A>B>C>A. Kendall calls an intransitive order of 3 ranks a circular triad, and it forms the basic unit in his coefficient of consistence, zeta. Zeta first calculates the number of "circular triads" (d) among n ordered criteria (Kendall, 1955:147). The ratio of d to the maximum number of triads is subtracted from one to form zeta. That is, if d=12 and the max number of triads was equal to 20, zeta would be equal to: 1- 12/20 = 0.4. If there are more circular triads, zeta drops decision maker is forced to compare alternatives which are associated with extreme points in the consequence space (Kamenetzky, 1982:711).

Ellsburg noted that inconsistency is to be expected, particularly with respect to utility differences that are almost equal. The most important information gained, he states, "concerns choices which the subject finds easy to make" (Ellsburg, 1954:274). Saaty tries to keep the comparisons in a given matrix (cluster on the same level of the hierarchy) within a factor of 10 of each other, to avoid the extreme points. If one of the factors is outside this range it should be removed and placed in another matrix comparing more similar factors, otherwise, the AHP comparisons are distorted and meaningless.

Saaty cautions users not to take "short cuts" with the AHP, such as asking subjects to fill the cells of only one row/column and then computing the other cells from these. This short cut assumes the judge will be perfectly consistent in completing the remainder of the matrix. In this case the eigenvalue will be equal to n which represents perfect consistency (Saaty, 1980:228).

Consistency can be measured for the single judge when he has a number of equivalent judgements that can be compared. Pairwise comparisons present different rows in the matrix that represent equivalent comparisons, which can be related. It does not matter if the preferences are measured by a ratio consistency needed to maintain coherence among the objects of one's experiences and the inconsistency necessary for human intellectual growth (Saaty, 1982:82). If the CR is considerably more than .10, say .20, then a reexamination of the judgments may be in order (Saaty, 1982:9-1).

It is important to emphasize that the objective is to make "good" decisions, not to minimize the CR. The intensity of concern with consistency and inconsistency differs by an order of magnitude. That is, if a unit amount of priorities were divided among the two, consistency would be about .90 and inconsistency about .10. Good decisions are most often based on consistent judgments but the converse is not necessarily true. It is very possible to make perfectly consistent judgments that are wrong.

To measure the inconsistency of all the judgments made in the hierarchy, the CI for each cluster is multiplied by the priority of the criterion with respect to which these comparisons are made. This number is summed over all the criteria which gives a single overall weighted number.

Kamenetzky notes that this consistency index measure may be high even though the judgements are consistent because the decision maker's value function may not be linear. This should not happen if the attributes are truly mutually preferentially independent. It is not unusual, however, for attributes that seem mutually preferentially independent on the first evaluation, to turn out to be not so when the equal to 1. Therefore, the trace, or sum of the main diagonal entries, would be equal to n, where n is the dimension of the perfectly consistent matrix. The trace will always be equal to, or greater than the dimension of the matrix. Saaty calls this a "monotone increasing function" of X_{ij} (Saaty, 1974:57). Since the trace is equal to the maximum eigen value, or lambda max, one may look at the difference (lambda max − n) as a measure of the average ratio deviation.

The AHP consistency index can be thought of as a measurement of the average amount each paired comparison deviates from computed ratio (Wi/W_j from the eigenvector). Gear describes Saaty's consistency index as a measure of the "fuzziness" introduced by the answers to pairwise ratio comparison scales (Gear, p13).

When the CI is zero there is complete consistency. To decide how acceptable this number was, Saaty determined what the average CI was from a randomly generated comparison matrix of different dimensions and called it the random index (RI). Using a sample size of 500 he obtained the following RIs:

Random Indexes

n:	3	4	5	6	7	8
ci(ri):	.58	.90	1.12	1.24	1.32	1.41

(Saaty, 1980:21)

The ratio of CI to RI for the same order matrix is called the consistency ratio (CR). Saaty allows some inconsistency in order to provide a balance between the

the judges could verify that the derived vectors reflected their "true" opinions. The priority vectors were drawn as histograms to ease the interpretation. Their original inputs were displayed to give them the opportunity to correct potential errors in their pairwise comparisons.

To assist the judges in identifying possible errors (reversed signs, etc), the comparisons that contributed the most to the inconsistency of the matrix were circled. The judge was then asked to verify that the circled comparisons were what he had intended. This was accomplished only for those matrices that exceeded 10% CR.

These comparisons were isolated because they had the largest ratio of pairwise ratings (Xij) divided by the ratio of the priority vector elements (Wi/Wj). This is the method recommended by Saaty as being the most relevant (Saaty, 1980:66). The comparisons were isolated serially. That is, after the first "faulty" input was corrected with the nearest integer rating, the eigenvector was recalculated. If the CR remained above 10%, the comparison that contributed the most to the inconsistency of the revised matrix was isolated, and so on - until the CR dropped to 10%. Appendix C1 shows the computer program to identify the potential errors. As seen in Appendix B, the judge was not given any reason why the inputs were circled nor the order of their importance, to prevent biasing the results. He was simply asked to verify that the circled rating was what he had intended.

Statistical feedback was considered inappropriate for the AHP portion because it would require an excessively "busy" survey. It would entail displaying both the group mean vectors and the judge's own vectors for nine matrices. Instead, a type of Press's Quality Feedback Control (QFC) was used to improve the consensus of the AHP judgments.

The feedback, shown in Appendix B, consisted of three pages of anonymous reasons why individuals had deviated outside one standard deviation of the group mean for the top level criteria. Although only the top level was originally solicited, many of the judges included reasons for their ratings for subsequent criteria. All the written responses were included in the second survey, Appendix B.

Analysis

Introduction. As explained earlier, the purpose of this analysis was to examine the effect of applying three different aggregation methods on both the consistency and final priority vectors using the AHP and to discover the critical parameters. The actual application of the AHP and majority rule was accomplished using three pascal programs written on an Apple IIe computer, Appendix C. Saaty's basic interactive code was converted into pascal to interact with files (Saaty, 1982:167). The files contained each decision maker's ratings for the entire hierarchy (Sample file in Appendix D).

These programs provided the tool to accomplish the two major objectives: 1) measuring the effect of feedback, and 2) measuring the effect of the aggregation technique. The two statistical measures used to evaluate the significance of the correlation between the derived priority vectors were Kendall's tau for two vectors, and Kendall's concordance, W, for n-vectors.

Kendall Correlation Tau. The Kendall rank correlation coefficient is suitable as a measure of correlation with data that is at least ordinal. The tau will give a measure of the degree of association or correlation between the two sets of ranks. The sampling distribution of tau under the null hypothesis is known, and therefore tau, unlike Spearman's rho (another correlation coefficient between ranks), is subject to tests of significance.

One may think of tau as a function of the minimum number of inversions or interchanges between neighbors which is required to transform one ranking into another. That is, tau is a measure of the disarray of a series of pairwise comparisons (Siegel, 1956:316). It is determined by calculating the value of the "disarray" (S) by starting with the first number on the left and counting the number of ranks to its right which are larger. Then the number of ranks to its right which are smaller are subtracted. This number is determined for all the ranks and summed to obtain S.

It's calculation is best shown in an example. Suppose judge Y and X ranked the objectives a,b,c and d in the following order:

		Objectives			
		a	b	c	d
Judge	X	3	4	2	1
Judge	Y	3	1	4	2

Rearranging the order, so that judge X's appear in natural order:

		d	c	a	b
Judge	X	1	2	3	4
Judge	Y	2	4	3	1

Judges X's revised rankings are in their natural order, so their contribution to S is 0. One next proceeds to Y to determine how many pairs of ranks in judge Y's set are in their correct (natural) order with respect to each other.

First look at all possible pairs of ranks in which Y's rank 2, the rank farthest to the left in the set, is one member of the pair. The first pair, (2&4), has the correct order; 2 precedes 4, so a score of +1 is assigned to this pair. The second pair of ranks (2&3) is also in the correct order so it also earns a score of +1. The third pair (2&1) are not in natural order so this pair has a score of -1. The total score for all pairs which include the rank 2 is:

$$(+1) + (+1) + (-1) = +1.$$

The pairs of ranks which include the second from the left number (4) are: (4&3) and (4&1), which get assigned (-1) and (-1) respectively for a score of -2. When looking at rank 3 and succeeding ranks, there is only one pair (3&1) which is scored as -1. The total of all the scores is then:

$$(+1) + (-2) + (-1) = -2 = S$$

Tau is then determined by dividing this number (S) by the maximum amount of "disarray" possible, which is N(N-1)/2. This would have been yielded if the rankings of judges X and Y had agreed perfectly, because every pair of judge Y's ranks would be in the same (correct) order as judge X, and thus every pair would receive a score of +1. The maximum possible total would occur in the case of perfect agreement between X and Y, which would be six (four things taken two at a time).

Tau is the degree of relation between the two sets of ranks and is indicated by the ratio of the actual total of +1's and -1's to the possible maximum total:

tau = actual/possible total = -2/6 = -.33

The tau = -.33 is a measure of the agreement between the ranks assigned to the objectives by judge X and those assigned by judge Y.

When two or more observations on either the X or the Y variable are tied, the tied values are given the average of the ranks they would have received if there were no ties. The effect of ties is to change the denominator for tau. In the case of ties, tau becomes:

$$\text{tau} = \frac{S}{[N(N-1)/2 - T_x]^{1/2}[N(N-1)/2 - T_y]^{1/2}}$$

where: $T_x = \sum_i t_i(t_i-1)$ and t_i is the number of tied observations in each group i

T_y = same as T_x for group y

Example:

	Objectives					
	a	b	c	d	e	f
Judge X (Eigen VM):	6	5	3	1	2	4
Judge Y (vote mean):	5.5	5.5	3.5	1	2	3.5

rearranging on X:

	d	e	c	f	b	a
Judge X:	1	2	3	4	5	6
Judge Y:	1	2	3.5	3.5	5.5	5.5

calculating S in the usual way:

$$S = (+5) + (+4) + (2) + (2) + (0) = 13$$

There are two sets of tied ranks. Two objectives are tied at rank 3.5 and two are tied at 5.5 (both by "Judge Y"). In each of these cases, t=2, the number of tied observations . Thus Ty may be computed:

$$\begin{aligned} T_y &= \sum t_i(t_i-1)/2 \\ &= [2(2-1) + 2(2-1)]/2 \\ &= 2 \end{aligned}$$

$$\text{tau} = \frac{13}{[15-0]^{1/2}[15-2]^{1/2}} = \frac{13}{13.96} = .931$$

This example shows actual data and is a correlation between the eigenvector means (EigenVM) and the majority rule mean (VoteM) shown in Table III.

Kendall developed a table to evaluate the significance of tau for $N \leq 10$. This is copied in Appendix E. For $N \geq 8$, the sampling distribution of tau is practically indistinguishable from the normal distribution (Siegel, 1956:220). Appendix E may be used to determine the exact probability associated with the occurrence (one-tailed) under the null hypothesis (vectors are correlated) of any value as extreme as an observed S.

The sampling distributions of S and tau are identical, in a probability sense. In as much as tau is a function of S, either might be tabled, but Kendall found it more convenient to tabulate S. For such small samples, the significance of an observed relation between two samples of ranks may be determined by simply finding the value of S and then referring to Appendix E to determine the one-tailed probability associated with that value. If the $P \leq$ alpha (probability of rejecting a true hypothesis), the null hypothesis may be rejected. In the above example, entering Appendix E with $S=13$ and $N=6$, one reads .0083 as the probability of associated with values as large as 13. Arbitrarily picking alpha = .05, one rejects that the vectors are not correlated and accepts the alternate hypothesis that the vectors are correlated.

Kendall Concordance W. To examine the effect of feedback, this thesis examined the overall agreement between ranks derived by the Delphi process, the AHP, and majority rule voting. to evaluate if one method resulted in more "consensus" than the other. Also this evaluation was necessary to evaluate the effect of feedback for the Delphi process.

As a solution to the problem of ascertaining the overall agreement among N sets of rankings, it might seem reasonable to find all the tau's between all possible pairs of the rankings and then compute the average of these coefficients to determine the overall association. Unless N is very small, such a procedure would be extremely tedious. The variance between judges for each objective would reflect this agreement. However there is no statistical test for the significance of this measure. This thesis chose to apply the Kendall Coefficient of Concordance, which is a function of the variance. The tables to test the significance of W are in Appendix E.

The Kendall Coefficient of Concordance (W) was used to statistically evaluate the independence of the N judges' rankings. The 12 judges' priority vectors for the top level objectives were converted to ranks for the eigenvector and direct assessment approaches. The concordance test evaluated if the clusters of vectors for each approach were independent of each other.

There are six steps in the determination of W:

1. Let k = the number of entities to be ranked, and let N = the number of judges assigning ranks. Cast the observed ranks in a k X N table.
2. For each objective, determine R_j, the sum of the ranks assigned to that objective by the N judges.
3. Determine the mean of the R_j. Express each R_j as a deviation from that mean. Square these deviations, and sum the squares to obtain S.
4. If the proportion of ties in the N sets of ranks is large, add in the T factor below (This tie correction is similar Kendall's correlation for two vectors: tau).

$$W = \frac{S}{N^2(k^3 - k)/12 - N\sum_{T=x,y} T}$$

where

$$T = \sum_i (t_i^3 - t_i)/12$$

where:
t = number of observations in a group tied for a given rank and is summed over all group of ties within any one of the N rankings.

5. The method for determining whether the observed value of w is significantly different from zero depends on the size of k:

   a. If k is 7 or smaller, Appendix E gives critical values of S associated with W's significance at the .05 and .01 levels.
   b. If k is larger than 7, the chi square distribution = N(k-1)W whose significance, for df = k-1, may be tested using chi square tables.

(Siegel, 1956:237)

The following shows an example of the procedures in calculating the concordance between the first five judges' rankings of the top level objectives (Appendix F shows the orginal eigenvectors). The ranks are shown below:

Judges' Ranks for the Top Level Objectives

	Judge 1	2	3	4	5	R_j
Requirements	6	4	4.5	6	4	24.5
Performance	3	5	4.5	5	5	22.5
Costs	4	3	6	1	6	18.0
Risk	1	1	3	4	1	10.0
Logistics	5	2	2	2	2	13.0
Survivability	2	6	1	3	3	15.0

The mean of the R_j is 17.17. The sum of the squared deviations from this mean is S = 53.8 + 28.4 + .7 + 51.3 + 17.3 + 4.7 = 156.3. With k=6 and N=5, S must be at least 182.4 to be significant at the .05 level. Therefore, one cannot reject the null hypothesis that the first five judges' rankings are unrelated to each other. The conclusion is that the agreement among the 5 judges is no higher than it would be by chance. The complete results will be discussed in the results chapter.

Although the proportion of ties is small, for the sake of this example, the correction factor T will be calculated. Judge #3 has one set of ties: requirements and performance is tied at 4.5. Therefore, the number of tied objectives (2) are summed over the number of ties per judge (1):

$$T(\text{judge } 1-2) = 0$$
$$T(\text{judge } \#3) = t(t^2-1)/12 = 2(4-1)/12 = .5$$
$$T(\text{judge } 4-5) = 0$$
The sum of T_j = 0.5

$$W = \frac{S}{k^2(N^3-N)/12 - k\sum T} \quad \frac{156.3}{(6)^2(5^3-5)/12 - .5} = \frac{156.3}{359.5} = .435$$

The effect of ties, if left uncorrected, is to slightly depress the value of W and make the decision more conservative. That is, one is slightly less likely to reject the null hypothesis if he had ties and did not correct for them. To determine the significance of the revised W one must convert it in terms of S because Appendix E is designed around s. The conversion is accomplished by multiplying the original S (156.3) by the ratio of the old denominator (360) to the corrected denominator (359.5). This corrected S is then used to determine the significance at k=6 and N=5.

A high or significant value of W may be interpreted as meaning that the observers or judges are applying essentially the same standard in ranking the N objects under study. Often their pooled ordering may serve as a "standard," especially when there is no relevant external criterion for ordering the objects (Siegel, 1956:237).

Feedback Effect. Before evaluating different aggregation techniques, it is important to discover the effect that feedback has on AHP and compare it to the effect feedback has on the direct assessment technique (Battelle). The variance among the 12 judges' criteria weights (top level vector) derived by AHP before and after feedback will be compared with the corresponding variance change for the Battelle vectors. This variance will isolate those criteria on which there was little aggreement. The agreement in the overall rankings of the vectors will be measured by the Kendall Coefficient of Concordance, "W." Kendall's W will show if there is agreement amongst the judges for each method: direct assessment and the AHP and it will discover if the feedback significantly changed the rank order of either method.

Aggregation Effect. A separate issue from feedback is how to most accurately aggregate the opinions of the group into one group opinion. This study will examine three mathematical methods to arrive at the "group opinion:" 1) calculate the arithmetic mean of the eigenvectors of the 12 judges, 2) calculate the geometric mean of each pairwise comparison for the 12 judges prior to computing an eigenvector, and 3) convert each judge's matrix into a voting matrix and use majority rule to arrive at a weighted vector. The remainder of the chapter discusses each of these methods in more detail.

Arithmetic Mean. The arithmetic mean of the weights is the most straight forward of the four methods. Each judge's criterion weight (an element of the eigenvector) will be summed across the 12 judges and divided by 12. The mean CI will be the average of the 12 judges' matrix CIs. Note that this thesis did not examine the geometric mean of the 12 judges' eigenvectors. This has been left for further research.

Geometric Input Mean. Each judge's criterion rating will be multiplied across the 12 judges and the 12th root will be used as the input rating. Because the inputs are averaged prior to the calculation of an eigenvector, the resulting consistency index will reflect the "true" CI, versus the mean arithmetic CI calculated above.

Majority Rule. Each matrix will be converted to a "voting" matrix by converting the AHP ratio inputs into "votes." Each AHP rating greater than one will be assigned one (vote) and each rating less than one will be assigned zero. Each AHP rating equal to one will be assigned one half of a vote. The priority vector will be the percentage of total votes received by each criterion. The voting program (Appendix C4) shows the pascal code to convert the AHP matrix into a voting matrix.

Zeta. The consistency measure for the majority rule matrices will be Kendall's Coefficient of Consistence (zeta). Zeta measures the degree of intransitivity among n ordinally ranked elements determined by n(n-1)/2 paired comparisons.

In preference matrices of more than three alternatives, it is possible to have the majority preferences of three alternatives aligned to be circular triads (Dobbins, 1980a:67). For example, an aggregate may have a rank order of A=C > B=E=F > D which has five circular triads: ACDA, ABDA, AEDA, AFDA, and BEFB. Kendall proved that the maximum and minimum number of triads can be attained by arrangement of preferences. Kendall's equation for d, the number of circular riads in a preference matrix, consisted of the number of lternatives and the sum of the votes in row i (Ai) of the reference matrix:

$$d = n(n-)(n-2)/6 - [\sum_{i} Ai(Ai-1)]/2$$

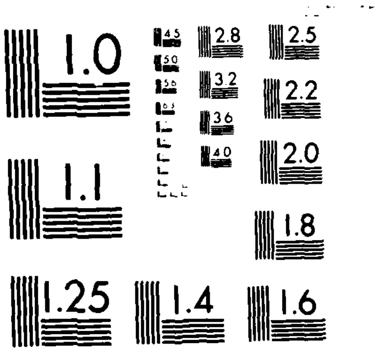
eta is 1 - d/(max number of triads) where the maximum number f triads depends whether n is odd or even:

	odd	even
max triads =	$(n^3 - n)/24$	$(n^3 - 4n)/24$

The derivation of zeta is based on Ai being integer valued (no tied pairs). To resolve this problem the model for this research brackets the possible values if fractional pairs of Ai's exist. The steps of the d bracketing are in the computer procedure "CalcZeta" in Appendix C4 and are described below (Dobbins, 1980a:29):

1) Arrange Ai row totals in order of their value.
2) Count the number of fractional Ai row totals.
3) Round the upper one-half of each of the fractional Ai values upward to their next larger integer values.
4) Round the lower one-half of each fractional Ai values downward to their next smaller integer.
5) Verify that the sum of the rounded Ai's = n(n-1)/2.
6) Use this rounded set of Ai's to calculate a lower d (gives a "low" zeta even though it is a high d estimate)
7) Return to the ordered unrounded Ai's and round the upper one-half of each pair of the fractional Ai values downward to their next smaller integer values.
8) Round the lower one-half of each pair of the fractional Ai's upward to their next larger integer values.
9) Verify that the sum of the second rounded Ai's = n(n-1)/2.
10) Calculate an upper d based on this second rounded set of Ai's.
11) Average the lower d and upper d to form an approximate d for the matrix with the tied pairs.

AD-A155 858 AGGREGATING INDIVIDUAL PREFERENCES IN THE ANALYTIC 2/4
HIERARCHY PROCESS APPL..(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. S E REED
UNCLASSIFIED 15 MAR 85 AFIT/GST/OS/85M-13 F/G 9/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

The corrected zeta above (zeta(c)) will always show improvement over the uncorrected zeta (zeta(u)) when fractionized Ai's exist. Therefore, there is less discrimination with zeta(c) than with zeta(u) and any reference to zeta will imply zeta(u). When the distinction is necessary, it will be made clear to the reader.

It can readily be seen that zeta=1 when there are no circular triads, which is the only time that the data can be ranked. (Kendall, 1970:147). Kendall determined the distribution zeta would have if all the preferences were allotted at random (Appendix E). The distribution is dependent on n for a given significance level. As n increases, the calculated zeta value that rejects the null hypothesis (zeta=1) slowly drops. That is, at .05 significance, when n = 3, any calculated zeta other than one will reject zeta=1; whereas at n = 8, the calculated zeta must be lower than .60 to reject that zeta=1 (Dobbins, 1980a:32-35).

Another way to look at zeta's significance is to compare it to the AHP CI. Kendall changes his zeta limit for a given significance depending on n, but the source zeta remains the same. Saaty, on the other hand, changes the source CI depending on n (CI to CR), but not the cut off (.10). These relative cutoffs do not concern this research because the focus here is on zeta and CI as comparative measures of effectiveness. These comparisons are between matrices of the same dimensions (n), and so the cutoff is irrelevant.

Summary

This thesis will determine the variance reduction brought about by feedback of group information for both direct assessment and the AHP. It will also compare the aggregated priority vectors, both in rank order and the level of consistency. There will be three types of aggregated vectors: 1) The eigenvector calculated from the geometric mean of individual comparisons (AHP), 2) The average vector calculated from 12 judges' eigenvectors (AHP), and 3) The vector calculated using the majority rule process.

Chapter V. Results

Introduction

The analysis focussed on three aspects of aggregating the results gained by the AHP. The first aspect was the effect feedback had on increasing the agreement between the judges. The Kendall Coefficient of Concordance (W) was used to statistically evaluate this agreement. Several other aspects of feedback were also examined.

The second aspect was an analysis of the aggregation method: the AHP geometric mean input, the AHP vector mean, and majority rule vote mean.The effect on the consistency measure and the resulting rank orders was examined.

The third aspect was a closer examination of the consistency measures: CI and zeta. The equality of their means was determined by analysis of variance varying the judge, the matrix size, and whether the consistency measure was CI or zeta. The Kendall Correlation Coefficient, tau, indicated the extent the rank orders were the same between consistency measures.

Finally, an ancillary effort was to apply the final priority vectors ("bottom vector") to the original Battelle attribute values and examine the difference the AHP would make to the original study. Battelle found the results were insensitive to large changes in the weights, but they did not go beyond the top level. This thesis sought to discover if

Battelle's results would change if the weights were elicited throughout the hierarchy.

Feedback

The effect of feedback was evaluated by the change in Kendall's concordance (W) between the original Battelle survey (Delphi0) and the repeat Battelle survey (Delphi1). The original Battelle survey elicited direct assessment ratings between 1 and 10 for the top level weights only. This thesis returned the same questions on the Battelle survey along with the group mean rating and standard deviation for each objective in the top level. Each judge was asked to reevaluate his original ratings (accomplished one year earlier) and to explain any of his new ratings that remained outside of one standard deviation of the original mean.

Twelve of the original 13 judges on the TAV steering committee who responded to the original Battelle survey were located. Eleven completed the survey and justified their ratings for the top level weights. An additional judge from the TAV program office completed the AHP portions (judge #5), but did not participate in the Delphi portion of the study.

The AHP portion of the survey was returned with "Quality Feedback:" an additional three pages of reasons that the judges gave to justify their ratings of the top level, and often subsequent levels of the hierarchy (Appendix B). Each page of the repeat AHP survey displayed the resulting priority histogram and the original responses of each recipient's comparison matrix. He was asked to rate (1-10) how well the histogram reflected his "true" priorities. If he rated the histogram poor, he was asked to review his original AHP inputs.

Judges were asked to review certain comparisons of the original inputs to insure they were correct. These potentially "erroneous" comparisons were located by computer as the ones that contributed the most to an excess of a consistency ratio equal to .10. They were circled on the returned matrix.

Delphi. This thesis examined the overall agreement between ranks derived by the Delphi process to evaluate the effect of feedback for direct solicitation of weights. The ratings are shown for both Delphi0 (Original Battelle) and Delphi1 in Table III. Table IIIa shows the weights converted to ranks, and Table IIIb shows the statistical correlations. The effect of feedback was measured by Kendall's concordance, W, and the variance of the judge's priorities.

As seen in Table IIIb, feedback reduced the variance and increased the concordance (agreement) between the judges. The significant W (sig. < .01) shows that there is statistically significant agreement between both Delphi0 and Delphi1 priority ranks. The significant Tau shows the two average vectors are also correlated. Feedback did not affect the rank order of the priority vector. This can be seen graphically in the histogram in Figure 3.

TABLE III

Top Level Battelle Ratings

Battelle Original (Delphi0)

Obj	1	2	3	4	6	7	8	9	10	11	12	Ave
1	10	10	10	10	10	10	10	7	10	10	10	9.7
2	6	8	7	6	6	9	5	5	10	7	8	7.2
3	6	8	8	10	8	8	10	9	6	8	7	8.1
4	8	9	10	10	7	5	8	9	4	6	10	7.8
5	6	5	10	7	5	7	6	9	6	6	8	7.0
6	8	5	6	7	7	6	10	8	8	7	9	7.5
7	8	5	9	8	8	10	8	7	7	6	4	7.5
8	5	1	5	5	2	5	5	4	3	2	3	3.7

(Battelle, 1983:6-2)

Second Survey (Delphi1)

Obj	1	2	3	4	6	7	8	9	10	11	12	Ave
1	10	10	10	10	10	9	10	7	10	10	10	9.6
2	6	5	7	5	7	7	7	7	10	7	5	6.6
3	7	9	8	10	8	10	10	9	7	8	8	8.5
4	8	9	10	10	7	5	8	9	5	6	9	7.8
5	6	8	10	6	6	6	5	9	6	6	8	6.9
6	8	5	6	8	8	7	10	8	10	8	9	7.9
7	7	5	9	8	9	10	7	7	8	7	5	7.4
8	4	1	5	5	5	3	4	4	3	2	3	3.5

Where:

Judge #5: Added after initial Battelle survey so was not included for Delphi feedback data.

Objectives:

1: Requirements
2: Goals
3: Performance
4: Costs
5: Technology Risk
6: Logistics/Supportability
7: Survivability
8: Environmental Impact

TABLE IIIa

Delphi0 and Delphi1 Ranks

Battelle Survey (Delphi0)

	JUDGE											
OBJ	1	2	3	4	5	6	7	8	9	10	11	AVE
1	8	8	7	7	8	7.5	7	3.5	7.5	8	7.5	8
2	3	5.5	3	2	3	6	1.5	2	7.5	5.5	4.5	3
3	3	5.5	4	7	6.5	5	7	7	3.5	7	3	7
4	6	7	7	7	4.5	1.5	4.5	7	2	3	7.5	6
5	3	3	7	3.5	2	4	3	7	3.5	3	4.5	2
6	6	3	5	5	6.5	7.5	4.5	3.5	5	3	2	4.5
7	6	3	2	3.5	4.5	3	7	5	6	5.5	6	4.5
8	1	1	1	1	1	1.5	1.5	1	1	1	1	1

Delphi-Battelle Survey (Delphi1)

	JUDGE											
OBJ	1	2	3	4	5	6	7	8	9	10	11	AVE
1	8	8	7	7	8	6	7	3	7	8	8	8
2	2.5	3	3	2	3.5	4.5	3.5	3	7	4.5	2.5	2
3	4.5	6.5	4	7	5.5	7.5	7	7	4	6.5	4.5	7
4	6.5	6.5	7	7	3.5	2	5	7	2	2.5	6.5	5
5	2.5	5	7	3	2	3	2	7	3	2.5	4.5	3
6	4.5	3	5	4.5	7	7.5	3.5	3	5	4.5	2.5	4
7	6.5	3	2	4.5	5.5	4.5	7	5	7	6.5	6.5	6
8	1	1	1	1	1	1	1	1	1	1	1	1

TABLE IIIb

Concordance and Tau Between Delphi0 and Delphi1

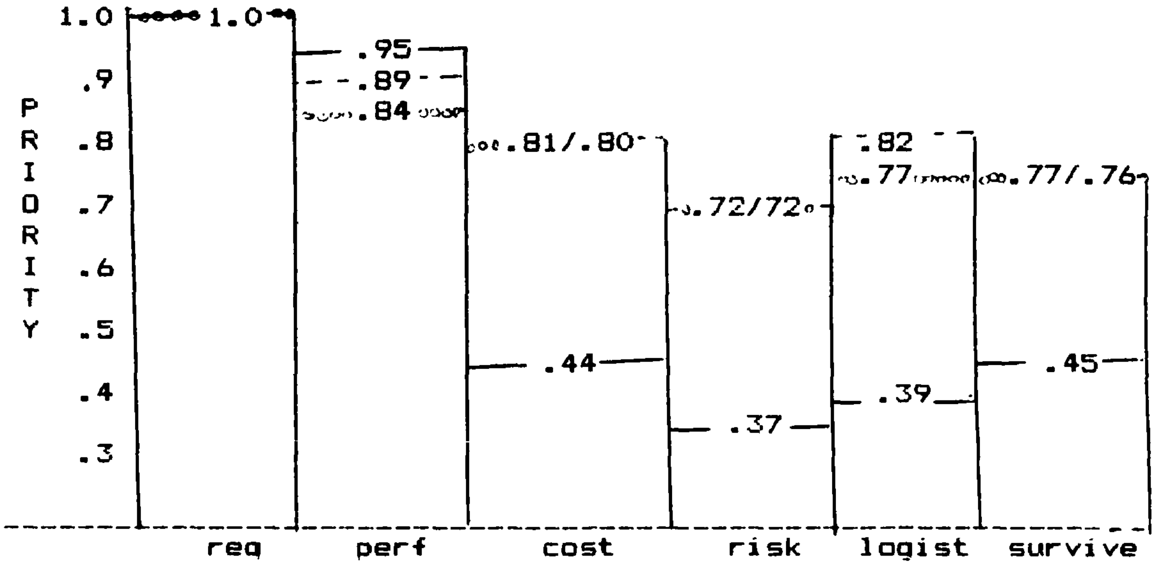
	Delphi0	Delphi1
Kendall's W	.516	.564
Variance	1.44	1.22

Kendall's Tau Between AveDelphi0 and AveDelphi1 = .837 (sig<.01)

Where:
Variance is equal to the average variance for the ratings on the 8 top level objectives.

FIGURE 3

Top Level Priority Histogram
DelphiO, Delphi1, and Eigen GM



where:

DelphiO: Rank is derived from the Delphi approach with zero iterations, i.e., it is the priority vector Battelle received by direct assessment.
ooooo

Delphi1: Rank is derived from the delphi approach with one iteration, i.e., it is the Battelle priority vector after feedback (direct assessment).
- - - -

EigenGM: Rank is derived from the eigen vector from the geometric mean of the 12 judges' inputs.
━━━

AHP Feedback. Nine of the twelve judges returned the second AHP survey. These nine judges had 56 pairwise comparisons that caused a few of their matrices to exceed 10% consistency ratio. This was 5% of the total number of comparisons made. Of these 56 potential "errors" that were called to their attention, the judges changed 46% of them (26). These changes included 17 rating changes for an average of 3.0 units of change and 9 sign changes.

The nonresponding judges' (10,11,12) inputs were corrected for major errors only. These "major" errors were identified if they were the most "deviant" comparisons and if a change made a substantial improvement in the consistency (20%). The effort was intended to make the resulting matrices more representative of the nonresponding judges' opinions. It was not an effort to improve the consistency. Appendix J shows the revised priorities calculated for both sets of revised groups: the 9 judge revised (natural) group and the 12 judge revised group (three "computer-revised" judges). The priorities between these groups caused only minor consistency and rank changes. Table IV shows the respective priorities and IVa shows the priorities converted to ranks and the statistical analysis.

TABLE IV

Original and Revised AHP Priorities (EigenGM)

Original Survey

	Effective	Require	Perform	Risks	Logist	Survive
1	0.312	0.262	0.479	0.234	0.202	0.059
2	0.241	0.170	0.186	0.382	0.161	0.150
3	0.110	0.064	0.335	0.384	0.638	0.156
4	0.091	0.119				0.135
5	0.127	0.116				0.079
6	0.120	0.045				0.137
7		0.106				0.284
8		0.117				
cr	0.033	0.030	0.003	0.001	0.005	0.019
ci	0.027	0.006	0.006	0.001	0.009	0.015

	Propellants	Maintainable	Maneuver
1	0.376	0.127	0.457
2	0.219	0.265	0.368
3	0.405	0.333	0.176
4		0.274	
cr	0.014	0.003	0.008
ci	0.023	0.004	0.013

Second Survey (12 Judges)

	Effective	Require	Perform	Risks	Logist	Survive
1	.297	.239	.478	.240	.224	.065
2.	.261	.121	.184	.402	.147	.148
3	.113	.058	.338	.358	.630	.149
4	.094	.156				.125
5	.120	.148				.089
6	.120	.035				.136
7		.090				.289
8		.154				
ci	.006	.022	.003	.000	.000	.010
cr	.005	.016	.005	.000	.001	.008

	Propellants	Maintainable	Maneuver
1	.369	.106	.457
2	.196	.282	.368
3	.435	.363	.176
4		.248	
ci	.003	.001	.008
cr	.005	.001	.001

TABLE IVa

Ranks and Correlations Between Priority Vectors First AHP, Second AHP, and Vote Mean*

	Effectiveness			Requirements		
OBJECTIVE	AHP1	AHP2	VoteM	AHP1	AHP2	VoteM
1	6	6	5.5	8	8	8
2	5	5	5.5	7	4	5.5
3	3	3	3	1.5	1.5	2
4	1	1	1	4.5	6	5.5
5	3	3	3	4.5	6	5.5
6	3	3	3	1.5	1.5	1
7				4.5	3	3
8				4.5	6	5.5

TAU

AHP1 -	1.0	.96	AHP1 -	.67	.84
sig: -	.02	.03	sig:	.05	.02
			AHP2 -	-	.91
			sig:	-	.01

	Survivability			Maintainability		
OBJECTIVE	AHP1	AHP2	VoteM	AHP1	AHP2	VoteM
1	1.5	1	1.5	1	1	1
2	4.5	4.5	4.5	2.5	2.5	3
3	4.5	4.5	4.5	4	4	4
4	4.5	4.5	4.5	2.5	2.5	2
5	2	2	1.5			
6	4.5	4.5	4.5			
7	7	7	7			

TAU

AHP1: -	1.0	.96	-	1.0	.91
sig:	.02	.03		.08	.08

TAU (3 Element Priorities): 1.0
Sig: .12

* Vote Mean derived from second AHP
Priorities considered tied within .03 of each other

The affect of "quality" feedback on the AHP was not measured because the judges changed inputs, not in response to the quality feedback, but in response to the prompting to review certain comparisons. Only two of the nine returned surveys that had changes that were not prompted. These changes were the result of the judges' dissatisfaction with the histogram of the orginal eigenvector. One judge did not like the 7:1 ratio for one pair of the objectives reflected in the histogram, so he changed the comparison to 5:1. Another judge changed a comparison from 2:1 to 1.2:1 after he saw the histogram.

Feedback Conclusions. The AHP seems resilient to feedback. Even when directed to reexamine isolated pairwise comparisons, 54% of the returned comparisons were not changed. Individuals expressed general satisfaction with the AHP priorities. The few minor changes made had little impact on the rank order of the priorities.

One surprise was that the top level AHP weights correlated more strongly with the original Battelle study than to the second iteration (Table V and Figure 3). The original Battelle study was accomplished a year earlier than the AHP and Delphi iteration.

One needs to exercise caution prior to saying this supports Saaty's contention that pairwise comparisons are better able to elicit the underlying opinions. The reason for the large shift in tau is that the direct assessment weights

Comparison Battelle Results

The final ancillary effort of this thesis was to examine the difference that applying the AHP would make to the outcome of the Battelle study. The original Battelle results are "generic" in this study to avoid proprietary information from defense contractors. The reader who has an official need may contact ASD/XR.

To compare the Battelle final scores and the AHP final scores, this study applied the original Battelle weights to the revised 32 criterion hierarchy rather than the original 47 criteria hierarchy. The minor shifts in the TAV scores between Battelle's original hierarchy and the revised hierarchy were mainly due to the "single" stage concepts losing points without the environmental impact objective. The largest shift was a drop from 5th to 8th place (TAV # 13).

The AHP priority vector applied for the Battelle comparison was derived from the geometric mean of the nine judges who revised their original inputs. As shown earlier in this chapter, the difference with the 12 judge "revised" priority vector was negligible so there was no significant impact on this results.

Table XII shows the scores for the 14 TAV designs by applying the bottom priority vectors to the Battelle attribute scores. Figures 7 and 8 graphically protray the scores. Table XIII shows the correlation between the scores listed in Table XII. Since they are all significantly looking at the five matrices in this thesis that all have the same dimension (3), the relationship breaks down between CI and variance. Table XI shows the tau for CI and the variance between judges is insignificant (sig.=.804) for the five matrices that have three objectives. Therefore, this research has no conclusive information to show a strong relationship between consistency and variance between judges.

TABLE XI

Correlation Between CI and Deviation for Matrix Size 3

CI	Deviation * 10
.038	1.98
.106	1.57
.106	2.26
.188	1.75
.230	2.15

tau = .1054 Significance = .804

Position in Hierarchy. It was thought that the general or specific nature of the objectives may affect the consistency. It was believed that the nature of the objectives was mainly determined if they were near the bottom of the hierarchy or near the top. It was originally thought that the more technical, lower level objectives would lead to less consistency from the high level decision makers used in this study. However, comparing the consistencies of the matrices (size = 3) with their scattered distribution, shows no evidence that either the variance or the consistency of the judgements was affected by level in the hierarchy.

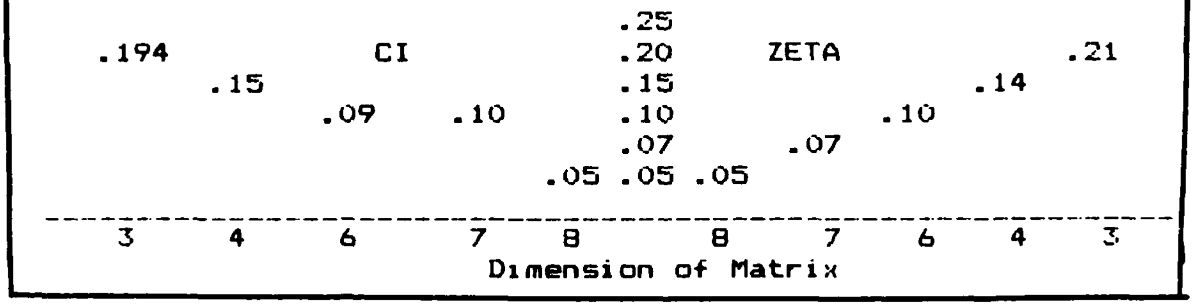
TABLE X

Correlation Between Consistency and Average Matrix Standard Deviations (Between Judges' Priority Vector Elements)

Matrix Dimension	Voting Matrix		AHP Matrix	
	Zeta	Dev * 10	CI	Dev * 10
8	.79	.54	.22	.52
7	.81	.73	.16	.96
6	.83	1.0	.14	.92
4	.88	1.4	.12	1.52
3	.87	.73	.07	1.75
Tau (significance)	.738(.082)		.8 (.051)	

Before interpreting this relationship, however, one must consider the strong relationship between the size of the matrix and consistency. The strong correlation between consistency and judge variance may be due to the correlation between matrix size and judge variance. Figure 6 shows that the larger the matrix, the greater the variance between objective weights.

FIGURE 6


Deviation Between Objective Weights versus Matix Dimension

Vertical Axis: Standard Deviation Between Objective Weights

One may incorrectly interpret Figure 6 as showing that consistent judges have less variance, and both consistency and variance are a function of matrix size. However, when

This is not to say that the dimension of the matrix is irrelevant to zeta. Zeta counts the number of circular triads and as such, it shows greater consistency with the smaller matrices. This is reflected in Table VII, which shows a strong correlation between the matrix dimension and the consistency.

Judge. Another factor that contributes to the variance of the consistency is the individual judge. The individual judges accounted for a significant (sig.=.073) portion of the variance of both consistency measures (Apppendix H). The judge influence is significant because his inconsistent judgement will cross the "boundaries" between the other factors: CI, zeta, and the matrix size.

Priority Vector Variance. After examining the strong correlation between consistency with judges and matrix size and the role of variance and matrix size, the next question emerges: Does the consistency of the individual affect the actual variance between judges. In other words, does a group of consistent individuals result in less variance between priority vectors than a group of inconsistent individuals? Table X shows the strong correlation between consistency and variance between judges (alpha=.05). This may lead one to say that the more consistent the judges are, the greater the variance between the judges.

must be compared, whether one is examining ratio consistency or ordinal transitivity.

Saaty developed a table and an adjustment to CI to account for the fact that consistency becomes better as a function of increasing matrix size (Saaty, 1980:62). Saaty divided CI by an adjustment for the matrix size, called the ratio index, to arrive at the consistency ratio (CR). Kendall adjusted the significance of zeta so that as the number of objectives being compared decreased, the tolerances for zeta narrowed. That is, zeta had to be closer to one with smaller matrices, to be statistically equal to one (see the statistical tables in Appendix E).

This relationship between consistency and matrix size is shown by the significance of the proportion of variance accounted for by the size of the matrix (Appendix H). For zeta the significance is .677 and for CI the significance is .054.

The reason why matrix size (n) is not as important to zeta is that zeta is based on an n-cubed factor divided by another n-cubed factor to calculate the number of circular triads and the maximum number possible (see methodology, chapter 5). The AHP's CI, on the other hand, solves an nth order equation to calculate the eigen values. Thus, the size of the matrix has a larger influence in the determination of CI, especially for the larger matrices, than it does in the determination of zeta.

This test rejects the null hypothesis of equal means at a significance = .078. One must accept that the CI and zeta are not the same in magnitude. This is a reasonable conclusion as the total mean CI = .06 and total mean zeta = .08.

Although they are not statistically the same size, CI and zeta are highly correlated measures of consistency. Table IX shows the strong (alpha=.001) relationship between zeta and CI. This significance is stronger than originally expected and illustrates that CI reflects the intransitivities among the rankings and that zeta may also reflect the "strength" of these intransitivities.

TABLE IX

Kendall's Correlation Tau for Consistency

	CI	Matrix Size
Zeta	-.4518 (.001)	.1520 (.006)
CI	-	.1674 (.002)

Before too strong a conclusion can be drawn about the CI-zeta correlation, one must examine how the different factors affect them both. One of these factors is the matrix size.

Matrix Size. The dimension of the comparison matrix has a strong influence on the consistency of the judgements, whether that measure is CI or zeta. The consistency drops for both CI and Zeta as the matrix size increases. This is expected because the chances for finding a consistent framework are smaller the larger the number of objects that

Consistency

This examination sought to discover the similarity of Saaty's consistency index (CI) and Kendall's coefficient of consistence (zeta). Their correlation with each other, the number of objectives being compared, and the judge making the comparison were determined through Kendall's tau and analysis of variance (anova).

The zeta value was subtracted from one to make it conceptually equal to the CI. That is, both measures ranged from zero for perfect consistency to one for random consistency. This would have no effect on the statistical evaluations made.

CI and Zeta. The 126 pairs of consistency measures [9 clusters X (12 judges + geometric mean input + arithmetic mean vector)] were divided into two groups: CI and zeta measures. Table VIII shows the summary of the anova results between CI and zeta (Appendix H).

TABLE VIII

ANOVA: Consistency Measure by CI and Zeta

Source of Variation	Sum Sqrs	df	Mean Sqr	F	Signif
Measure(ci,zeta)	.090	1	.090	3.14	.078
Residual	7.184	250	.029		
Total	7.274	251	.029		

This test shows that when CI and Zeta are combined, that the type (CI or zeta) of consistency measure contributes a significant amount of the variation in the combined measures.

TABLE VII

Correlation Between Bottom Level Priority Vectors
Kendall's Tau (Spearman's Rho in parens)

	EigVM	VoteM	Battel	EqWts
EigenGM	.847	.821	.549	.399
	(.962)	(.941)	(.716)	(.530)
EigenVM	-	.858	.587	.394
	-	(.960)	(.743)	(.522)
VoteV	-	-	.545	.404
	-	-	(.689)	(.530)
Battel	-	-	-	.629
	-	-	-	(.750)

Where:
EigGM: Weights from geometric mean input comparison
EigVM: Weights from average of judges' EigenVectors
VoteM: Weights from "Voting" comparison Matrix
Battel: Original Battelle Weights (Revised Hierarchy)
Sig: All significances of TAU and rho < .005

TABLE VI

Bottom Priority Vector * 100
EigenGM, EigenVM, VoteM, Battel, and Equal Weights

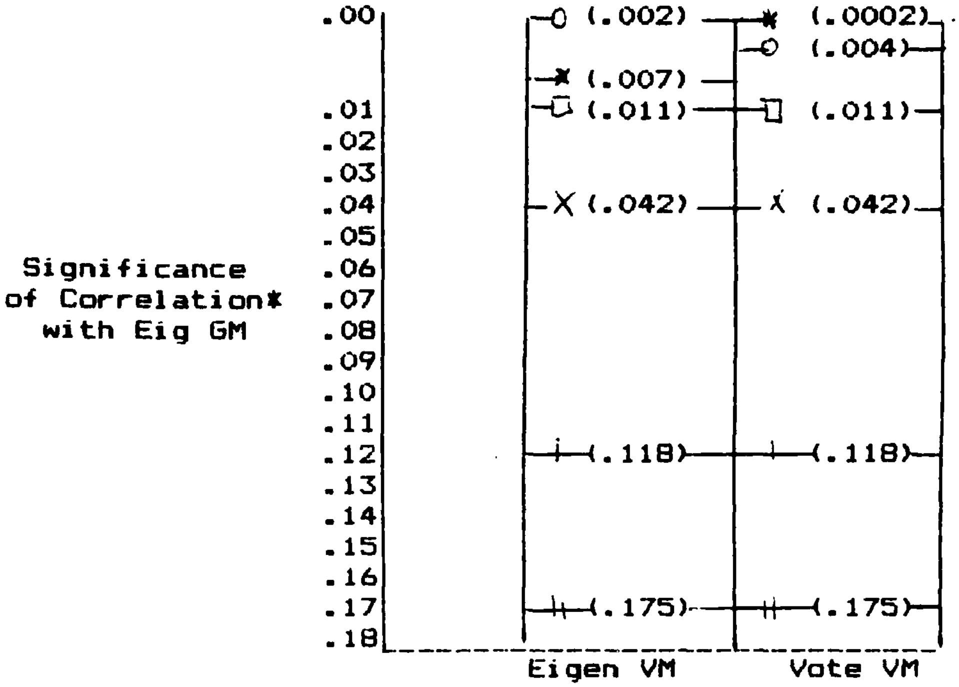
Obj	EigenGM	EigenVM	VoteM	Battel	EqualWts
1	6.3940	6.4167	4.7310	3.54	2.083
2	3.7252	3.4867	3.4113	3.54	2.083
3	1.6958	1.9631	1.7679	3.54	2.083
4	4.0310	4.4536	3.9591	3.54	2.083
5	4.1700	4.3657	3.8595	3.35	2.083
6	0.8896	0.9962	0.7968	3.35	2.083
7	2.5854	3.4281	2.3904	3.35	2.083
8	4.2812	4.1606	3.9591	3.54	2.083
9	12.8607	10.6714	12.4500	4.877	5.556
10	4.7603	4.0542	3.8346	4.877	5.556
11	8.6790	8.5744	8.6154	4.877	5.556
12	12.3000	12.8000	13.6000	14.823	16.667
13	3.0702	2.6220	1.9885	3.19	5.556
14	4.0902	3.3304	3.9770	6.39	5.556
15	3.0396	3.2568	3.7345	3.19	5.556
16	0.6572	1.2440	1.2977	2.26	1.852
17	0.6521	0.6950	0.6714	1.13	1.852
18	1.2086	1.2376	1.7778	1.13	1.852
19	1.7440	1.9311	1.8753	5.52	5.556
20	0.5510	0.9051	0.5449	1.13	1.389
21	2.0711	1.9323	2.3099	1.13	1.389
22	2.4495	2.6075	2.8010	1.13	1.389
23	1.5666	1.7455	2.0183	1.13	1.389
24	0.7500	0.9694	0.9928	1.96	2.778
25	1.5750	2.2008	2.0944	1.96	2.778
26	1.7375	2.2139	2.1624	1.96	2.778
27	1.3500	1.5196	1.9448	1.96	2.778
28	1.1500	1.0611	1.3192	1.96	2.778
29	1.9875	1.8209	2.0672	1.96	2.778
30	1.7183	1.5206	1.3164	0.653	0.926
31	1.6195	1.1646	1.1986	0.653	0.926
32	0.6123	0.6422	0.5042	0.653	0.926

Where:

EigGM:	Eigen vector calculated from the geometric mean input
EigVM:	Eigen vector from the arithmetic average judges' vectors
VoteM:	Priority vector from "voting" pairwise comparison matrix
Battel:	Original Battelle weights applied to revised hierarchy
Equal:	Each subobjective contributes an equal portion to the next higher objective in hierarchy.

FIGURE 5

Significance of Tau Between Priority Vectors
as a Function of N



Where:

EigenGM: Rank is the eigenvector derived from the geometric mean of the 12 judges' inputs.

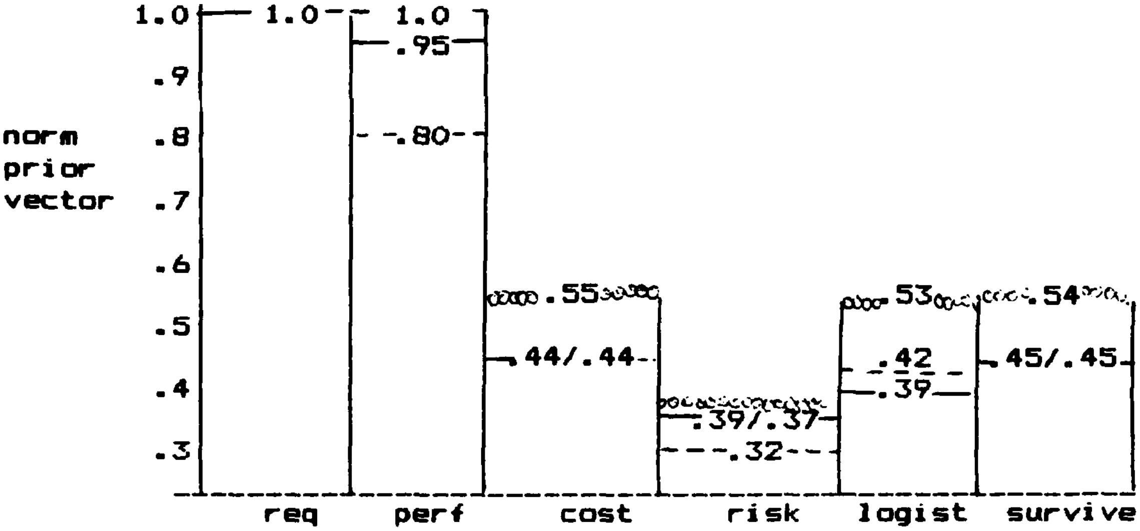
EigenVM: Rank is the vector mean (arithmetic) of the 12 judges' eigenvectors.

VoteVM: Rank is the vector mean (arithmetic) of the 12 judges' voting vectors, i.e., it is the proportion of votes received for each objective.

—✱— 8 objectives (Requirements)
—□— 7 objectives (Survivability)
—○— 6 objectives (Tav Effectiveness)
—×— 4 objectives (Maintainability)
—+— 3 objectives (Performance,Propellants,Maneuver)
—‖— 3 objectives (Risk, Logistics)

FIGURE 4

Top Level Priority Histogram
EigenVM, VoteM, and EigenGM



where:

EigenGM: ────	Rank is derived from the eigenvector from the geometric mean of the 12 judges' inputs.
EigenVM: - - -	Rank is derived from the mean (arithmetic) of the 12 judges eigenvectors.
VoteM: ∞∞∞	Rank is the arithmetic mean of the 12 judges' voting vectors, i.e., the mean vector is comprised of the proportions of votes received by each objective.

The general trend for the AHP vectors established in the first level holds at the bottom level. The geometric mean input is closer to the vector mean than the vote mean. The importance of this correlation is in the closeness of the vote mean to the geometric mean and vector mean. It shows that a ratio scaled input converted to an ordinal input can reflect the strength of preference. This will be further discussed in Chapter VI, Conclusions.

Besides the mathmatical aggregation techniques, this thesis sought to apply interpersonal value comparisons in the form of individual self evaluations. However, there was neglible discrimination among the jduges so this examination was discontinued. All but one of the 108 self evaluations rated themselves "good" or better. The single "poor" self evaluation was judge #3 on the logistics criterion. Because his comparisons were close to the mean, there would be no additional insight gained by deemphasizing his inputs.

Aggregation

The aggregation analysis showed that the three different aggregation methods: geometric mean input, eigen vector arithmetic mean, and the vote mean, all resulted in statistically identical priorities. Both the top level and the bottom level priority vectors were examined.

The similarity between the three aggregation methods for the top level is graphically seen in Figure 4, which displays a histogram of the top level weights. The significance of Kendall's tau between these priority vectors is displayed as a function of the size of the matrix in Figure 5. Note that perfect aggreement for three ranks is only significant to .118 because of the small dimension of the matrix.

The similarity for the bottom level priorities was extended to include the priorities from equal weights throughout the hierarchy and the original Battelle ranks (for the reduced number of criteria in the revised hierarchy). Table X shows the bottom vectors and Table XI shows the correlation (tau) between the different vectors.

Table XI shows that all of the vectors statistically correlated (sig.=.005). It can be seen that AHP and the voting vectors have less correlation with equal weights vector than Battelle. This is expected as the Battelle hierarchy was closer to equal weights because it elicited fewer weights.

had a small range. The small changes in the ratings caused the rank order to shift in the Delphi iteration (Figure 3). This supports Eckenrode's findings that direct assessment ratings result in priority vectors that have small ranges and large variances. It also helps explain why there is such a wide correlation difference between the AHP priority vector and two Delphi iterations.

TABLE V

Correlation (tau) Between Top Level Priorities AHP Vectors and Direct Assessment

	EigVM	VoteM	Delphi0	Delphi1
EigGM	1.0	.931	.733	.600
EigVM	-	.931	.733	.600
VoteM	-	-	.788	.645
Delphi0	-	-	-	.867

Where:

EigGM:	Rank is the eigenvector derived from the geometric mean of the 12 judges' inputs.
EigVM:	Rank is the vector mean (arithmetic) of the 12 judges' eigenvectors.
VoteM:	Rank is the vector mean (arithmetic) of the 12 judges' voting vectors, i.e., it is the proportion of votes received for each objective.
Delphi0:	Rank of the original Battelle Weights
Delphi1:	Rank of the first Delphi iteration of the Battelle weights

correlated, what is important is the magnitude of the change in correlation. Note that the final column shows the hypothetical situation where there were equal weights given to all the criterion. The lowest correlation is with the geometric mean of the inputs. The highest correlation is with the Battelle scores, which is expected because Battelle, had the fewest weights. They weighted the top level plus three of the 32 revised hierarchy criterion.

The tau's in the "NoWts" column are inversed from the equal weights column. With no weights, the importance of a given objective is directly proportional to the number of subobjectives that constitute it (the larger the sum). It is only by coincidence that the number of these subobjectives is more closely aligned to the weights gained throughout the heirarchy (AHP) than to weights applied to just the top level (Battelle). The "NoWts" column is included for completeness and its application is limited to the data in this survey.

TABLE XII

TAV Design Scores
By Weighting Schemes

TAV	EigGM	EigVM	VoteM	Battel	Equal	NoWts
1	488	492	499	504	558	583
2	520	525	532	553	598	541
3	537	539	551	577	632	576
4	705	696	699	633	649	697
5	686	687	688	662	669	586
6	587	598	599	620	653	574
7	703	707	708	692	716	636
8	741	745	740	729	741	664
9	616	629	623	606	643	664
10	544	558	548	555	592	556
11	569	577	568	555	588	572
12	621	631	619	650	651	619
13	597	610	597	618	619	623
14	686	694	682	690	690	666

Where:

EigGM: Eigen vector calculated from the geometric mean input
EigVM: Eigen vector from the arithmetic average judges' vectors
VoteM: Priority vector from "voting" pairwise comparison matrix
Battel: Original Battelle weights applied to revised hierarchy
Equal: Each subobjective contributes an equal portion to the next higher objective in hierarchy.
NoWts: No weights applied to Revised Hierarchy

TABLE XIII

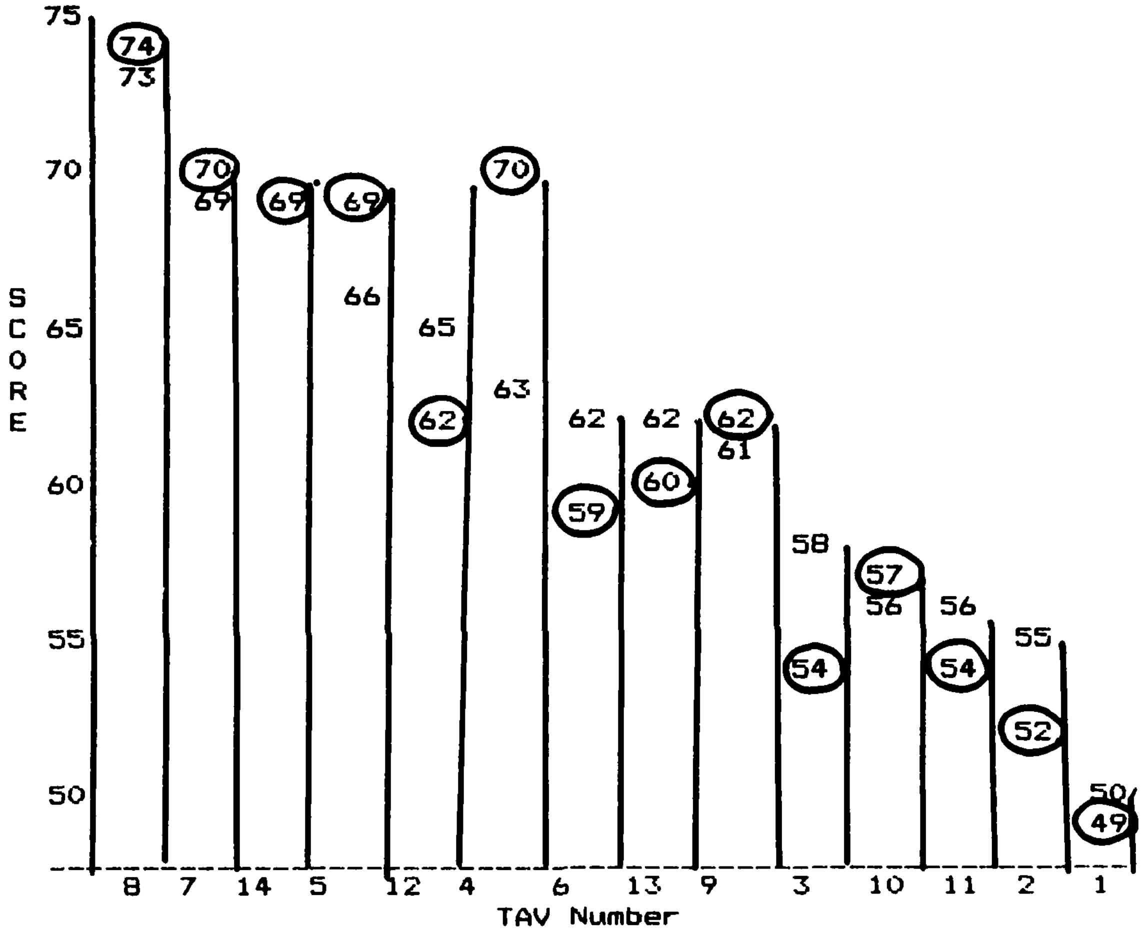
Correlation Between Final Scores
Kendall's Tau (Spearman's Rho in parens)

	EigVM	VoteM	Battel	NoWts	EqWts
EigenGM	.972	.906	.790	.611	.685
	(.995)	(.981)	(.923)	(.804)	(.841)
EigeVM	-	.912	.818	.597	.714
	-	(.982)	(.942)	(.799)	(.864)
VoteM	-	-	.818	.597	.714
	-	-	(.931)	(.799)	(.886)
Battel	-	-	-	.500-.014-	.862
	-	-	-	(.691)	(.959)
NoWts	-	-	-	-	.398-.049-
	-	-	-	-	(.607)

Where:
EigGM: Weights from geometric mean input comparison
EigVM: Weights from average of judges' Eigen Vectors
VoteM: Weights from "Voting" comparison Matrix
Battel: Original Battelle Weights (Revised Hierarchy)
NoWts: No weights applied: score was sum of attribute values
-Sig-: If the significance of TAU (= Significance of rho) is greater .01 then sig shown next to tau -xxx-

FIGURE 7

Final TAV Scores: AHP vs Battelle



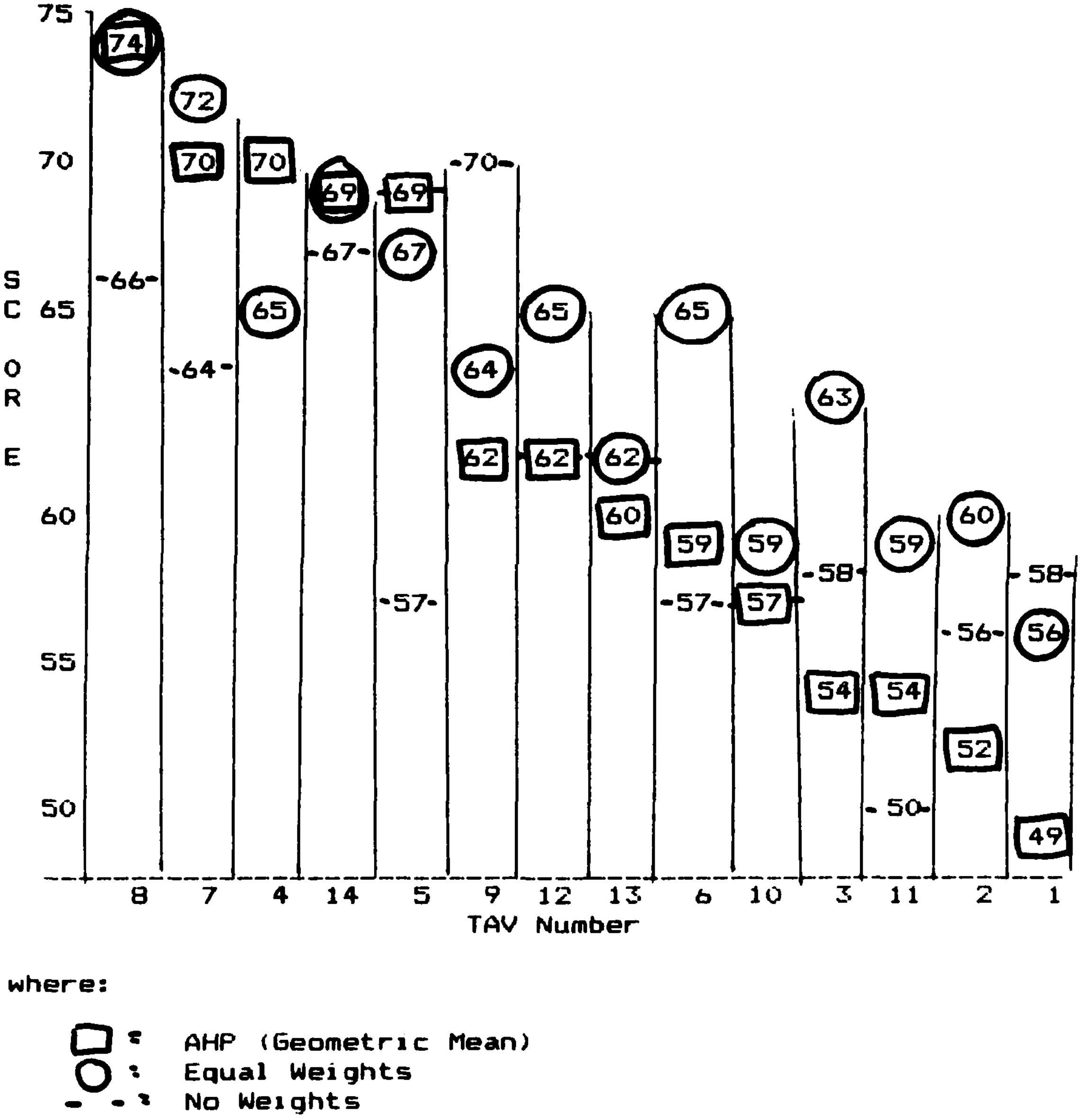
where:

Battelle Original Weights Applied to Revised Hierarchy

○ AHP (Geometric Mean)

FIGURE 8

Final TAV Scores: AHP (Geometric Mean)
Equal Weights and No Weights



Chapter VI. Conclusions

Introduction.

The conclusion discussion will fall into three categories. The first catagory are the formal conclusions drawn from the research purpose, to analyze the three facets of the AHP: feedback, aggregation methods, and consistency measures. The second category of conclusions consist of lessons learned applying AHP by survey. Finally, the last division of conclusions are suggestions for follow-on research.

Feedback

The feedback analysis was limited to the direct assessment portion of the study (Battelle) because it could not be determined that any of the changes in the AHP portion of the survey were due to subjects reading the "Quality Controlled Feedback." However, the top level priority vectors derived from direct assessment showed both a variance reduction and increase in concordance after the judges had received the means from the first survey. This reflected that there was more agreement after the feedback than before the feedback.

There was one unexpected outcome. The paired comparison results, both the voting vector and the eigenvector for the top level objectives correlated closer to the original

Battelle survey than to the second Delphi-Battelle survey. This is remarkable considering the Delphi-Battelle survey was accomplished simultaneously with the first AHP survey, while the original Battelle survey was accomplished over one year earlier. Perhaps the explanation is that the feedback did force an unnatural, "bandwagon," variance reduction while the AHP elicited the "true" opinions that came closer to matching the original survey.

A word of caution is in order. Both the original and second Delphi-Battelle priority vector values had very narrow ranges and large variances between judges. These are the characteristics that Eckenrode predicted for vectors derived from direct assessment, which makes them poor techniques for discrimination purposes. These same characteristics allow very minor shifts to alter the rank order which reduces the tau correlation between vectors. The graphical display in Figure 3 shows much less of the correlation drop between the iterations as is shown statistically in Table III.

Aggregation Methods

All three of the aggregation methods resulted in graphically and statistically the same priority vectors. Ellsburg mentioned that, in general, converting interval comparisons to an ordinal scale does not preserve the interval (Ellsburg, 1954:228). Graphically and with rank ordered statistics, this research showed that the interval was well preserved when converting AHP matrices into voting matrices. However, there may be untested boundaries in the number of judges or size of the matrix that exist when this relationship no longer exists.

There is another word of caution about the close relationship between the ordinal (voting) and ratio (AHP) priority vectors. The "voting" matrix was not elicited separately from the AHP inputs. The AHP ratio inputs were converted to votes (preference direction only). This conversion assumes that the judge would state the same strict preferences as he had with the ratio scale.

This assumption may not be valid. Further research may show that when going from a continuous ratio scale (-9 to +9) to a three level ordinal scale (0,1/2,1), the indifferent ordinal point may absorb many of the comparisons previously judged "weakly" more important. That is, the judge would rather rate a weak preference as indifferent when his only options are strict preference or indifference.

The voting matrix should be elicited separately from the AHP matrix to obtain a valid indication of the correlation between these two methods. This thesis showed that when the voting matrix is generated from the AHP matrix, there is a strong correlation between the resultant priority vectors and that the vectors were graphically very similar.

Consistency

The ratio consistency measure, CI, is highly correlated with the ordinal consistency measure, zeta. Both measures reflect the inconsistency in a matrix of pairwise comparisons. The ordinal measure, zeta is not affected by the matrix dimension (number of objectives being compared), as much as ratio consistency is. One reason may be that the matrix dimension determines the exponential factor for the iterative solution to the eigenvalue solution while the zeta solution is a ratio of two third order equations. That is, a plot of the consistency index versus the matrix dimension results in an exponential decay. When the dimension $\geq$ 10 there is almost perfect consistency, less than .05 (Saaty, 1980:63).

Zeta, although its significance is solely dependent on the dimension as seen in Appendix H, is not as influenced by the matrix size. Zeta does not indicate ratio consistency, but the close correlation (significance = .001) to the CI shows that it is an equivalent measure.

Battelle Results

The fact that there were only minor shifts in the TAV design rankings when the Battelle weights were applied to the original and revised hierarchies shows that the discarded elements had little impact on most of the TAV designs. The actual differences between applying Battelle's weights for the entire hierarchy or just for the revised hierarchy is actually irrelevant for this thesis, because this scope is limited to comparing techniques on a fixed hierarchy size. One could have accomplished the study with any fixed size hierarchy.

Applying the weights through out the hierarchy (AHP) shifted the following priorities from the Battelle priorities. Consequently, the "value" to the designs strong/weak in these objectives shifted:

Emphasis Increased:
    #9: Payload Mass
    #11: Trajectory Flexibility
    #12: Rapid Response
De-emphasis:
    #24: Loiter
    #20: # Jets (Maintainability)
    #19: # Rockets (Maintainability)
    #6: Single Stage
    #3: Horizontal Take Off/Land

Survey Application

Much insight was gained on what should be included in a survey application of the AHP. While Saaty promotes group interactions with a knowledgeable monitor, this is often not practical. The alternative is to mail the AHP solicitation to the "experts." As such, the insight gained in this application may be beneficial to others.

The matrix format used in this study to obtain the pairwise comparisons was selected over the continuous line suggestion by Saaty (1980:35). The plan was to reduce the "business" and the bulk of the survey. This approach should be avoided. The small savings in display bulk was more than compensated for by the additional instruction to insure the comparisons were not inverted when making the judgement. Although less than 1% of the returned comparisons had been inverted (sign errors), there would probably be far fewer errors on the continuous line format.

Scale. The scale used in the solicitation should be displayed differently from the Saaty presentation (1980:54). The scale proved sound and very workable but this thesis found that there was an indication that some of the respondents treated the scale as interval rather than ratio. For example, suppose that a judge felt objective A was three units more important than objective B and objective B was two units more important than C which had a value of one unit. If the judge put these interval responses into the AHP matrix, the AHP "ratio" priority vector would be different from his "true" "interval" priority vector:

Priority Vectors based on Judge's Scale

Interval	vs	Ratio (AHP)
A=6 => 1.00		=> 1.00
B=3 => .50		=> .35
C=1 => .17		=> .19

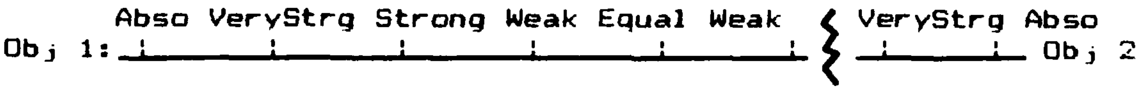
This study also found that the respondents were reluctant to use other than odd integers when given the Saaty format (Saaty, 1980:54). Inaddition, no one responded with a fraction of a number, although the scale is continuous between one and nine. Thus, they were unable to achieve a full range of weights.

The discontinuous jumps in the priority vector were especially evident when there were less than five objectives being compared because the few comparisons resulted in incremental jumps in the resulting priority vector elements. This dissatisfied at least two judges who sought weights between .5 and 1, but did not use a ratio rating between one and two. Only after one respondent was informed that "weak" importance meant three times the importance of the other criteria, did he realize he overrated the objective and so he evaluated the comparison as 1.25 as important.

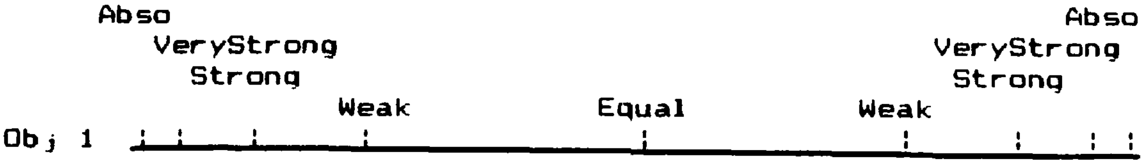
Saaty has described the derivation of the 1-9 ratio scale (Saaty, 1980:53-66). The scale is excellent for large matrices where the numerous comparisons wash out the incremental jumps (at some cost to consistency). However, this research found that his interval portrayal of the scale distorted the weights, especially for the smaller matrices.

The author believes few people judge less than "weakly" more important as twice as important, or interpret "weak to absolute" comparisons on a ratio scale. In order to better represent the subjective values of the expert, the questionnaire should reflect the ratio nature of the scale:

Saaty Presentation:



Revised Presentation:



The revised presentation has two major advantages for eliciting weights by survey. First, it more accurately represents the effect of the ratings - the logarithmic versus additive effect that Saaty's presentation implies. Secondly, it graphically shows a continuous scale which is asymptotic at either end. The asymptote ("absolute") emphasizes that the comparisons must be within the same order of magnitude to give valid weights.

Further Research

The discrimination, or distance between objective weights in the resulting priority vector is another area requiring further research. The statistical evaluations used in this research tested rank order concordance (W) and correlation (tau). These tests fail to account for the distance between the ranks, which may be substantially different between aggregation methods.

This research appealed to graphical displays to show the distance similarity (Figures III and IV). Graphs cannot prove relationships or provide the sensitivity analysis necessary to establish the boundaries where the strength of preference is preserved. For example, the size of the matrix may have to be greater than six to to preserve the strength of preference when converting the AHP to a "voting" matrix.

Further research is necessary to determine the effect that the revised presentation would have on the consistency and range of the priority vectors. The author suspects that consistency would improve while the range, and thus the discriminating power, of the priority vector would diminish.

Consistency should improve, especially in smaller matrices ($n \leq 5$) because "true" ratings between one and two would not require that the matrix be inconsistent, as what happens with integer ratings. For example, if the respondent limited himself to integer values and his "true" normalized priorities for options A, B, and C were 1,.6, and .3 his best choices for the AHP matrix would be:

"True"		A	B	C	"AHP"
1.0	A	-	2	3	1.00
.6	B	-	-	2	.55
.3	C	-	-	-	.30

The comparsions above would result in a CI = .005. Worse, there is a divergence of (.6-.55) = .05 from the "true" normalized vector. However, if the judge made continuous ratings from the revised scale he would have:

	A	B	C	"AHP"
A	-	1.7	3.3	1.00
B	-	-	2.0	.59
C	-	-	-	.31

The matrix above gives a CI = .0001 and a divergence from the "true" vector = .01. The judge may still give integer ratings with the revised presentation, but the author feels the logarithmic intervals makes this less likely.

Another advantage of the logarithmic presentation is that the judge may be more aware the importance of all the attributes being on the same order of magnitude. The clear

APPENDIX A: Initial Thesis Survey

The following comprises the criteria for survivability:

Loiter: Space - Rated lower if need to reduce payload (OMS Propellent)
Atmosphere - Rated lower if single stage

Mobile Launch: Rated lower if required long runways and/or cryogenics

Base Escape: Rated lower if required large carrier aircraft
(Ability of TAV to quickly escape from the base once launch ordered)

Dispersal Range: Rated 1.0 if greater than 1000 miles else given .8-.9 for 300-600 miles

Laser Hardness: Rated 1.0 if tile TPS and .5 if metal TPS

Maneuverability: Below

1 - Equal Importance
3 - Weak Importance
5 - Moderate Importance (Column -, row +)
7 - Strong Importance
9 - Absolute Importance

Which factor contributes more to TAV maneuverability?
(column -, row +)

MANEUVERABILITY

−

+

	AERODYNAMIC (L/Drag + TPS)	POWERED (air breathing)
SPACE (OMS + propellents)		
AERODYNAMIC (L/Drag + TPS)		

Which factor contributes more to TAV survivability?
(column -, row +)

SURVIVABILITY

−

+

	MOBILE LAUNCH	BASE ESCAPE	DISPERSAL RANGE	LASER HARDNESS	RCS	MANEUVERABILITY
LOITER						
MOBILE LAUNCH						
BASE ESCAPE						
DISPERSAL RANGE						
LASER HARDNESS						
RCS						

APPENDIX A: Initial Thesis Survey

The following comprise the criteria for logistics (supportability).

1 - Equal Importance
3 - Weak Importance
5 - Moderate Importance (Column -, row +)
7 - Strong Importance
9 - Absolute Importance

Facilities: Rated lower if large hangers and/or complex mate/demate apparatus

Which factor contributes more to logistics/supportability?
(column -, row +)

LOGISTICS −

+	FACILITIES	MAINTAINABILITY
PROPELLANTS		
FACILITIES		

Circle your level of knowledge/experience with logistics

Minimal	Average	Good
1 2 3	4 5 6 7	8 9 10

APPENDIX A: Initial Thesis Survey

The following comprise the factors for measuring TAV technological risk.

1 - Equal Importance
3 - Weak Importance
5 - Moderate Importance (Column -, row +)
7 - Strong Importance
9 - Absolute Importance

Structure: Higher risk if hot structure, metal matrix, advanced ceramic TPS

Mass Fraction: Higher risk if greater fraction than Shuttle (.87)

Propulsion: ABES - generally lower risk, except turbo ramjet
ROCKETS - disparity from shuttle engines increased risk

Which contributes more to technological risk? (column -, row +)

RISKS – +	STRUCTURE	MASS FRACTION
PROPULSION		
STRUCTURE		

Circle your level of knowledge/experience with these factors of Technological risk

Minimal	Average	Good
1 2 3	4 5 6 7	8 9 10

APPENDIX A: Initial Thesis Survey

The following comprise the criteria for propellants and maintainability.

1 - Equal Importance
3 - Weak Importance
5 - Moderate Importance (Column -, row +)
7 - Strong Importance
9 - Absolute Importance

Which criterion is more important with regard to propellant logistics (supportability)?

PROPELLANTS

−

+	NUMBER OF DIF TYPES	CRYOGENIC OR STORABLE
AMOUNT(to deliver equivalent mass)		
NUMBER OF DIF TYPES		

Circle your level of knowledge/experience with propellants

Minimal	Average	Good
1 2 3	4 5 6 7	8 9 10

Which factor, as it decreases in number or complexity, contributes more to TAV maintainability?
(column −, row +)

MAINTAINABILITY

−

+	NUMBER OF ROCKETS	TPS TYPE	NUMBER OF ELEMENTS
NUMBER OF JETS			
NUMBER OF ROCKETS			
TPS TYPE			

Circle your level of knowledge/experience with maintenance

Minimal	Average	Good
1 2 3	4 5 6 7	8 9 10

APPENDIX A: Initial Thesis Survey

The following comprise the factors for measuring TAV performance.

1 - Equal Importance
3 - Weak Importance
5 - Moderate Importance (Column -, row +)
7 - Strong Importance
9 - Absolute Importance

Trajectory: Ability to alter mission after launch: Based on a baseline value plus a value if powered reentry and minus a value if expendable equipment.

Payload: Mass deliverable on a 90° low (87m) orbit

Which factor is a better measure of TAV performance? (column -, row +)

PERFORMANCE -

+

	VOLUME	TRAJECTORY (flex)
PAYLOAD		
VOLUME		

Circle your level of knowledge/experience with your knowledge of performance.

Minimal	Average	Good
1 2 3	4 5 6 7	8 9 10

APPENDIX A: Initial Thesis Survey

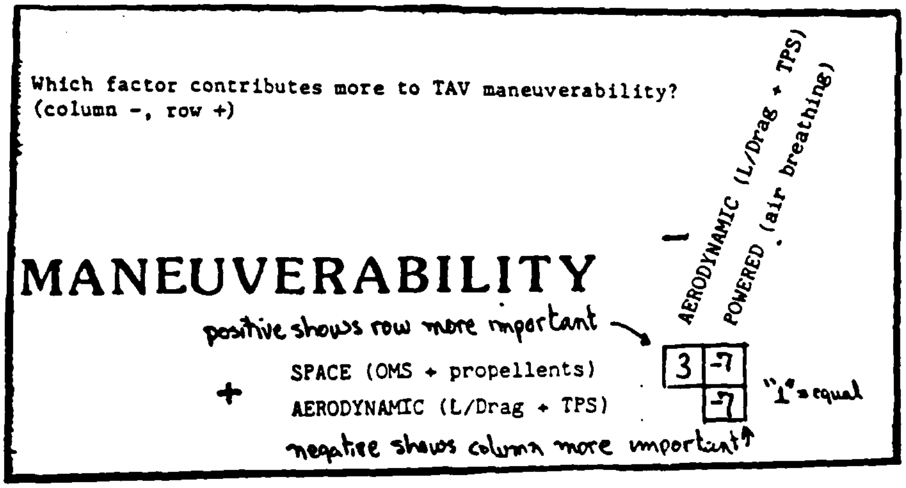
The comparisons may seem rather obtuse at times: " Which is more important, an apple or an orange with regard to taste?" - but this series of comparisons can reliably determine the overall priorities, or weights, of the decision maker. However, it is important for you, as the "expert decision maker," to expeditiously accomplish these comparisons without looking back to correct for consistency. The final results will be returned to you to verify that the weights reflect what you intended.

Inorder to have a common denominator for the comparisons, the scenerio is arbitrarily set as a general world conflict. The TAV's mission is multi-purpose: weapon delivery (space and ground) and reconnaissance. Furthermore, the TAV is threatened by the same threats that face our 21st century triad forces: preemptive strikes, terrorists, ground and space-based lasers, nuclear - conventional weapons, particle beams, etc.

For the more technical criteria, a self-assessment question is presented. Your answer will provide feedback about how confident you feel in that particular area. Again, thank you for your cooperation. Any comments you may have will be appreciated.

APPENDIX A: Initial Thesis Survey

The opposite table shows the values you should assign the comparisons between elements. For example, with regard to TAV maneuverability, if you feel that space maneuverability is weakly more important than aerodynamic maneuverability, then you would give the first cell a '3'. (Note: space maneuverability is measured by whether the system has OMS and the necessaary propellents, while aero maneuverability is measured by the lift to drag ratio and the ability to withstand re-entry temperatures). If you feel that the column, "powered re-entry," is "strongly" more important than either of the row elements: Space or Aero Maneuvering, you would put "-7" in the two remaining cells. Remember, the cell is positive if the row titles are more important and negative if the column titles are more important. The following figure illustrates the completed matrix:



Which factor contributes more to TAV maneuverability?
(column -, row +)

APPENDIX A: Initial Thesis Survey

COMPARISON SCALE

INTENSITY OF IMPORTANCE	DEFINITION	EXPLANATION
1	Equal importance in both elements	Two elements contribute equally to the property
3	Weak importance of row element over column element	Experience and judgment slightly favor row over column element
5	Moderate importance of row over column element	Experience and judgment moderately favor row over column element
7	Strong or essential importance of row over column element	Experience and judgment strongly favor row over column element
9	Absolute or demonstrated importance of row over column element	The evidence favoring the row element is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two judgements	Compromise is needed between two judgments

Negative: The inverse relationship holds. The column element is more important than the row element with regard to the given property.

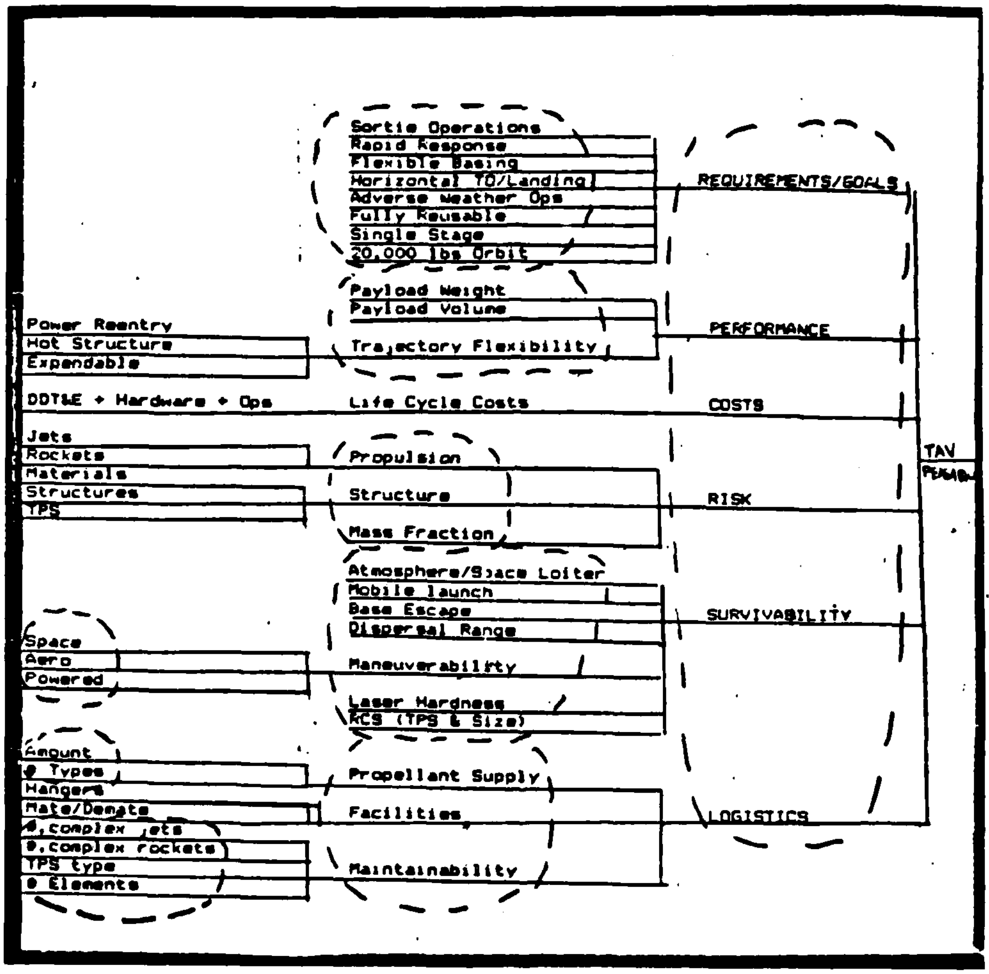
APPENDIX A: Initial Thesis Survey

INSTRUCTIONS PART II

Part II hierarchy is a subset of the original Battelle hierarchy. I combined Requirements and Goals (Feedback from the original Battelle survey) and eliminated those criteria that failed to distinguish between design proposals. These criteria were: manned flight, few orbits, launch within 5 minutes, and two missions per day. Multiple dispersal sites, a criterion under survivability, was eliminated because it was measured in a similar way that the criterion, mobile launch, was measured (by the runway length required). Finally, environmental impact was eliminated because of the insignificant weight given to it in the 1983 Battelle study.

The hierarchy on the opposite page shows the resulting relationships. The circled clusters indicate the groups of paired comparisons that you will be asked to make in the subsequent pages.

APPENDIX A: Initial Thesis Survey



APPENDIX A: Initial Thesis Survey

Part I

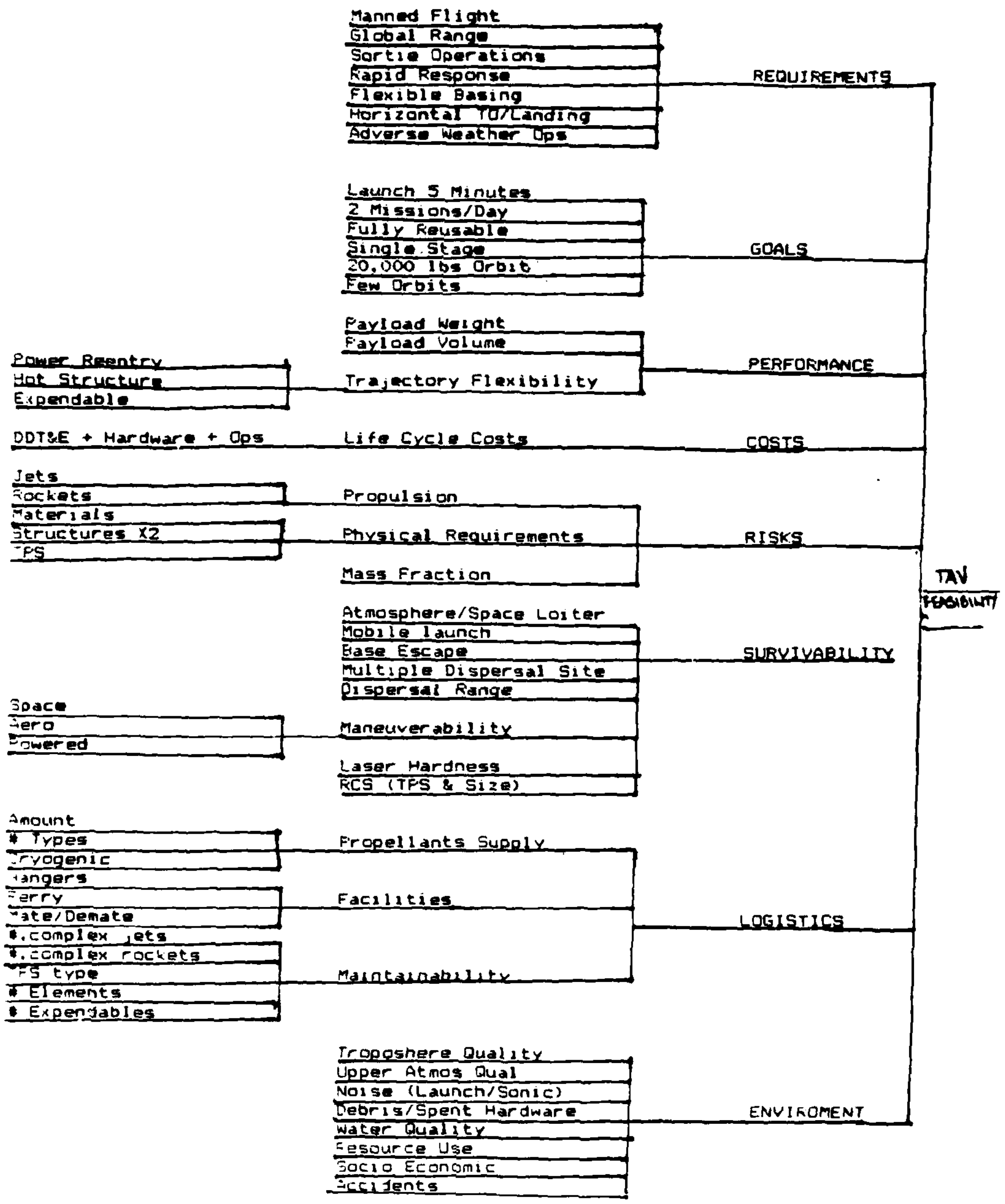
The table below lists the group average weights (1983) for the criteria used to measure the TAV feasibility/effectiveness. Also listed is your 1983 estimate of these weights. Please write in what you now feel the weights should be based on the same subjective 1- 10 scale (least important to most important).

Note: The hierarchy on the opposite page shows the criteria that Battelle used to measure these objectives. If your current estimate exceeds one standard deviation of the group average (1983), please jot down a few words explaining your reasons. Thank you.

	REQUIREMENTS	GOALS	PERFORMANCE	COSTS	RISKS	SURVIVABILITY	LOGISTICS	ENVIRON
average :	9.77	7.15	8.08	7.77	7.00	7.46	7.54	3.69
standard dev :	.63	1.57	1.38	1.92	1.56	1.66	1.39	1.44
your 1983 input:								
your 1984 input:								

Reasons/comments:

APPENDIX A: Initial Thesis Survey



APPENDIX A: Initial Thesis Survey

DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE OF TECHNOLOGY (AU)
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433

Major Stalker Reed
2506 Cross Country RD
Fairborn, OH 45324

INTRODUCTION

Thank you for agreeing over the phone to assist me in my thesis effort at the School of Engineering, Air Force Institute of Technology. The purpose of my thesis is to analyze an alternative method to evaluate multiple objective problems. The method is called the Analytical Hierarchy Process (AHP), and it establishes criteria weights by a series of pair-wise comparisons between criteria. I am using the 1983 Battelle TAV study as the source of data. To achieve comparable findings, I need as many of the 13 original TAV steering committee members as possible. In addition, to reach valid conclusions, I need your "expert" knowledge and insight regarding various aspects of the TAV.

The first page shows the group weights for the top level of objectives from the 1983 study and asks you to update your 1983 inputs. The subsequent pages apply AHP to the entire hierarchy, which is altered from the original Battelle Hierarchy. Two abbreviations are used: OMS stands for Orbital Maneuvering System, and TPS stands for the Thermal Protection System (Ceramic tiles versus metal).

The trial runs indicate the survey should take between 25 and 35 minutes. I would be very grateful if you could return this questionaire, along with any insights that you would like to share, within a week of receipt. Again, thank you for your generous offer to assist my thesis effort.

Stalker E. Reed
Major, USAF

asymptote at "absolutely more important" emphasizes the "extremity" of the comparisons. Again, this does not prevent objectives outside of one magnitude from being compared; the scale only serves to highlight that "absolute" is absolute.

The revised presentation may result in less discrimination because there may be proportionally more ratings in the one to two range because the proportion of space on the scale may influence the number of ratings. Half the logarithmic space is between the ratings, one and two, so it is likely to pull some judgements into this range and subsequently reduce the discrimination of the resulting priority vector.

Concluding Remarks

The findings in this research indicate that there is very little differerence in the three aggregation methods examined. Also, the AHP scale should be presented so the interval between ratings reflects the ratio nature, i.e., it shoud be logarithmic.

However, one needs to exercise caution before applying these results because they are empirical results that are based on a sample size of twelve. A larger sample size of subjects who are not high level decision makers, should provide increased validity.

APPENDIX A: Initial Thesis Survey

The following matrices compare the criteria for measuring TAV requirements/goals and the overall TAV feasibility/effectiveness.

1 - Equal Importance
3 - Weak Importance
5 - Moderate Importance (Column -, row +)
7 - Strong Importance
9 - Absolute Importance

Sortie Operations: Measures the complexity of mating operations and the number of different vehicle elements.

Which element is a more important requirement/goal of the TAV? (column -, row +)

REQUIREMENTS/GOALS -

+

	RAPID RESPONSE	FLEXIBLE BASING	HORIZONTAL T.O AND LAND	ADVERSE WEATHER	FULLY REUSABLE	SINGLE STAGE	20,000lbs PAYLOAD	SORTIE OPS
GLOBAL RANGE								
RAPID RESPONSE								
FLEXIBLE BASING								
HORIZONTAL T.O. AND LAND								
ADVERSE WEATHER								
FULLY REUSABLE								
SINGLE STAGE								
20,000lbs PAYLOAD								

Costs: LCC based on 50 TAVs flying 100 flights/year for 20 years

Which element is more important to establish the feasibility/effectiveness of the TAV concept? (column -, row +)

TAV EFFECTIVENESS -

+

	PERFORMANCE	COSTS	RISKS	LOGISTICS	SURVIVABILITY
REQUIREMENTS/GOALS					
PERFORMANCE					
COSTS					
RISKS					
LOGISTICS					

APPENDIX B: Follow-up Thesis Survey

Major Stalker Reed
Box 4386
AFIT/ENA
WPAFB, OH 45433

4 Dec 84

TAV Steering Committee Member,

Thank you for your speedy response to my thesis inquiry. As promised, I am returning a few of my intermediate findings. I am very pleased with the results. I have inclosed a few of the individual comments, in case you would like to consider them in your judgments. Note: the comments are for information only and do not reflect any results of this study.

The process used in this survey is called the Analytical Hierarchy Process. It is being used extensively in DOD to elicit weighting factors from experts. A recent example is HQ USAF's "Air Force 2000" study. Generally, the results are valid reflections of decision makers opinions.

I need you to review the weights this process derived from your comparisons to insure they reflect your opinions. A simple "yes" or "no" is all that is necessary on the respective pages. The original comparison matrices are inclosed to allow you to make any changes you deem necessary.

Please have a blessed and warm Christmas Holiday

Stalker E. Reed
Major, USAF

PS: I would be grateful if you could return this prior to the Christmas break.

If you would like an executive summary of my results, please circle below:

yes--send a summary (Mar-Apr 85)

APPENDIX B: Follow-up Thesis Survey

The numbers are computed as
ratios: ex: $\frac{\text{requirements}}{\text{costs}}$ = 5 times more important
The computer checks for errors by comparing these ratios

COMPARISON SCALE

INTENSITY OF IMPORTANCE	DEFINITION	EXPLANATION
1	Equal importance in both elements	Two elements contribute equally to the property
3	Weak importance of row element over column element	Experience and judgment slightly favor row over column element
5	Moderate importance of row over column element	Experience and judgment moderately favor row over column element
7	Strong or essential importance of row over column element	Experience and judgment strongly favor row over column element
9	Absolute or demonstrated importance of row over column element	The evidence favoring the row element is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two judgements	Compromise is needed between two judgments

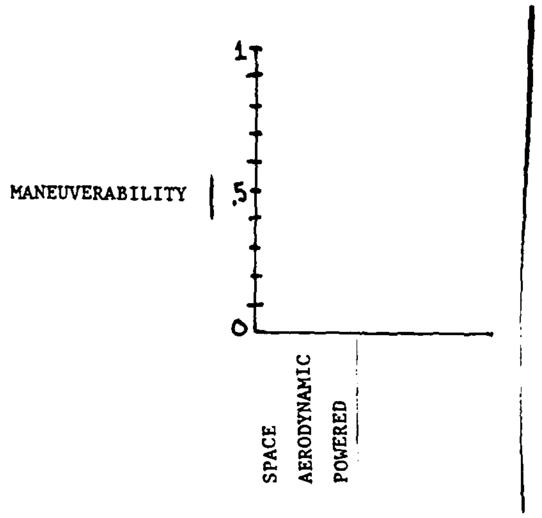
Negative: The inverse relationship holds. The column element is more important than the row element with regard to the given property.

If you are satisfied with the resulting weights,
just ignore the "errors" the computer has isolated are not
errors (obvious: sign error, etc). Please do not be concerned
with ratio consistency. This review should only take 5-10 min.
Thanks Stalker

APPENDIX B: Follow-up Thesis Survey

Below are the priorities derived from the comparison matrix.

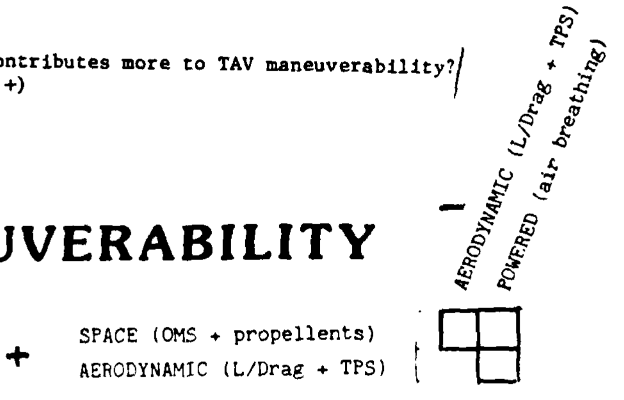
Please circle how well these weights reflect your opinions.
Poor Adequate Good
1 2 3 4 5 6 7 8 9 10
(if "poor" - please draw in your "true" weights and review matrix below)



Please verify the circled comparisons below. If there is no mistake (inverted signs, etc), just check off the circle. Otherwise, write in what you believe the judgment should be.

Which factor contributes more to TAV maneuverability?
(column -, row +)

MANEUVERABILITY



APPENDIX B: Follow-up Thesis Survey

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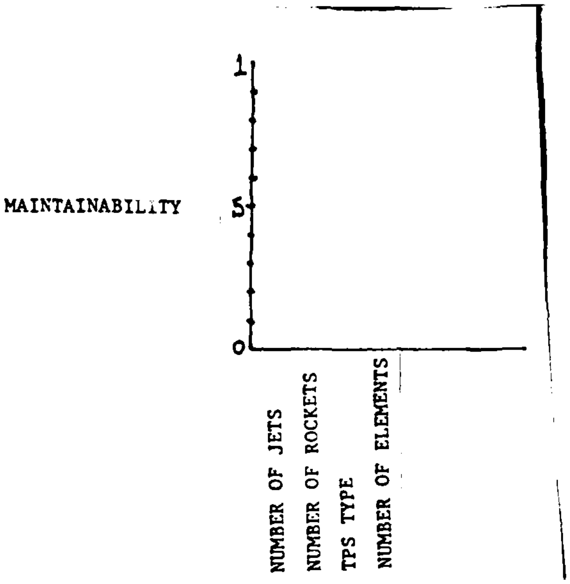
Please circle how well these weights reflect your opinions.
Poor Adequate Good
1 2 3 4 5 6 7 8 9 10
(if "poor" - please draw in your "true" weights and review matrix below)



Please verify the circled comparisons below. If there is no mistake (inverted signs, etc), just check off the circle. Otherwise, write in what you believe the judgment should be.

Which factor, as it decreases in number or complexity, contributes more to TAV maintainability?
(column -, row +)

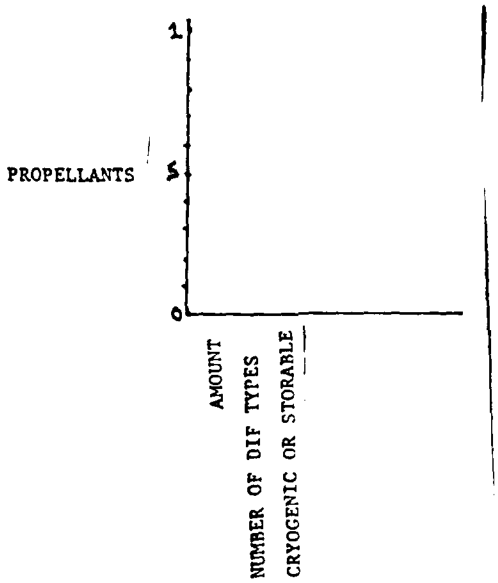
MAINTAINABILITY −

+	NUMBER OF ROCKETS	TPS TYPE	NUMBER OF ELEMENTS
NUMBER OF JETS			
NUMBER OF ROCKETS			
TPS TYPE			

APPENDIX B: Follow-up Thesis Survey

Below are the priorities derived from the comparison matrix.

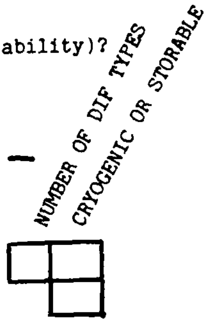
Please circle how well these weights reflect your opinions.
Poor Adequate Good
1 2 3 4 5 6 7 8 9 10
(if "poor" - please draw in your "true" weights and review matrix below)



Please verify the circled comparisons below. If there is no mistake (inverted signs, etc), just check off the circle. Otherwise, write in what you believe the judgment should be.

Which criterion is more important with regard to propellant logistics (supportability)?

PROPELLANTS –

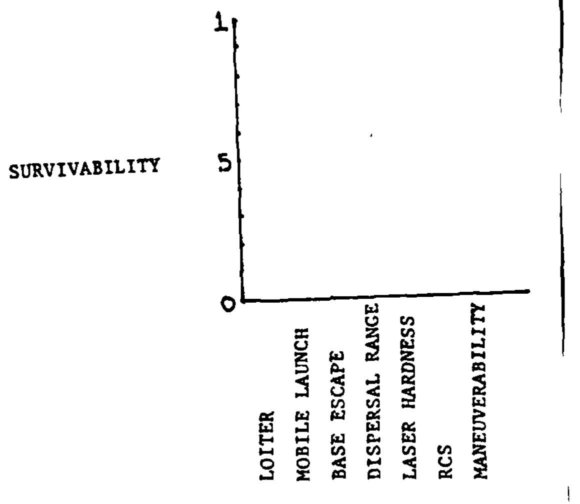


AMOUNT(to deliver equivalent mass)
NUMBER OF DIF TYPES +

APPENDIX B: Follow-Up Thesis Survey

Below are the priorities derived from the comparison matrix.

Please circle how well these weights reflect your opinions.
Poor Adequate Good
1 2 3 4 5 6 7 8 9 10
(if "poor" - please draw in your "true" weights and review matrix below)



Please verify the circled comparisons below. If there is no mistake (inverted signs, etc), just check off the circle. Otherwise, write in what you believe the judgment should be.

Which factor contributes more to TAV survivability?
(column -, row +)

SURVIVABILITY

-

+	MOBILE LAUNCH	BASE ESCAPE	DISPERSAL RANGE	LASER HARDNESS	RCS	MANEUVERABILITY
LOITER						
MOBILE LAUNCH						
BASE ESCAPE						
DISPERSAL RANGE						
LASER HARDNESS						
RCS						

1 - Equal Importance
3 - Weak Importance
5 - Moderate Importance
7 - Strong Importance
9 - Absolute Importance

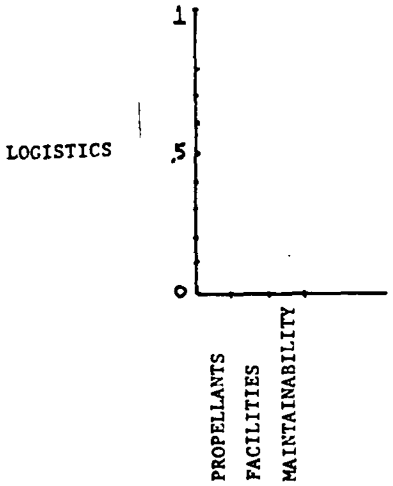
APPENDIX B: Follow-Up Thesis Survey

Below are the priorities derived from the comparison matrix.

Please circle how well these weights reflect your opinions.

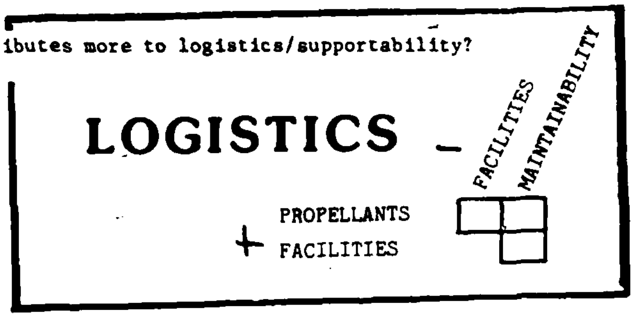
Poor	Adequate	Good
1 2 3	4 5 6 7	8 9 10

(if "poor" - please draw in your "true" weights and review matrix below)



Please verify the circled comparisons below. If there is no mistake (inverted signs, etc), just check off the circle. Otherwise, write in what you believe the judgment should be.

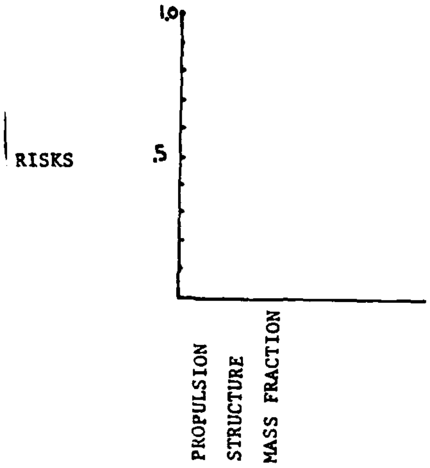
Which factor contributes more to logistics/supportability? (column -, row +)



APPENDIX B: Follow-Up Thesis Survey

Below are the priorities derived from the comparison matrix.

Please circle how well these weights reflect your opinions.
Poor Adequate Good
1 2 3 4 5 6 7 8 9 10
(if "poor" - please draw in your "true" weights and review matrix below)



Please verify the circled comparisons below. If there is no mistake (inverted signs, etc), just check off the circle. Otherwise, write in what you believe the judgment should be.

Which contributes more to technological risk? (column −, row +)

RISKS −	STRUCTURE	MASS FRACTION
+ PROPULSION		
STRUCTURE		

APPENDIX B: Follow-Up Thesis Survey

Below are the priorities derived from the comparison matrix.

Please circle how well these weights reflect your opinions.
Poor Adequate Good
1 2 3 4 5 6 7 8 9 10
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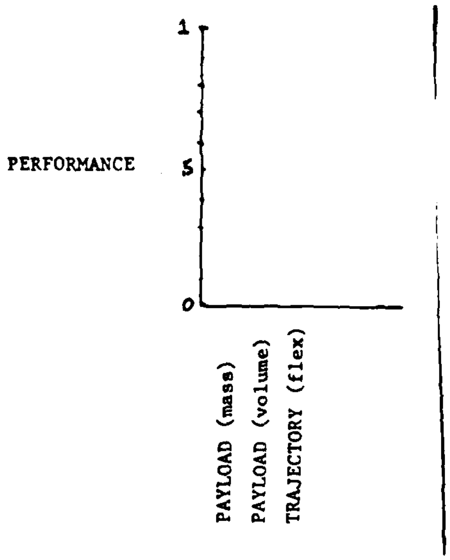
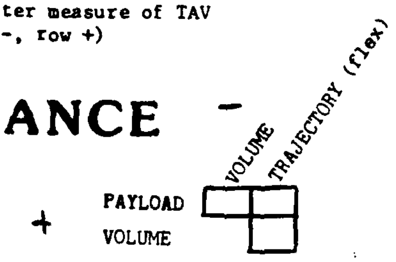


Please verify the circled comparisons below. If there is no mistake (inverted signs, etc), just check off the circle. Otherwise, write in what you believe the judgment should be.

Which factor is a better measure of TAV performance? (column -, row +)

PERFORMANCE

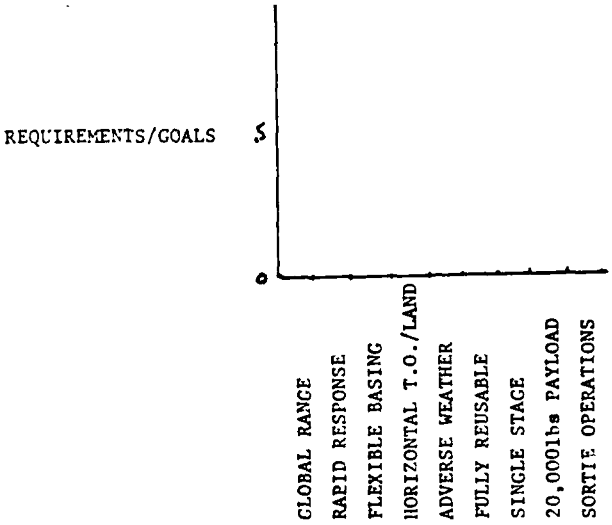


1 - Equal Importance
3 - Weak Importance
5 - Moderate Importance
7 - Strong Importance
9 - Absolute Importance

APPENDIX B: Follow-Up Thesis Survey

Below are the priorities derived from the comparison matrix.

Please circle how well these weights reflect your opinions.
Poor Adequate Good
1 2 3 4 5 6 7 8 9 10
(if "poor" - please draw in your "true" weights and review matrix below)



Please verify the circled comparisons below. If there is no mistake (inverted signs, etc), just check off the circle. Otherwise, write in what you believe the judgment should be.

Which element is a more important requirement/goal of the TAV?
(column -, row +)

REQUIREMENTS/GOALS –

- 1 - Equal Importance
- 3 - Weak Importance
- 5 - Moderate Importance
- 7 - Strong Importance
- 9 - Absolute Importance

+	RAPID RESPONSE	FLEXIBLE BASING	HORIZONTAL T.Q AND LAND	ADVERSE WEATHER	FULLY REUSABLE	SINGLE STAGE	20,0001bs PAYLOAD	SORTIE OPS
GLOBAL RANGE								
RAPID RESPONSE								
FLEXIBLE BASING								
HORIZONTAL T.O. AND LAND								
ADVERSE WEATHER								
FULLY REUSABLE								
SINGLE STAGE								
20,0001bs PAYLOAD								

APPENDIX B: Follow-up Thesis Survey

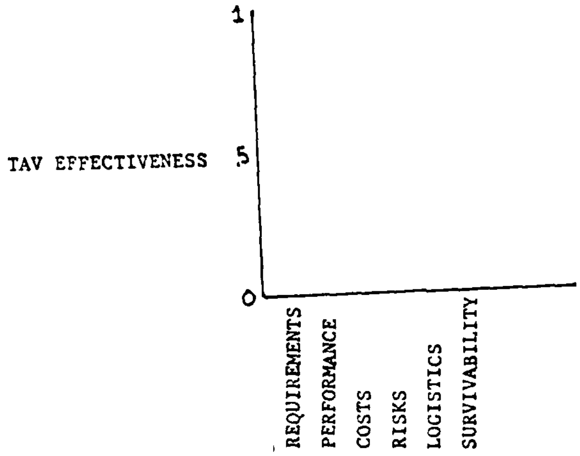
Below are the priorities derived from the comparison matrix.

Please circle how well these weights reflect your opinions.

Poor Adequate Good

1 2 3 4 5 6 7 8 9 10

(if "poor" - please draw in your "true" weights and review matrix below)



Please verify the circled comparisons below. If there is no mistake (inverted signs, etc), just check off the circle. Otherwise, write in what you believe the judgment should be.

Which element is more important to establish the feasibility/effectiveness of the TAV concept? (column -, row +)

TAV EFFECTIVENESS -

\+

	PERFORMANCE	COSTS	RISKS	LOGISTICS	SURVIVABILITY
REQUIREMENTS/GOALS					
PERFORMANCE					
COSTS					
RISKS					
LOGISTICS					

APPENDIX B: Follow-up Thesis Survey

Feedback (reasons why people deviated from group mean)

General

11 In some cases your criteria for comparison tended to compare an absolete (global range) with variables and in general category with a sub-element of that category.

11 In no cases were missions specified, which is a driver in weighting criteria. I generally used the Space Command missions.

Requirements/Goals

2 If it can't meet valid requirements/goals, it should not be done (but they should be revised).

9 Requirements rank behind performance and survivability, such as: manned flight, global reach, sortie ops, and flexible basing.

11 Requirements, goals, and performance are subsets of the same element. The importance of some factors under each heading drives the weighting. Risks are a subset of costs. Survivability, logistics, and environmental issues tend to group together also.

13 This is not a balanced set of requirements. Some, like rapid response and flexible basing are quite important. Some, like horizontal TO and landing are not very important. If the vehicle is capable of rapid response, flexible basing and etc, it does not matter what the TO/landing mode is.

4 Goals moves down because: 5 minute launch capability, 2 missions/day, and 20,000lbs payload take away a lot of flexibility you may need in funding later on (STS isn't to 20K yet, regardless what NASA/DOD says).

5 2 missions/day, single stage, few orbits are either not possible or undesirable. For example, single stage is undesirable because it increases weight and degrades performance.

Costs

4 It is simply unreasonable, and a frequent criticism of DOD, that we do not adequately address costs. Today, as well as tomorrow, the competition for resources should never be taken lightly and such a prgam like TAV will be priced in the billion $ range. Let's not plan without this in mind. Some may say a high ranking here is synonymous with its importance.

6 There is enough resistance throughout the Air Force/DOD to kill this unless it makes significant improvements in the payload to orbit costs catagory.

9 Although costs are important, I have problems in my mind viewing costs as a main driver. TAV will be very expensive. It may very well shelve TAV for a decade until the dollar figure representing LCC isn't so scary, but I believe that TAV will be and cost will not stand in its way.

APPENDIX B: Follow-up Thesis Survey

Risks

6 I know more about the technologies required than last year. The large size of the initial investment makes risk more important.

13 The items listed under risks are extremely important since they largely determine the feasibility of the vehicle concept.

Survivability

4 Survivability seems somewhat less an issue in the basic TAV concept with its relatively short taskings. Dispersals should not necessarily be a problem since launches from runway environments could occur from a multitude of suitable launches (5 min or less).

6 Simply cannot be done to same degree of a JP-4 fueled B-1.which appears to the standard. However, I do think some level of survivability can be achieved by operational decisons (better planning) versus system design.

7 Survivability is a subset of performance. If it can't survive, it can't perform.

9 Performance (payload) and the ability of TAV to survive in order to deliver a payload are paramount. Without these, there would be no TAV.

Logistics

2 Logistics includes maintainability which is a design element. Logistics also is driver in LC costs, sortie generation capability, reaction times, etc. It is a crucial element to be considered early: e.g. proper consideration to maintainability aspect of design up front can facilitate rapid low cost changes (mods) to survivability (threats change), performance (propulsion technology changes), ability to cope with environ (tech changes), etc.

4 Don't build if you can't properly support! Support capabilities often the first to be cut (funding wise) when programs are in trouble. If we are going to hav TAV, let's be able to support it so it can do its mission up front and not let maintainability suffer in the long run.

6 Again, if the Tech/Req/Cost/Perf categories can be solved, logistics are a tail and can be solved.

7 Things such as environmental impact and logistics are too far down the road to worry about at this point. The real quesiton at this point should be: "Do the requirements justify the costs and risks associated to achieve the desired performance?"

APPENDIX C3: AHP Summary Program

```
procedure DoOneFile(var filenum:integer);
      (* Finds the eigenvectors for each file and stores them
         in a large matrix 'results' for output
      *)
   var
     crit,i : integer;
   begin
     crit := 0;
     reset(matrix1,infile[filenum]);
     readln(matrix1,last);
     readln(matrix1,author);
     cluster :=1;
     readln(matrix1,dimen[cluster]);
     repeat
       while dimen[cluster] = 0 do readln(matrix1,dimen[cluster]);
       GetMatrix(dimen[cluster]); (* returns inputs + criterion[i] *)
       FindWeights(dimen[cluster]);
       for i := 1 to  dimen[cluster] do begin
         crit := crit + 1;
         Results[crit,filenum] := w[i];
       end; (* for *)
       if criterion[cluster]  <> last then begin
         cluster := cluster + 1;
         readln(matrix1,dimen[cluster]);
       end;  (* if *)
     until criterion[cluster] = last;
     criterion[cluster] := 'bogus';  (* prevents premature termination for
                                       subsequent file numbers *)
     writeln('File #',filenum:2,' done.');
     close(matrix1);
   end; (*  DoOneFile *)

   procedure DisplaySummary(var Limit:integer);
     (* displays judges 1-13 priority vectors and also computes the
        standard deviation * 10 and the arithmetic mean of the priority
        vectors and outputs the results.
     *)
     var
       filen,start,cease,crit,i,j : integer;
       totci,meanci  : real;
       MeanWeight : column;
        (*******************)
     procedure FindClusterWeights;
       (* subprocedure to compute the standard deviation and arithmetic mean
          of the vectors. Could have been accomplished while displaying the
          main part of the cluster, but that would have exceeded the size
          for an Apple Pascal procedure.
       *)
       var
         total,SumSqr : real;
```

APPENDIX C3: AHP Summary Program

```
procedure FindWeights(num : integer);
   (* finds eigenvectors as in consistency check progam and follows
      the logic and variables shown in Saaty's Decision Making for Leaders *)
  var
     c7,w2 : column;
     lamda,d,s,t4, rowsum, wtrow : real;
     k,i,j : integer;
begin
  t4 := 0;
  for i := 1 to num do begin
    rowsum := 0;
    for j := 1 to num do
      rowsum := rowsum + c[i,j];
    w2[i] := rowsum;
    t4 := t4 + rowsum;
  end; (* for i *)
  for i := 1 to num do
    w2[i] := w2[i]/t4;
  k := 0;
  repeat
    t4 := 0;
    k := k+1;
    for i := 1 to num do begin
      wtrow := 0;
      for j := 1 to num do
        wtrow := wtrow + c[i,j] * w2[j];
      w[i] := wtrow;
      t4 := t4 + wtrow;
    end; (* for i *)
    d := 0;
    for i := 1 to num do begin
      w[i] := w[i]/t4;
      d := d + abs(w[i] - w2[i]);
    end; (* for i *)
    for i := 1 to num do
      w2[i] := w[i];
  until (k>1000) or (d<1.0E-6);
  for i := 1 to num do begin
    s := 0;
    for j := 1 to num do
      s := s + c[i,j] * w[j];
    c7[i] := s;
  end; (* for i *)
  s := 0;
  for i := 1 to num do
    s := s + c7[i]/w[i];
  lamda := s/num; (* not used in this program *)
  ci[cluster,filenum] := (lamda-num)/(num-1);
  cr[cluster,filenum] := ci[cluster,filenum]/r[num];
end; (* FindWeights *)
```

APPENDIX C3: AHP Summary Program

```
program eigenvector(input,output);
  (* reads raw data and computes eigenvectors, ci, and cr, and outputs
     to file "eigout." Eigout includes the means and variances
     (10 * Standard Deviations) of each element (subobjective) of the
     normalized eigen vectors. That is, the variance between judges'
     priority vectors and the mean vector. Note: the data in this thesis
     computed the mean and variance using judge 13, which was the geomean
     input "judge." This caused slight conservative bias that has since
     been corrected in this program.
  *)
  uses
    transcend;  (* necessary for Apple to do logarithms *)
  type
    matrix = array[0..9 ,0..9 ] of real;
    column = array[1..15] of real;
  var
    c : matrix;   (* AHP input comparison matrices *)
    results : array[0..40,0..15] of real;  (* Summary of Judges priorities *)
    ci,cr  : array[0..10,0..15] of real;   (* ci,cr[cluster,judge] *)
    dimen : array[1..10] of integer;       (* dimension of [cluster] read in *)
    w,r : column;                          (* weights *)
    filenum,cluster,Limit: integer;        (* limit = user input # judges files *)
    outmatrix,matrix1 : text;              (* output, input files *)
    author,last,title : string;            (* last=flag criterion to stop *)
    infile,criterion : array[1..13] of string; (* judges infile names, cluster criterions *)

 procedure GetMatrix(num:integer);
   (* reads in half matrix of AHP comparisons and converts negative numbers
      to the recriprocal ratio value while completing the matrix
   *)
   var
     i,j : integer;
   begin
     for i := 1 to num-1 do
       for j := i+1 to num do
         read(matrix1,c[i,j]);
     readln(matrix1);
     readln(matrix1,criterion[cluster]);
     for i := 1 to num-1 do begin
       for j := i+1 to num do begin
         if c[i,j] < 0 then
           c[i,j] := -1/c[i,j];
         c[j,i] := 1/c[i,j];
       end; (* for j *)
       c[i,i] := 1;
     end; (* for i *)
     c[num,num] := 1;
   end; (* procedure GetMatrix *)
```

APPENDIX C2: Geometric Mean Program

```
 (*******************)
procedure InitNew;
  begin
    infile[ 1] := '#5:judge1*.text';  infile[ 2] := '#5:judge2*.text';
    infile[ 3] := '#5:judge3*.text';  infile[ 4] := '#5:judge4*.text';
    infile[ 5] := '#5:judge5*.text';  infile[ 6] := '#5:judge6*.text';
    infile[ 7] := '#5:judge7*.text';  infile[ 8] := '#5:judge8*.text';
    infile[ 9] := '#5:judge9*.text';  infile[10] := '#5:judge10*.text';
    infile[11] := '#5:judge11*.text'; infile[12] := '#5:judge11*.text';
    infile[13] := '#5:geomean*.text';
  end; (* InitOld *)

 begin (* initialize *)
   writeln('This program will take raw data from a max of 12');
   writeln('judges'' files  and will compute means and ');
   writeln('will output the results on file #5:geomean');
   writeln;
   write('Do you want to use new (updated) or original data (n or o)');
   readln(answer);
   if answer = 'o' then InitOld
     else begin
       writeln ('New Files being used');
       InitNew;
     end; (* else *)
   write('How many files do you want to use?  ');  readln(ans);
   if ans = 1 then begin  (* note: ans passed globally *)
     write('Which file number do you want to work? '); readln(filenum);
     infile[1] := infile[filenum]; (* if 1 file, only infile[1] read *)
   end; (* if *)    (* note: filenum overwritten in main program *)
  end;  (* initialize *)

begin (* main program *)
  rewrite(outmatrix,'#5:geomean.text');
  Initialize:
  filenum := 1;
  GetFile(filenum):(*  num of crit=i, num of P-W comp=j, in Survey[i,j] *)
  CopyFile(survey); (* copies survey into bogus[i,j], ie inits bogus *)
  while filenum < ans do begin  (* go through files in order *)
    filenum := filenum +1;
    GetFile(filenum);
    GatherBogus;   (* Multiplies Bogus by Survey  *)
  end; (* while *)
  if filenum > 1 then AverageBogus(filenum); (* Takes "filenum" root Bogus *)
  DisplayBogus;
  close (outmatrix,lock);
 end. (* program     *)
```

APPENDIX C2: Geometric Mean Program

```
procedure DisplayBogus;
  (* places the geometric mean of the inputs back into a similar
     file structure as was inputed. The difference is that the
     output needs to have "0" put in the appropriate spots inorder
     that subsequent programs will be able to sequence the priority
     vectors
  *)
  var
    dimension,crit,count,i,j : integer;
  begin
    writeln(outmatrix,last);
    writeln(outmatrix,'Geometric Mean for',filenum:3,' Judges');
    writeln(last);
    writeln('Geometric Mean for',filenum:3,' Judges');
    for crit := 1 to 9 do begin
      dimension := round(survey[crit,0]);  (* use "dimen." for understanding *)
      writeln(outmatrix,dimension:3);
      writeln(dimension:3);
      count := 0;
      for i := 1 to dimension-1 do begin
        for j := i+1 to dimension do begin
          count := count +1;
          if bogus[crit,count]<1 then
             bogus[crit,count] := -1/bogus[crit,count];
          write(outmatrix,bogus[crit,count]:8:4);
          write(bogus[crit,count]:8:4);
        end; (* for j *)
        writeln(outmatrix);
        writeln;
      end; (* for i *)
      writeln(outmatrix,criterion[crit]);
      writeln(criterion[crit]);
    end; (* for crit  *)
  end; (* procedure DisplayBogus *)

  procedure Initialize;
   (* sets up files, note: apple specific names. Need to lable files
      ever system calls them.
   *)
   var
     answer : string;
   (******************)
   procedure InitOld;
    begin
      infile[ 1] := '#5:judge1.text';  infile[ 2] := '#5:judge2.text';
      infile[ 3] := '#5:judge3.text';  infile[ 4] := '#5:judge4.text';
      infile[ 5] := '#5:judge5.text';  infile[ 6] := '#5:judge6.text';
      infile[ 7] := '#5:judge7.text';  infile[ 8] := '#5:judge8.text';
      infile[ 9] := '#5:judge9.text';  infile[10] := '#5:judge10.text';
      infile[11] := '#5:judge11.text'; infile[12] := '#5:judge11.text';
      infile[13] := '#5:geomean.text';
     end; (* InitOld *)
```

APPENDIX C2: Geometric Mean Program

```
procedure CopyFile(var survey : matrix);
  var
    dimension,crit,count,i,j : integer;
  begin
    for crit := 1 to 9 do begin
      dimension := round(survey[crit,0]);
      bogus[crit,0] := round(survey[crit,0]);
      count := 0;
      for i := 1 to dimension-1 do begin
        for j := i+1 to dimension do begin
          count := count +1;
          bogus[crit,count] := survey[crit,count];
        end; (* for j *)
      end; (* for i *)
    end; (* for crit do not use criterion because need constants for aver *)
  end; (* procedure CopyFile *)

procedure GatherBogus;
     (*  product of "n" factors and take nth root later *)
  var
    dimension,crit,count,i,j : integer;
  begin
    for crit := 1 to 9 do begin
      dimension := round(survey[crit,0]);  (* just for ease of understanding *)
      count := 0;
      for i := 1 to dimension-1 do begin
        for j := i+1 to dimension do begin
          count := count +1;
          bogus[crit,count] := bogus[crit,count] * survey[crit,count];
        end; (* for j *)
      end; (* for i *)
    end; (* for crit  *)
  end; (* procedure GatherBogus *)

  function root(base:real; n:integer) : real;
    begin
      root := exp( ln(abs(base)) /n );
    end;  (* root *)

  procedure AverageBogus(n:integer);
     (* "n" = numfile *)
  var
    dimension,crit,count,i,j : integer;
  begin
    for crit := 1 to 9 do begin
      dimension := round(bogus[crit,0]);(* dimension for ease  understanding *)
      count := 0;
      for i := 1 to dimension-1 do begin
        for j := i+1 to dimension do begin
          count := count +1;
          bogus[crit,count] :=  root(bogus[crit,count],n);
        end; (* for j *)
      end; (* for i *)
    end; (* for crit *)
  end; (* procedure AverageBogus *)
```

APPENDIX C2: Geometric Mean Program

```
program geomean(input,output);
  (* reads in raw judge data and combines the judges' inputs by
     the geometric mean and puts the output to file 'geomean' -
     note: to be read by program "ConsistencyCheck," the geomean
     file needs to have sequencing zeros as shown in the sample
     input file
  *)
  uses
    transcend;
  type
    matrix = array[0..9,0..36] of real;
  var
    bogus,survey : matrix;
    criterion: array[0..9] of string;
    infile: array[0..13] of string;
    filenum,numfiles,ans,count : integer;
    outmatrix,matrix1 : text;
    author,last : string;

procedure GetFile(filenum : integer);
  (* "filenum" is the file sequence number. This procedure puts entire
     file into a 9 X 36 array called survey. The i X 0 element is
     the dimension of the ith  (of 9) criterion *)
  var
    dimension,crit,count,i,j : integer;
  begin
    reset(matrix1,infile[filenum]);
    readln(matrix1,last);     (* last = subtitle of last matrix to enter *)
    readln(matrix1,author);
    readln(matrix1,dimension);
    for crit := 1 to 9 do begin
      while dimension = 0 do readln(matrix1,dimension);
      survey[crit,0] := dimension;
      count := 0;
      for i := 1 to dimension-1 do begin
        for j := i+1 to dimension do begin
          (* i,j  count variables to keep matrix format straight *)
          count := count +1;
          read(matrix1, survey[crit,count]);
          if survey[crit,count] < 0 then
            survey[crit,count] := -1/survey[crit,count];
        end; (* for j *)
      end; (* for i *)
      readln (matrix1);  (* reset pointer to start of line *)
      readln (matrix1,criterion[crit]);
      if criterion[crit] <> last then readln(matrix1,dimension);
    end; (* for crit do not use criterion because need constants for aver *)
    close(matrix1);
  end; (* procedure GetFile   *)
```

```
            for i := 1 to n3 do begin
              count := count + 1;  (* count is total * in current generation *)
              compos[count] := b[elem,i]; (* b needed for display *)
            end; (* for i *)
            totrandom := totrandom + prevcomp[elem] * r[n3];
            totconsis := totconsis + prevcomp[elem] * ci;
          end (* if n3 > 1 *)
          else begin (* only one element related *)
            count := count + 1;
            b[elem,1] := prevcomp[elem];
            compos[count] := prevcomp[elem];
          end; (* else *)
        end; (* if last - allows putting last anywhere *)
      end;   (* for elem *)
    end; (* NextLevel *)

begin (* program saaty *)
  reset(matrix1,'#5:matrix1.text'); (* first generation program - see program
                                          eigenvector for better method to read
                                          in files *)
  rewrite(outmatrix,'#5:outmatrix.text');
  InitR;
  L := 2;
  elem := 0;
  totconsis := 0; totrandom :=0;
  readln(matrix1,last);    (* last = subtitle of last matrix to enter *)
  readln(matrix1,title);
  readln(matrix1,n1);
  GetMatrix(n1);   (* returns subtitle: flag to continue to next level *)
  FindWeights(n1);
  display(n1); (* makes hard copy of orginal,since L=2, b[] not necessary *)
  if cr > 0.10 then begin
    consistency(n1);
    display(n1); (* final hard copy after consistency revisions *)
  end; (* if cr *)
  for i := 1 to n1 do begin
    prevwt[i] := w[i];   (* can't remember what prevwt[] is used for *)
    prevcomp[i] := prevwt[i];
  end; (* for i *)
  while subtitle <> last do begin
    L := L + 1;
    for i := 1 to n1 do
      for j := 1 to n1 do
        b[i,j] := 0;
    Nextlevel;   (* returns count, compos[i], and subtitle-for while loop *)
    for i := 1 to count do prevcomp[i] := compos[i];
    n1 := count;
  end; (* while subtitle <> last goto next level *)
  writeln(outmatrix);
  writeln(outmatrix,'The Consistency of this hierarchy = ',totconsis/totrandom:6:4);
  writeln('The Consistency of this hierarchy = ',totconsis/totrandom:6:4);
  close(outmatrix,lock);
  close(matrix1);
 end. (* program saaty *)
```

```
    for i := 1 to s1 do begin
      for j := 1 to s1 do
        write (c[i,j]:6:2,' ');
      write(w[i]:6:5,' ');
      if L > 2 then write(b[elem,i]:7:4);
      writeln;
    end; (* for i *)
    write('lamda(max): ',lamda:6:4);
    write('   C.I.: ',ci:6:5);
    writeln('   C.R.: ',cr:7:5);
  end; (* display *)


procedure InitR;
          (*  Random Consistency Table *)
 begin
   r[1] := 0.0;  r[2] := 0.0 ;  r[3] := 0.58;
   r[4] := 0.9;  r[5] := 1.12;  r[6] := 1.24;
   r[7] := 1.32; r[8] := 1.41;  r[9] := 1.45;
   r[10]:= 1.49; r[11]:= 1.51;  r[12]:= 1.48;
   r[13]:= 1.56; r[14]:= 1.57;  r[15]:= 1.59;
   for i := 1 to 33 do factor[i] := 'bogus';
 end;  (* InitR *)

 procedure NextLevel;
                  (* n1 is used as the number of 'parents' in the
                     current level. Variable names from Saaty.
                  *)
   var
     i, j : integer;
     s9 : real;
   begin
     count := 0;            (* left to right number of siblings *)
     for elem := 1 to n1 do begin
       if subtitle <> last then begin
         readln(matrix1,n3);  (* n3 = # of siblings of parent 'elem' *)
         if n3  > 1 then begin
           GetMatrix(n3);
           FindWeights(n3);
           for i := 1 to n3 do (* b necessary for display *)
           b[elem,i] := w[i] * prevcomp[elem]; (* this does not work for
                 "L"evel greater than 3. The fix would cost me a day I
                  don't have, sorry. I prefer program "eigenvector" as
                  a better program to copy, anyway. This was my first
                  program, and it is a little rough and hard to follow.
                  However, if you are reading this, I am preaching to
                  the choir. *)
           Display(n3);
           if cr > 0.10 then begin
             consistency(n3);(* unfortuately, perm copy of changes only *)
             for i := 1 to n3 do b[elem,i] := w[i] * prevcomp[elem]:
             Display(n3);  (* final hard copy with revised b wts *)
           end; (* if cr *)
```

```
        write (' Column:'); read(bigcol);
        writeln;
      end; (* if want to change location *)
      write ('Write value you want to insert: ');
      readln(c[bigrow,bigcol]);
      writeln;
      c[bigcol,bigrow] := 1/c[bigrow,bigcol];
      FindWeights(sl);
      writeln (outmatrix,' actual: [',bigrow:2,',',bigcol:2,'] =',
          c[bigrow,bigcol]:3:1,' with C.R.=',cr:7:5);
      ScreenDisplay(sl);
      if cr > 0.10 then consistency(sl);
    end; (* if ans *)
  end; (* procedure consistency *)

procedure display(sl:integer);
  var
   i,j : integer;
  begin
    oldbigcol := 0; oldbigrow := 0; (* for consistency called in display *)
    writeln(outmatrix);
    if L = 2 then writeln (outmatrix,title:20,' RESULTS');
    writeln(outmatrix,subtitle:20,',  Factor #',elem:2,'  Level #',L:2);
    writeln(outmatrix);
    write(outmatrix,'1':4,' ');
    for i := 2 to sl do
      write(outmatrix,i:6,' ');
    write(outmatrix,'    Weight');
    if L>2 then writeln(outmatrix,'  Comp-Wt') else
      writeln(outmatrix);
    for i := 1 to sl do begin
      for j := 1 to sl do
        write (outmatrix,c[i,j]:6:2,' ');
      write(outmatrix,w[i]:6:5,' ');
      if L > 2 then write(outmatrix,b[elem,i]:7:4);
      writeln(outmatrix);
    end; (* for i *)
    write(outmatrix,'lamda(max): ',lamda:6:4);
    write(outmatrix,'   C.I.: ',ci:6:5);
    writeln(outmatrix,'   C.R.: ',ci/r[sl]:7:5);
    if L > 2 then begin
      writeln;
      writeln(subtitle:20,',  Factor #',elem:2,'  Level #',L:2);
      writeln;
    end; (* L <> 2 accomplished so that subtitles print out right*)
    write('1':4,' ');
    for i := 2 to sl do
      write(i:6,' ');
    write('    Weight');
    if L>2 then writeln('  Comp-Wt') else
      writeln;
```

APPENDIX C1: Consistency Check Program

```
   if L>2 then writeln('  Comp-Wt') else
     writeln;
   for i := 1 to s1 do begin
     for j := 1 to s1 do
       write (c[i,j]:6:2,' ');
     write(w[i]:6:5,' ');
     if L > 2 then write(b[elem,i]:7:4);
       (* note: b[] gets overwritten for L > 3 so not valid at L > 3 *)
     writeln;
   end; (* for i *)
   write('lamda(max): ',lamda:6:4);
   write('   C.I.: ',ci:6:5);
   writeln('   C.R.: ',cr:7:5);
  end; (* subprocedure ScreenDisplay *)

procedure consistency(s1:integer);
        (*   calculates matrix element[bigrow,bigcol] that most
             contributes to the inconsistency. Allows user the
             option of changing the location and magnitude of
             input.
        *)
  var
    difold,difnew : real;
  begin
    difold := 0;
    for i := 1 to s1 do begin
      for j := 1 to s1 do begin
        if (i<> oldbigcol)  or (j<>oldbigrow ) then begin
          difnew := c[i,j]*w[j]/w[i];
          {difnew := abs(c[i,j]-w[i]/w[j]);}
          if difnew > difold then begin
            bigrow := i;
            bigcol := j;
            difold := difnew;  (* only updates if greater *)
          end; (* if difnew *)
        end; (* if i<> *)
      end; (* for j *)
    end; (* for i *)
    oldbigrow := bigrow;
    oldbigcol := bigcol;
    write ('Element[',bigrow:2,',',bigcol:2,'] should be:',
              w[bigrow]/w[bigcol]:5:2,'. Type ''y'' if you want to ',
              'replace it:');
    write (outmatrix,'[',bigrow:2,',',bigcol:2,'] should be:',
              w[bigrow]/w[bigcol]:5:2);
    readln(ans);
    writeln;
    if (ans = 'y') or (ans = 'Y') then begin
      write ('Do you want to put value in another location (y or n)?');
      readln(ans);
      if (ans = 'y') or (ans = 'Y') then begin
        write (' Row:');read (bigrow);
```

APPENDIX C1: Consistency Check Program

```
begin
  t4 := 0;
  for i := 1 to num do begin
    rowsum := 0;
    for j := 1 to num do
      rowsum := rowsum + c[i,j];
    w2[i] := rowsum;
    t4 := t4 + rowsum;
  end; (* for i *)
  for i := 1 to num do
    w2[i] := w2[i]/t4;
  k := 0;
  repeat
    t4 := 0;
    k := k+1;
    for i := 1 to num do begin
      wtrow := 0;
      for j := 1 to num do
        wtrow := wtrow + c[i,j] * w2[j];
      w[i] := wtrow;
      t4 := t4 + wtrow;
    end; (* for i *)
    d := 0;
    for i := 1 to num do begin
      w[i] := w[i]/t4;
      d := d + abs(w[i] - w2[i]);
    end; (* for i *)
    for i := 1 to num do
      w2[i] := w[i];
  until (k>1000) or (d<1.0E-6);
  for i := 1 to num do begin
    s := 0;
    for j := 1 to num do
      s := s + c[i,j] * w[j];
    c7[i] := s;
  end; (* for i *)
  s := 0;
  for i := 1 to num do
    s := s + c7[i]/w[i];
  lamda := s/num;
  ci := (lamda-num)/(num-1);
  cr := ci/r[num];
 end; (* FindWeights *)

 procedure ScreenDisplay(sl:integer); (* consistency too long *)
   begin
     writeln(subtitle:20,',  Factor #',elem:2,'  Level #',L:2);
     writeln;
     write('1':4,' ');
     for i := 2 to sl do
       write(i:6,' ');
     write('    Weight');
```

APPENDIX C1: Consistency Check Program

```
program ConsistencyCheck(input,output);
  (* Reads input file "matrix1" of AHP pairwise comparisons.
     Computes the matrix ci,cr, and eigenvectors after allowing
     the user to input corrections to the most "deviate" inputs. The
     erroneous inputs are identified by the largest divergent ratio, as
     explained in Saaty AHP, page 65. Note: this program is rough and
     non-eloquent. It computes a total hierarchy consistency - the only
     addition over the "eigenvector" program listed next.
  *)
  type
    matrix = array[0..40,0..40] of real;
    column = array[1..40] of real;
  var
    c,b : matrix;
    prevwt,w,prevcomp,compos : column;
    r : array[1..15] of real;
    totconsis,totrandom,ci,cr,lamda : real;
    oldbigrow,oldbigcol,count,m3,i,j,L,elem,n1 : integer;
    bigrow,bigcol : integer;
    subnames,outcomp,outmatrix,matrix1 : text;
    last,title,subtitle : string;
    factor : array [1..35] of string;
    ans : char;
    atend : boolean;

 procedure GetMatrix(s1:integer);
   (* Reads in AHP comparisons and inverts numbers < 0 to complete matrix *)
   var
     i,j : integer;
   begin
     for i := 1 to s1-1 do
       for j := i+1 to s1 do
         read(matrix1,c[i,j]);
     readln(matrix1);
     readln(matrix1,subtitle);
     for i := 1 to s1-1 do begin
       for j := i+1 to s1 do begin
         if c[i,j] < 0 then
           c[i,j] := -1/c[i,j];
         c[j,i] := 1/c[i,j];
       end; (* for j *)
       c[i,i] := 1;
     end; (* for i *)
     c[s1,s1] := 1;
   end; (* procedure GetMatrix *)

    procedure FindWeights(num : integer);
     (* variable names from Saaty's text, little intuitive meaning *)
     var
       c7,w2 : array[1..10] of real;
       d,s,t4, rowsum, wtrow : real;
       k,l,j : integer;
```

Optional Detailed Feedback (comparison matrices)

2 Maintainability is a design function which encompasses accessability, reliability, modularity, etc. Early concept formulation absoultely must give great consideration to this critical design element.

11 For maneuverability to be meaningful for mission applications, maneuverability in space is the driver. Maneuverability for launch/recovery provides flexibility and allowance for error. Orbital injection/selection is a different issue from maneuverability.

11 Payload mass and volume are determined by mission which drives requirement for maneuverability (orbital change). A higher orbit can be traded for payload, etc. Basically you want to maximize all three factors. Trades are based on missions and cost.

2 Propellants are a consumable resource (supply problem).

11 Cryogenic fits under the category of amount and different types. Another case of the total set being more important than the subset. The terms cryo and storable both cover a multitude of sins. Hydrozine is probably worse than LOX but LOF is probably worse than both. The issue of number of different types is that a failure to provide one may be a cause for abort thus there is a potential for lots of small critical points vice one or two big ones.

2 Facilities, by your definition, may be either "nice to have" or "critical."

11 What is an element? Big rockets, little rockets, expendable rockets?

6 Structure and Mass Fraction are not mutually exclusive.

6 Without global range, forget mission.

11 The issue "global range" should be expendables (fully reusable) or flexible basing as defined by Battelle, not global range. All Phase I concepts achieved orbital velocity, even for "once around" missions.

9 Base escape and mobile launch essential (regards to survivability).

11 Invalid questions tend toward invalid analysis. Analyzing "How high is a duck?" can lead to interesting conclusions but not necessarily a MS degree. I wish you success in your endeavor.

3

```
 begin
  i := 0;
  for crit := start to cease do begin
   i := i + 1;
   SumSqr := 0;
   total := 0;
   for filen := 1 to Limit do begin
    total := total + Results[crit,filen];
    SumSqr := SumSqr + sqr(Results[crit,filen]);
   end; (* for filen *)
   Results[crit,14] := total/Limit;
   MeanWeight[i] := Results[crit,14];
      (* Insures MeanVote in column format for CalcZeta *)
   Results[crit,15] := sqrt(SumSqr/Limit-sqr(MeanWeight[i]))*10;
      (* Standard Deviation is a very small number so * 10 *)
  end; (* for crit *)
 end;  (* procedure FindClusterWeights *)

 procedure DisplayMainPart;
  (* displays the eigenvalues for all the judges *)
  begin
   write(outmatrix,'1':4);
   for i := 2 to Limit do write(outmatrix,i:6); writeln(outmatrix);
   write('1':4 );
   for i := 2 to Limit do write(i:6); writeln;
   for crit := start to cease do begin
    for filen := 1 to Limit do begin
     write(outmatrix,Results[crit,filen]:5:3);
     write(Results[crit,filen]:5:3);
    end; (* for filen *)
    writeln; writeln(outmatrix);
   end;  (* for crit  *)
   totci := 0;
   for filen := 1 to Limit do begin
    totci := totci + ci[cluster,filen];
    write(outmatrix,ci[cluster,filen]:5:3);
    write(ci[cluster,filen]:5:3);
   end; (* for *)
   meanci := totci/Limit;
   writeln; writeln(outmatrix);
   for filen := 1 to Limit do begin
    write(outmatrix,cr[cluster,filen]:5:3);
    write(cr[cluster,filen]:5:3);
   end; (* for *)
   writeln; writeln(outmatrix);
  end; (* DisplayMainPart *)
  (**************)
procedure DisplayCluster;
 (* Results["crit"erion, 1..13] = judges,14=mean,15=Dev * 10
   calls DisplayMainPart and then displays the vector mean
   and Standard Deviations of the priorities
 *)
```

```
    var
      totci, totcr : real;
    begin
      DisplayMainPart;
      writeln(outmatrix,'Mean':5,' Dev * 10':11);
      writeln('Mean':5,' Dev * 10':11);
      for crit := start to cease do begin
        write(outmatrix,Results[crit,14]:5:3);   (* Vector Mean for judges *)
        writeln(outmatrix,Results[crit,15]:8:2); (* Dev * 10 for judges *)
        write(Results[crit,14]:5:3);
        writeln(Results[crit,15]:8:2);
      end; (* for crit *)
      writeln(outmatrix,meanci:6:3 );
      writeln(meanci:6:3);
      writeln(outmatrix,meanci/r[dimen[cluster]]:6:3);
      writeln(meanci/r[dimen[cluster]]:6:3);
      writeln('----------------':30);
    end; (* procedure DisplayCluster *)
     (********************)
  begin  (* DisplaySummary *)
    if criterion[cluster] = 'bogus' then criterion[cluster] := last;
     (* insures the previous file does not prematurely terminate this
        program from reading the last cluster (matrix=maneuverability *)
    writeln(outmatrix,limit:3,' Decision Makers');
    writeln('Voting Summary':20,' for',limit:3,' Decision Makers');
    start := 1;   (* Begins new cluster in "for" loop *)
    for cluster := 1 to 9 do begin
      cease := start + dimen[cluster] - 1;
      writeln(outmatrix,criterion[cluster]);
      writeln(outmatrix,dimen[cluster]:3);
      writeln(criterion[cluster],dimen[cluster]:3);
      FindClusterWeights;    (* returns arithmetic means & variances *)
      DisplayCluster;
      start := cease + 1;    (* avoids printing same line twice *)
    end; (* for cluster *)
  end; (* procedure DisplaySummary *)

procedure Initialize;
 (* sets up files, note: apple specific names. Need to label files
    what ever system calls them.
 *)
 var
   answer : string;
 (*****************)
 procedure InitOld;
  begin
    infile[ 1] := '#5:judge1.text';  infile[ 2] := '#5:judge2.text';
    infile[ 3] := '#5:judge3.text';  infile[ 4] := '#5:judge4.text';
    infile[ 5] := '#5:judge5.text';  infile[ 6] := '#5:judge6.text';
    infile[ 7] := '#5:judge7.text';  infile[ 8] := '#5:judge8.text';
    infile[ 9] := '#5:judge9.text';  infile[10] := '#5:judge10.text';
    infile[11] := '#5:judge11.text'; infile[12] := '#5:judge11.text';
```

```
      infile[13] := '#5:geomean.text';
    end; (* InitOld *)
   (******************)
  procedure InitNew;
    begin
      infile[ 1] := '#5:judge1*.text';  infile[ 2] := '#5:judge2*.text';
      infile[ 3] := '#5:judge3*.text';  infile[ 4] := '#5:judge4*.text';
      infile[ 5] := '#5:judge5*.text';  infile[ 6] := '#5:judge6*.text';
      infile[ 7] := '#5:judge7*.text';  infile[ 8] := '#5:judge8*.text';
      infile[ 9] := '#5:judge9*.text';  infile[10] := '#5:judge10*.text';
      infile[11] := '#5:judge11*.text'; infile[12] := '#5:judge11*.text';
      infile[13] := '#5:geomean*.text';
    end; (* InitOld *)

  begin (* initialize *)
            (*  Random Consistency Table (reduced for problem ) *)
     r[3] := 0.58;
     r[4] := 0.9;  r[5] := 1.12;  r[6] := 1.24;
     r[7] := 1.32; r[8] := 1.41;  r[9] := 1.45;
     r[10]:= 1.49;
    writeln('This program will take raw data from a max of 13');
    writeln('judges'' files (13=geomean) and compute eigenvectors + means');
    writeln('and will output the results on file #5:eigout');
    writeln;
    write('Do you want to use new (updated) or original data (n or o)');
    readln(ans);
    if ans = 'o' then InitOld
      else begin
        writeln ('New Files being used');
        InitNew;
      end; (* else *)
    write('How many files do you want to use?  ');  readln(limit);
    if limit = 1 then begin
      write('Which file number do you want to work? '); readln(filenum);
      infile[1] := infile[filenum];       (* if 1 file, only infile[1] read *)
    end; (* if *)
  end;  (* initialize *)

begin (* main program *)
  rewrite(outmatrix,'#5:eigout.text');
  initialize; (* file titles set and user inputs "limit" *)
  for filenum := 1 to limit do
    DoOneFile(filenum);
  DisplaySummary(limit);
  close (outmatrix,lock);
end. (* program eigenvector *)
```

APPENDIX C4: Vote Conversion Program

```
program zeta (input,output);
  (* Reads in raw judges' files sequentially and outputs the
     converted weights and zeta coefficients to file indvotes. First
     converts the AHP matrix with 1-9 scale into a voting matrix (0,1/2,1).
     Calculates the max number of circular triads and subsequently
     the Kendall coefficient of consistency (zeta), following the procedures
     outlined by Kendall (1970:146). Tied ranks are taken care of by
     determining a range of triads possible and using the average to
     derive zeta - see Dobbins (1980:30).
   *)
   uses
     transcend;  (* apple for square root function *)
   type
     matrix = array[0..11,0..11] of real;
     column = array[0..12] of real;
   var
     copy, VoteCount: array[0..40,0..15] of real;
     c : matrix;
     ZetaU,ZetaC : array[0..10,0..15] of real;
     ordered,RowVotes,w : column;
     results : array[0..10,0..10,0..15] of real;
     sequence,dimen : array[0..11] of integer;
     limit,crit,filenum,i,j,cluster : integer;
     criterion,infile : array[1..14] of string;
     item : array[1..41] of string;
     AveZeta,ComZetaU,first,maxw : real;
     author, last : string;
     outmatrix,matrix1 : text;
     WantCopy : boolean;

   procedure Nameit;
     (* file of subobjective names *)
     var
       names : text;
       i,j : integer;
     begin
       reset (names,'#4:names.text');
       for i := 1 to 41 do
         readln(names,item[i]);
       close(names);
     end; (* procedure nameit *)

    function maxtriads(num:integer) : real;
      (* determines the maximum number of triads possible for a
         dimension of a pairwise comparison matrix
         *******************)
      function numeven (num:integer) : boolean;
        begin
          if trunc(num/2) = num/2 then
            numeven := true
          else
```

```
        numeven := false;
    end; (* function numeven *)
    (*********************)
  begin (* function maxtriads *)
    if numeven(num) then
      maxtriads := (num * (sqr(num) -4))/24
    else
      maxtriads := (num * (sqr(num) -1))/24;
  end; (* function maxtriads *)

  procedure sort(var colum : column; num : integer);
    (* determines sequence and maximum element of vector *)
    var
      i : integer;
      sorted : boolean;
      temp : real;
    begin
      (* pass through colum until sorted *)
      repeat
        (* assume colum is sorted *)
        sorted := true;
        (* start new pass *)
        for i := 1 to num-1 do
          (* start new pass *)
          if colum[i] < colum[i+1] then begin
            (* out of order - exchange and reset sorted *)
            temp := colum[i+1];
            colum[i+1] := colum[i  ];
            colum[i  ] := temp;
            sorted := false;
          end; (* if colum *)
          (* test sorted at completion of pass *)
      until sorted;
      maxw := colum[1];
    end; (* sort *)

procedure GetMatrix(num:integer);
  (* reads in raw AHP comparisons and converts to "voting" matrix *)
  var
    i,j : integer;
  begin
    for i := 1 to num-1 do
      for j := i+1 to num do
        read(matrix1,c[i,j]);
    readln(matrix1);
    readln(matrix1,criterion[cluster]);
    for i := 1 to num-1 do begin
      for j := i+1 to num do begin
        if c[i,j] < 0 then begin
          c[i,j] := 0;
          c[j,i] := 1;
        end  (* if *)
```

```
    else if c[i,j] = 1 then begin
     c[i,j] := 0.5;
     c[j,i] := 0.5;
    end (* else if *)
    else if c[i,j] > 1 then begin
     c[i,j] := 1;
     c[j,i] := 0;
    end; (* else if *)
   end; (* for j *)
  c[i,i] := 0;
 end; (* for i *)
 c[num,num] := 0;
end; (* procedure GetMatrix *)

procedure FindWeights(num:integer);
  (* returns w[i] : percentage of RowVotes for element i
    also returns first: "first" part of zeta calculation
    and zeta: Kendall's measure of consistence.
   *)
 var
  D,Zeta,SumD,TotalVotes : real;
  i,j : integer;
 begin
  TotalVotes := 0;
  for i := 1 to num do begin
   RowVotes[i] := 0;
   for j := 1 to num do
    RowVotes[i] := RowVotes[i] + c[i,j];
   TotalVotes := TotalVotes + RowVotes[i];
  end; (* for i *)
  SumD := 0;
  for i := 1 to num do begin
   crit := crit + 1;
   w[i] := RowVotes[i]/TotalVotes;
   SumD := SumD + RowVotes[i]*(RowVotes[i]-1);
   VoteCount[crit,filenum] := RowVotes[i];
  end;
  first := num*(num-1)*(num-2)/6; (* first is used in CalcZeta *)
  D := first - SumD/2; (* Actual * triads *)
  Zeta := 1 - D/maxtriads(num);
  ZetaU[cluster,filenum] := zeta;
 end; (* procedure FindWeights *)

procedure DisplayVotes(num:integer);
  (* "cluster","RowVotes", and "criterion" are passed globally *)
 var
  i,j : integer;
 begin
  writeln(criterion[cluster]);
  write(' ':3,'1');
  for i := 2 to num do
   write(i:6);
```

```
    writeln(' Total':9,' Weights');
    for i := 1 to num do begin
      for j := 1 to num do
        write(c[i,j]:6:2);
      writeln(RowVotes[i]:6:2,w[i]:8:3);
    end; (* for i *)
    writeln('Zeta(u) = ',ZetaU[cluster,filenum]:6:4,'   Zeta(c) = ',
      ZetaC[cluster,filenum]:6:4);
    writeln('------------':30);
    writeln(outmatrix,criterion[cluster]);
    write(outmatrix,' ':3,'1');
    for i := 2 to num do
      write(outmatrix,i:6);
    writeln(outmatrix,' Total':9,' Weights');
    for i := 1 to num do begin
      for j := 1 to num do
        write(outmatrix,c[i,j]:6:2);
      writeln(outmatrix,RowVotes[i]:6:2,w[i]:8:3);
    end; (* for i *)
    writeln(outmatrix,'Zeta(u) = ',ZetaU[cluster,filenum]:6:4,'   Zeta(c) = ',
      ZetaC[cluster,filenum]:6:4);
    writeln(outmatrix,'------------':30);
  end; (* procedure DisplayVotes *)

procedure CalcZeta(RowV:column;num:integer);
          (* Also need 'First' from FindWeights to Find a corrected
             Zeta for tied cases. Also verifies totals are appropriate
             to the Kendall assumptions *)
  var
    halfway,i,j,NumTies : integer;
    TieLocate : array [0..11] of integer;
    temp : column;
    verify,bogus,LowSumD, HighSumD, AveSumD : real;
     (**********************)
  procedure FindLowSumD;
    var
      LoSumD : real;
    begin
      for i := 1 to num do
        temp[i] := ordered[i];
      for i := 1 to halfway do
        temp[TieLocate[i]] := round(temp[TieLocate[i]] + 0.5);
            (* since in order of big to small, to obtain a large estimate
            of the number of triads need to round up larger values
            (the first half) and round down the smaller values *)
      for i := halfway+1 to NumTies do
        temp[TieLocate[i]] := round(temp[TieLocate[i]] - 0.5);
      verify := 0;
      for i := 1 to num do
        verify := verify + temp[i];
      bogus := num*(num-1)/2;
      if verify <> bogus then writeln('Sum of revised rowvotes (rounded high) = ',
```

```
       verify:7:1,' which should be = ',bogus:7:1);
     LoSumD := 0; (* Dobbins convention since high estimate gives
                       low zeta *)
     for i := 1 to num do
       LoSumD := LoSumD + temp[i]*(temp[i]-1);
     LowSumD := first - LoSumD/2;
   end; (* procedure FindLowSumD *)
     (****************)
procedure FindHighSumD;
   var
     HiSumD : real;
   begin
     for i := 1 to num do
       temp[i] := ordered[i];
     for i := 1 to halfway do
       temp[TieLocate[i]] := round(temp[TieLocate[i]] - 0.5);
     for i := halfway+1 to NumTies do
       temp[TieLocate[i]] := round(temp[TieLocate[i]] + 0.5);
     verify := 0;
     for i := 1 to num do
       verify := verify + temp[i];
     bogus := num*(num-1)/2;
     if verify <> bogus then writeln('Sum of revised row votes (rounded ',
          'low) = ',verify:7:1,' which should be = ',bogus:7:1);
     HiSumD := 0;
     for i := 1 to num do
       HiSumD := HiSumD + temp[i]*(temp[i]-1);
     HighSumD := first - HiSumD/2;
   end; (* FindHighSumD *)
     (****************)
 begin  (* procedure CalcZeta *)
   for i := 1 to num do
     ordered[i] := RowV[i];
   sort(ordered,num); (* causes 'i' index to be from largest to smallest *)
   NumTies := 0;
   for i := 1 to num do
     if trunc(ordered[i]) <> ordered[i] then begin
       (* 1/2 reflects tied ranks *)
       NumTies := NumTies + 1;
       TieLocate[NumTies] := i;
       (* TieLocate[1..NumTies] = row # of tied score *)
     end; (* if & incidentally, for i *)
   halfway := round(NumTies/2);
   FindLowSumD;
   FindHighSumD;
   AveSumD := (HighSumD + LowSumD)/2;
   AveZeta := 1 - AveSumD/maxtriads(num);
 end; (* procedure CalcZeta *)

procedure DoOneFile(index:integer);
  begin
    crit := 0;
```

```
  reset(matrix1,infile[index]);
  readln(matrix1,last); (* last = criterion of last matrix *)
  readln(matrix1,author);
  readln(matrix1,dimen[1]);
  if WantCopy then begin
    writeln('Judge *':20,index:3,' Results (Voting Matrix)');
    writeln(outmatrix,'Judge *',index:3,' Results (Voting Matrix)');
  end; (* if *)
  cluster := 1;
  criterion[9] := 'bogus'; (* inits 'last' criterion to complete repeat *)
  repeat
    while dimen[cluster] = 0 do readln(matrix1,dimen[cluster]);
    (* the '0' are for sequencing composite weights - something
       this progam is not interested in doing *)
    GetMatrix(dimen[cluster]);
    FindWeights(dimen[cluster]);(* out: w[i]:percentage votes & Rowvotes *)
    CalcZeta(RowVotes,dimen[cluster]);    (* outputs average zeta *)
    ZetaC[cluster,filenum] := AveZeta;
    if WantCopy then DisplayVotes(dimen[cluster]);
    if criterion[cluster]<>last then begin
      cluster := cluster + 1;
      readln(matrix1,dimen[cluster]);
    end; (* if *)
  until criterion[cluster] = last;
  close(matrix1);
end; (* procedure DoOneFile *)

procedure DisplaySummary(JudgeNum:integer);
   (* write out individual votes, total priorities, and variance
      between priorities for judges
   *)
  var
   filen,start,cease,crit,i,j : integer;
   SumSqr,TotZeta,SumD : real;
   total,MeanVote : column;
    (*******************)
  procedure FindClusterWeights;
    var
      numpos : real;
    begin
      i := 1;
      for crit := start to cease do begin
        VoteCount[crit,14] := 0;  (* init total to zero *)
        SumSqr := 0;
        RowVotes[i] := 0;
        SumD := 0; (* same as local variable in FindWeights *)
        numpos := dimen[cluster] * (dimen[cluster]-1)/2;
        (* numpos is number of possible votes for single voter *)
        for filen := 1 to JudgeNum do begin
          VoteCount[crit,14] := VoteCount[crit,14] + VoteCount[crit,filen];
          SumSqr := SumSqr + sqr(VoteCount[crit,filen]/numpos);
        end; (* for filen *)
```

```
      MeanVote[i] := VoteCount[crit,14]/limit;
           (* Insures MeanVote in column format for CalcZeta *)
     VoteCount[crit,15] := sqrt(SumSqr/limit - sqr(MeanVote[i]/numpos))*10;
     SumD := SumD + MeanVote[i]*(MeanVote[i]-1);
     i := i+1;
     total[cluster] := total[cluster] + VoteCount[crit,14];
   end; (* for crit *)
   first := dimen[cluster]*(dimen[cluster]-1)*(dimen[cluster]-2)/6;
   ComZetaU := (first-SumD/2)/maxtriads(dimen[cluster]);
 end;  (* procedure FindClusterWeights *)
    (************************)
procedure DisplayCluster;
  (* VoteCount["criterion", 1..13] = judges,14=total,15=variance *)
  var
    objective : integer;
  begin
    write(outmatrix,'Crit','1':4);
    for i := 2 to JudgeNum do write(outmatrix,i:5);
    writeln(outmatrix,'TotWt':7,'Dev*10':7);
    objective := 0;  (* to break crit into cluster criterion numbers *)
    for crit := start to cease do begin
      objective := objective + 1;
      write(outmatrix,objective:3,' ');
      for filen := 1 to JudgeNum do
        write(outmatrix,VoteCount[crit,filen]:5:1);
      write(outmatrix,VoteCount[crit,14]/total[cluster]:5:3);
      writeln(outmatrix,VoteCount[crit,15]:5:3);(* Dev*10 between judges *)
    end; (* for crit *)
    TotZeta := 0;
    write(outmatrix,'Z(u)');
    for filen := 1 to JudgeNum do begin
      write(outmatrix,ZetaU[cluster,filen]:4:2);
      TotZeta := TotZeta + ZetaU[cluster,filen];
    end; (* for *)
    writeln(outmatrix,TotZeta/Limit:5:3);
    TotZeta := 0;
    write(outmatrix,'Z(c)');
    for filen := 1 to JudgeNum do begin
      write(outmatrix,ZetaC[cluster,filen]:4:2);
      TotZeta := TotZeta + ZetaC[cluster,filen];
    end; (* for *)
    writeln(outmatrix,TotZeta/JudgeNum:5:3);
  end; (* procedure DisplayCluster *)
    (********************)
 begin  (* DisplaySummary *)
   rewrite(outmatrix,'#5:SumVotes.text');
   writeln(outmatrix,'Voting Summary':20,' for',limit:3,' Decision Makers');
   start := 1;   (* Begins new cluster in "for" loop *)
   for cluster := 1 to 9 do begin
     total[cluster] := 0;   (* votes per cluster *)
     cease := start + dimen[cluster] - 1;
     writeln(outmatrix,criterion[cluster]);
```

```
      writeln(criterion[cluster]);
      FindClusterWeights; (* returns MeanVote[i]' and 'first' *)
      CalcZeta(MeanVote,dimen[cluster]);
      DisplayCluster;
      start := cease + 1;    (* avoids printing same line twice *)
    end; (* for cluster *)
    close(outmatrix,lock);
  end; (* procedure DisplaySummary *)

procedure InitOld;
 begin
   infile[ 1] := '#5:arnettin.text';  infile[ 2] := '#5:mochelin.text';
   infile[ 3] := '#5:parringin.text'; infile[ 4] := '#5:perenicin.text';
   infile[ 5] := '#5:rallin.text';    infile[ 6] := '#5:robackin.text';
   infile[ 7] := '#5:ricein.text';    infile[ 8] := '#5:stanleyin.text';
   infile[ 9] := '#5:walbergin.text'; infile[10] := '#5:brownin.text';
   infile[11] := '#5:hartin.text';    infile[12] := '#5:hauserin.text';
   infile[13] := '#5:geomean.text';
 end; (* InitOld *)

procedure InitNew;
  begin
   infile[ 1] := '#5:arnettin*.text';  infile[ 2] := '#5:mochelin*.text';
   infile[ 3] := '#5:parringin*.text'; infile[ 4] := '#5:perenicin*.text';
   infile[ 5] := '#5:rallin*.text';    infile[ 6] := '#5:robackin*.text';
   infile[ 7] := '#5:ricein*.text';    infile[ 8] := '#5:stanleyin*.text';


procedure InitOld;
 (* sets up files, note: apple specific names. Need to lable files
    ever system calls them.*)
  begin
    infile[ 1] := '#5:judge1.text';  infile[ 2] := '#5:judge2.text';
    infile[ 3] := '#5:judge3.text';  infile[ 4] := '#5:judge4.text';
    infile[ 5] := '#5:judge5.text';  infile[ 6] := '#5:judge6.text';
    infile[ 7] := '#5:judge7.text';  infile[ 8] := '#5:judge8.text';
    infile[ 9] := '#5:judge9.text';  infile[10] := '#5:judge10.text';
    infile[11] := '#5:judge11.text'; infile[12] := '#5:judge11.text';
    infile[13] := '#5:geomean.text';
  end; (* InitOld *)

procedure InitNew;
  begin
    infile[ 1] := '#5:judge1*.text';  infile[ 2] := '#5:judge2*.text';
    infile[ 3] := '#5:judge3*.text';  infile[ 4] := '#5:judge4*.text';
    infile[ 5] := '#5:judge5*.text';  infile[ 6] := '#5:judge6*.text';
    infile[ 7] := '#5:judge7*.text';  infile[ 8] := '#5:judge8*.text';
    infile[ 9] := '#5:judge9*.text';  infile[10] := '#5:judge10*.text';
    infile[11] := '#5:judge11*.text'; infile[12] := '#5:judge11*.text';
    infile[13] := '#5:geomean*.text';
  end; (* InitNew *)
```

APPENDIX C4: Vote Conversion Program

```
procedure SetUp;
  (* Makes Headings and asks user for his inputs (limits, wantcopy) *)
  var
    ans,newfile : string;
  begin
    write('Do you want new or old files? (n or o) ');readln(newfile);
    if newfile = 'o' then
      InitOld
     else begin
      InitNew;
      writeln(' Using New Files');
    end; (* if *)
    Nameit;  (* puts criterion titles in an array for display *)
    write('How many files do you want to look at (13=geomean)? ');
    readln(limit);
    if limit = 1 then begin
      write('Which file number do you want to work? '); readln(filenum);
      infile[1] := infile[filenum]; (* if 1 file, only infile[1] read *)
    end; (* if *)
    writeln('File VotesOut will contain zeta and average weights and votes');
    write('Do you want individual matrices - file zetaout(y or n)? ');
    readln(ans);
    if (ans = 'y') or (ans = 'Y') or (ans = 'yes') then
      WantCopy := true
     else
      WantCopy := false;
  end;  (* SetUp *)

begin (* main program Zeta *)
  rewrite(outmatrix,'#5:zetaout.text');
  SetUp; (* initializes files, user inputs limit & WantCopy *)
  writeln('Standby this takes awhile');
  for filenum := 1 to limit do
    DoOneFile(filenum);
  close(outmatrix,lock);
  DisplaySummary(limit);  (* writes to file VotesOut *)
end.  (* main program Zeta *)
```

APPENDIX D: Sample Computer Input-Output

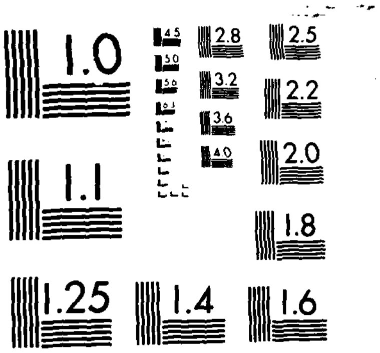
Sample Raw Input File

```
Maneuverability - - - Designates the Last Criterion Matrix to be read in (for shorter runs).
Judge # 3*      - - - Designates the "Title" or Judge's Name  (*= Revised Data).
6               - - - Designates the Dimension of Matrix about to be read.
1 1 3 5 7       :
1 3 5 7         :
3 7 7           :- - - AHP Comparisons for Half Matrix
5 7             :
3               :
TAV Effectiveness - - Designates Criterion of Matrix Just Read.
8
7 3 5 5 9 -3 1
3 -3 -5 5 -5 -5
-3 -7 3 -5 -3
-5 5 -5 -3
7 -3 3
-9 -9
3
Requirements
3
5 3
1
Performance
0               - - Zeros for Sequencing Composite Weights
3
-5 -7
-7
Risks
3
5 -3
-7
Logistics
7
7 3 7 -3 5 -5
-3 3 -5 1 -5
3 1 3 -5
-5 3 -7
5 -3
1
Survivability
```

APPENDIX D: Sample Computer Input-Output

```
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
3
1 -3
-1
Propellants
0
4
-1 -5 1
-1 1
1
Maintainability
0
0
0
[illegible]
[illegible]
0
0
1
5 -
5
Maneuverability
```

AD-A155 858 AGGREGATING INDIVIDUAL PREFERENCES IN THE ANALYTIC 3/4
HIERARCHY PROCESS APPL..(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. S E REED
UNCLASSIFIED 15 MAR 85 AFIT/GST/OS/85M-13 F/G 9/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX D: Sample Computer Input-Output

```
     Sample Results for Consistency Check Program

        Judge # 3*RESULTS
   TAV Effectiveness,  Factor # 0  Level # 2

   1      2      3      4      5      6     Weight
  1.00   1.00   1.00   3.00   5.00   7.00  0.25874
  1.00   1.00   1.00   3.00   5.00   7.00  0.25874
  1.00   1.00   1.00   3.00   7.00   7.00  0.27401
  0.33   0.33   0.33   1.00   5.00   7.00  0.13252
  0.20   0.20   0.14   0.20   1.00   3.00  0.04795
  0.14   0.14   0.14   0.14   0.33   1.00  0.02803
lamda(max):  6.2805   C.I.:  0.05609   C.R.:  0.04524

       Requirements,  Factor # 1  Level # 3

   1      2      3      4      5      6      7      8     Weight   Comp-Wt
  1.00   7.00   3.00   5.00   5.00   9.00   0.33   1.00  0.23933  0.0619
  0.14   1.00   3.00   0.33   0.20   5.00   0.20   0.20  0.04415  0.0114
  0.33   0.33   1.00   0.33   0.14   3.00   0.20   0.33  0.03548  0.0092
  0.20   3.00   3.00   1.00   0.20   5.00   0.20   0.33  0.06154  0.0159
  0.20   5.00   7.00   5.00   1.00   7.00   0.33   3.00  0.17343  0.0449
  0.11   0.20   0.33   0.20   0.14   1.00   0.11   0.11  0.01610  0.0042
  3.00   5.00   5.00   5.00   3.00   9.00   1.00   3.00  0.30151  0.0780
  1.00   5.00   3.00   3.00   0.33   9.00   0.33   1.00  0.12847  0.0332
lamda(max):  9.2068   C.I.:  0.17241   C.R.:  0.12227
[ 1, 5] should be: 1.38 actual: [ 1, 5] = 1.0 with C.R.= 0.08453

       Requirements,  Factor # 1  Level # 3

   1      2      3      4      5      6      7      8     Weight   Comp-Wt
  1.00   7.00   3.00   5.00   1.00   9.00   0.33   1.00  0.17577  0.0455
  0.14   1.00   3.00   0.33   0.20   5.00   0.20   0.20  0.04766  0.0123
  0.33   0.33   1.00   0.33   0.14   3.00   0.20   0.33  0.03642  0.0094
  0.20   3.00   3.00   1.00   0.20   5.00   0.20   0.33  0.06665  0.0172
  1.00   5.00   7.00   5.00   1.00   7.00   0.33   3.00  0.20798  0.0538
  0.11   0.20   0.33   0.20   0.14   1.00   0.11   0.11  0.01711  0.0044
  3.00   5.00   5.00   5.00   3.00   9.00   1.00   3.00  0.31420  0.0813
  1.00   5.00   3.00   3.00   0.33   9.00   0.33   1.00  0.13420  0.0347
lamda(max):  9.8343   C.I.:  0.11919   C.R.:  0.08453

       Performance,  Factor # 2  Level # 3

   1      2      3     Weight  Comp-Wt
  1.00   5.00   3.00  0.65864  0.1704
  0.20   1.00   1.00  0.15618  0.0404
  0.33   1.00   1.00  0.18517  0.0479
lamda(max):  3.0291   C.I.:  0.01453   C.R.:  0.02505
```

APPENDIX D: Sample Computer Input-Output

```
                 Risks,  Factor # 4  Level # 3

  1      2      3     Weight  Comp-Wt
 1.00   0.20   0.14  0.07193  0.0095
 5.00   1.00   0.33  0.27895  0.0370
 7.00   3.00   1.00  0.64912  0.0860
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594

            Logistics,  Factor # 5  Level # 3

  1      2      3     Weight  Comp-Wt
 1.00   5.00   0.33  0.27895  0.0134
 0.20   1.00   0.14  0.07193  0.0034
 3.00   7.00   1.00  0.64912  0.0311
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594

         Survivability,  Factor # 6  Level # 3

  1      2      3      4      5      6      7     Weight   Comp-Wt
 1.00   7.00   3.00   7.00   0.33   5.00   0.20  0.17865  0.0050
 0.14   1.00   0.33   3.00   0.20   1.00   0.20  0.04804  0.0013
 0.33   3.00   1.00   3.00   1.00   3.00   0.20  0.10180  0.0029
 0.14   0.33   0.33   1.00   0.20   3.00   0.14  0.03947  0.0011
 3.00   5.00   1.00   5.00   1.00   5.00   0.33  0.19958  0.0056
 0.20   1.00   0.33   0.33   0.20   1.00   0.14  0.03310  0.0009
 5.00   5.00   5.00   7.00   3.00   7.00   1.00  0.39935  0.0112
lamda(max):  7.8842   C.I.:  0.14736   C.R.:  0.11164
[ 5, 1] should be: 1.12 actual: [ 5, 1] = 1.0 with C.R.= 0.08807

         Survivability,  Factor # 6  Level # 3

  1      2      3      4      5      6      7     Weight   Comp-Wt
 1.00   7.00   3.00   7.00   1.00   5.00   0.20  0.20167  0.0057
 0.14   1.00   0.33   3.00   0.20   1.00   0.20  0.04976  0.0014
 0.33   3.00   1.00   3.00   1.00   3.00   0.20  0.10187  0.0029
 0.14   0.33   0.33   1.00   0.20   3.00   0.14  0.04068  0.0011
 1.00   5.00   1.00   5.00   1.00   5.00   0.33  0.15885  0.0045
 0.20   1.00   0.33   0.33   0.20   1.00   0.14  0.03410  0.0010
 5.00   5.00   5.00   7.00   3.00   7.00   1.00  0.41307  0.0116
lamda(max):  7.6975   C.I.:  0.11626   C.R.:  0.08807
```

APPENDIX D: Sample Computer Input-Output

```
        Propellants .  Factor #17  Level # 4

   1      2      3     Weight
  1.00   1.00   0.33  0.20000
  1.00   1.00   0.33  0.20000
  3.00   3.00   1.00  0.60000
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000

      Maintainability,  Factor #19  Level # 4

   1      2      3      4     Weight
  1.00   0.33   0.20   1.00  0.10685
  3.00   1.00   0.33   1.00  0.20979
  5.00   3.00   1.00   3.00  0.52550
  1.00   1.00   0.33   1.00  0.15786
lamda(max):  4.1155   C.I.:  0.03849   C.R.:  0.04276

      Maneuverability,  Factor # 1  Level # 5

   1      2      3     Weight
  1.00   5.00   7.00  0.71471
  0.20   1.00   5.00  0.21849
  0.14   0.20   1.00  0.06680
lamda(max):  3.1828   C.I.:  0.09138   C.R.:  0.15756
[ 3, 1] should be: 0.09 actual: [ 1, 3] = 9.0 with C.R.= 0.10095
[ 3, 1] should be: 0.08 actual: [ 1, 2] = 4.0 with C.R.= 0.06144

      Maneuverability,  Factor # 1  Level # 5

   1      2      3     Weight
  1.00   4.00   9.00  0.70852
  0.25   1.00   5.00  0.23115
  0.11   0.20   1.00  0.06033
lamda(max):  3.0713   C.I.:  0.03563   C.R.:  0.06144

The Consistency of this hierarchy =  0.0660
```

APPENDIX E: Statistical Tests

Significance of tau, concordance (W), and zeta

Ho:Measure is not significant. If P ≥ a, accept Ho, else reject

APPENDIX E:1

Probabilities Associated with Values as Large as Observed Values of S in the the Kendall Rank Correlation Coefficient

S	Values of N			S	Values of N	
	4	5	8		6	7
	(6)*	(10)*	(28)*		(15)*	(21)*
0	.625	.592	.548	1	.500	.500
2	.375	.408	.452	3	.360	.386
4	.167	.242	.360	5	.235	.281
6	.042	.117	.138	7	.136	.191
8		.042	.199	9	.068	.119
10		.008	.138	11	.028	.068
12			.089	13	.008	.035
14			.054	15	.001	.015
16			.031	17		.054
18			.016	19		.005
20			.007	21		.001

*(a) - conversion factor: S = (a)(tau)

(Siegel, 1956:285)

APPENDIX E:2

Critical Values of S in the Kendall Coefficient of Concordance

	Objectives(k)				
N	3	4	5	6	7
			(.05 significance)		
3			64.4	103.9	157.3
4		49.5	88.4	143.3	217.0
5		62.6	112.3	182.4	276.2
6		75.7	136.1	221.4	335.2
8	48.1	101.7	183.7	299.0	453.1
			(.01 significance)		
3			75.6	122.8	185.6
4		61.4	109.3	176.2	265.0
5		80.5	142.8	229.4	343.8
6		99.5	176.1	282.4	422.6
8	66.8	137.4	242.7	388.3	579.9

(Siegel, 1956:286)

APPENDIX E:3

Significance of Zeta, for N = 3 through 9

N = 3

Zeta	P
0	1.0
1.0	0

N = 4

Zeta	P
0	.625
.50	.375
1.0	0

N = 5

Zeta	P
0	1.0
.20	.703
.40	.469
.60	.234
.80	.117
1.0	0

N = 6

Zeta	P
0	1.0
.125	.773
.250	.509
.375	.398
.500	.208
.625	.120
.750	.051
.875	.022
1.0	0

N = 7

Zeta	P
0	1.0
.072	.964
.143	.853
.214	.737
.286	.553
.357	.420
.429	.287
.500	.198
.572	.112
.643	.069
.715	.033
.787	.017
.858	.006
.929	.002

N = 8

Zeta	P
0	1.0
.050	.949
.100	.859
.150	.768
.200	.629
.250	.520
.300	.390
.350	.299
.400	.208
.450	.153
.500	.094
.550	.063
.600	.037
.650	.023
.700	.011
.750	.006
.800	.003

(Dobbins, 1980b:32)

APPENDIX F: AHP Summary of Priorities

AHP Summary for 13 Decision Makers
Judge #13 = Geometric Mean Input for the First 9 Judges
Mean = Arithmetic Mean of Individual Priority Vectors

TAV Effectiveness

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.313	0.159	0.259	0.600	0.166	0.181	0.611	0.241	0.040	0.345	0.395	0.211	0.278
2	0.141	0.203	0.259	0.127	0.234	0.278	0.149	0.269	0.323	0.100	0.326	0.386	0.263
3	0.167	0.142	0.274	0.040	0.268	0.044	0.026	0.212	0.074	0.084	0.022	0.188	0.123
4	0.051	0.069	0.133	0.104	0.101	0.073	0.083	0.033	0.270	0.066	0.074	0.051	0.102
5	0.244	0.151	0.048	0.047	0.114	0.031	0.037	0.184	0.190	0.166	0.132	0.125	0.109
6	0.083	0.275	0.028	0.083	0.117	0.393	0.094	0.061	0.103	0.239	0.051	0.039	0.125
CI	0.069	0.062	0.056	0.198	0.082	0.310	0.147	0.095	0.121	0.141	0.319	0.248	0.011
CR	0.056	0.050	0.045	0.160	0.066	0.250	0.119	0.077	0.097	0.114	0.258	0.200	0.009

Mean	Dev % 10
0.293	1.37
0.233	0.52
0.128	0.77
0.092	0.51
0.123	0.54
0.131	0.97
0.143	
0.115	

Requirements

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.134	0.164	0.239	0.254	0.129	0.237	0.410	0.075	0.246	0.179	0.422	0.136	0.230
2	0.134	0.187	0.044	0.040	0.215	0.075	0.121	0.208	0.132	0.108	0.146	0.018	0.134
3	0.155	0.175	0.035	0.028	0.140	0.036	0.036	0.018	0.019	0.074	0.024	0.069	0.061
4	0.155	0.183	0.062	0.332	0.058	0.044	0.174	0.129	0.150	0.234	0.242	0.063	0.145
5	0.155	0.029	0.173	0.183	0.324	0.115	0.105	0.205	0.076	0.082	0.047	0.295	0.150
6	0.027	0.029	0.016	0.067	0.036	0.014	0.027	0.015	0.030	0.051	0.013	0.086	0.032
7	0.084	0.099	0.302	0.011	0.033	0.390	0.029	0.111	0.063	0.076	0.021	0.185	0.093
8	0.155	0.135	0.128	0.086	0.064	0.089	0.097	0.238	0.284	0.197	0.085	0.148	0.154
CI	0.034	0.036	0.172	0.466	0.090	0.317	0.087	0.157	0.140	0.104	0.441	0.840	0.021
CR	0.024	0.026	0.122	0.330	0.064	0.225	0.062	0.111	0.099	0.074	0.313	0.596	0.015

Mean	Dev % 10
0.219	0.78
0.119	0.50
0.067	0.49
0.152	0.69
0.149	0.75
0.034	0.19
0.117	1.04
0.142	0.48
0.224	
0.159	

APPENDIX F: AHP Summary of Priorities

Performance

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.429	0.429	0.659	0.191	0.443	0.564	0.600	0.685	0.158	0.097	0.753	0.487	0.489
2	0.429	0.143	0.156	0.048	0.169	0.172	0.200	0.234	0.076	0.202	0.184	0.078	0.181
3	0.143	0.429	0.185	0.761	0.387	0.264	0.200	0.080	0.766	0.701	0.063	0.435	0.330
CI	0.000	0.000	0.015	0.164	0.009	0.788	0.000	0.147	0.068	0.068	0.147	0.006	0.002
CR	0.000	0.000	0.025	0.282	0.016	1.359	0.000	0.254	0.117	0.117	0.254	0.011	0.004

Mean	Dev * 10
0.458	1.51
0.174	0.76
0.368	2.14
0.109	
0.188	

Risks

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.091	0.088	0.072	0.722	0.550	0.778	0.333	0.132	0.308	0.200	0.067	0.078	0.301
2	0.455	0.669	0.279	0.227	0.210	0.111	0.333	0.694	0.308	0.400	0.218	0.435	0.401
3	0.455	0.243	0.649	0.051	0.240	0.111	0.333	0.174	0.385	0.400	0.715	0.487	0.298
CI	0.000	0.004	0.032	0.104	0.009	0.000	0.000	0.040	0.000	0.000	0.091	0.006	0.000
CR	0.000	0.006	0.056	0.180	0.016	0.000	0.000	0.069	0.000	0.000	0.158	0.011	0.000

Mean	Dev * 10
0.285	2.27
0.362	1.32
0.354	1.60
0.022	
0.038	

Logistics

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.143	0.258	0.279	0.048	0.163	0.203	0.455	0.134	0.600	0.130	0.633	0.055	0.231
2	0.429	0.105	0.072	0.191	0.297	0.055	0.091	0.119	0.200	0.062	0.063	0.203	0.160
3	0.429	0.637	0.649	0.761	0.540	0.742	0.455	0.747	0.200	0.808	0.304	0.742	0.609
CI	0.000	0.019	0.032	0.164	0.005	0.218	0.000	0.006	0.000	0.068	0.068	0.218	0.001
CR	0.000	0.033	0.056	0.282	0.008	0.376	0.000	0.011	0.000	0.117	0.117	0.376	0.001

Mean	Dev * 10
0.258	1.69
0.157	0.95
0.584	0.84
0.061	
0.106	

Survivability

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.060	0.035	0.179	0.020	0.053	0.025	0.063	0.039	0.048	0.053	0.016	0.295	0.060
2	0.144	0.078	0.048	0.019	0.295	0.095	0.128	0.364	0.093	0.041	0.449	0.261	0.126
3	0.164	0.066	0.102	0.250	0.039	0.074	0.569	0.022	0.194	0.406	0.073	0.065	0.139
4	0.144	0.092	0.039	0.055	0.107	0.046	0.045	0.238	0.194	0.191	0.149	0.093	0.108
5	0.049	0.056	0.200	0.084	0.094	0.138	0.054	0.073	0.038	0.105	0.035	0.042	0.092
6	0.219	0.214	0.033	0.280	0.051	0.294	0.063	0.060	0.252	0.121	0.036	0.043	0.159
7	0.219	0.460	0.399	0.293	0.360	0.328	0.077	0.204	0.181	0.083	0.242	0.200	0.316
CI	0.072	0.109	0.147	0.208	0.129	0.215	0.137	0.139	0.086	0.221	0.333	0.236	0.007
CR	0.054	0.082	0.112	0.158	0.098	0.163	0.104	0.106	0.065	0.168	0.252	0.179	0.006

APPENDIX F: AHP Summary of Priorities

Mean	Dev * 10
0.074	0.72
0.168	1.20
0.169	1.46
0.116	0.52
0.081	0.39
0.139	0.88
0.254	0.83
0.157	
0.119	

Propellants

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.143	0.287	0.200	0.070	0.297	0.766	0.091	0.591	0.111	0.649	0.761	0.735	0.261
2	0.429	0.078	0.200	0.672	0.163	0.076	0.455	0.261	0.111	0.072	0.048	0.058	0.259
3	0.429	0.635	0.600	0.257	0.540	0.158	0.455	0.148	0.778	0.279	0.191	0.207	0.480
CI	0.000	0.047	0.000	0.218	0.005	0.068	0.000	1.115	0.000	0.032	0.164	0.059	0.026
CR	0.000	0.081	0.000	0.376	0.008	0.117	0.000	1.923	0.000	0.056	0.282	0.101	0.046

Mean	Dev * 10
0.392	2.38
0.219	1.73
0.390	1.63
0.133	
0.230	

Maintainability

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.094	0.091	0.107	0.059	0.136	0.075	0.063	0.047	0.045	0.645	0.034	0.119	0.083
2	0.176	0.117	0.210	0.342	0.340	0.234	0.313	0.536	0.511	0.192	0.204	0.047	0.312
3	0.483	0.396	0.526	0.121	0.287	0.613	0.313	0.298	0.292	0.044	0.683	0.298	0.369
4	0.247	0.396	0.158	0.478	0.237	0.078	0.313	0.119	0.153	0.119	0.080	0.536	0.236
CI	0.072	0.011	0.038	0.260	0.062	0.398	0.000	0.130	0.076	0.162	0.195	0.130	0.003
CR	0.080	0.012	0.043	0.288	0.069	0.442	0.000	0.144	0.084	0.180	0.217	0.144	0.004

Mean	Dev * 10
0.126	1.49
0.269	1.13
0.363	1.41
0.243	1.27
0.118	
0.131	

Maneuverability

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.101	0.109	0.715	0.761	0.167	0.778	0.455	0.701	0.188	0.114	0.742	0.649	0.435
2	0.674	0.163	0.218	0.191	0.667	0.111	0.455	0.240	0.731	0.481	0.203	0.072	0.410
3	0.226	0.729	0.067	0.048	0.167	0.111	0.091	0.059	0.081	0.405	0.055	0.279	0.155
CI	0.043	0.043	0.091	0.164	0.000	0.000	0.000	0.147	0.032	0.015	0.218	0.032	0.010
CR	0.074	0.074	0.158	0.282	0.000	0.000	0.000	0.254	0.056	0.025	0.376	0.056	0.017

Mean	Dev * 10
0.457	2.41
0.350	1.96
0.193	1.77
0.061	
0.106	

APPENDIX G: Voting Summary of Priorities

```
              Voting Summary for 13 Decision Makers
            Judge #13 = Converted AHP Geometric Mean Input
TAV Effectiveness
Crit  1    2    3    4    5    6    7    8    9    10   11   12   13  TotWt Dev#10
  1  4.5  2.5  4.0  5.0  2.5  3.0  5.0  3.5  0.0  5.0  5.0  3.5  5.0 0.249 0.948
  2  2.5  3.5  4.0  3.5  4.5  4.5  3.5  4.0  4.5  1.5  4.0  4.5  4.0 0.249 0.564
  3  3.0  2.0  4.0  0.5  4.5  1.0  0.0  3.5  1.0  1.0  0.0  3.5  1.0 0.128 1.011
  4  0.0  0.5  2.0  3.0  1.0  1.5  2.5  0.0  4.0  0.5  2.0  1.0  0.0 0.092 0.808
  5  4.0  2.5  1.0  1.0  1.0  0.5  1.0  3.0  3.5  3.0  3.0  2.5  3.0 0.149 0.747
  6  1.0  4.0  0.0  2.0  1.5  4.5  3.0  1.0  2.0  4.0  1.0  0.0  2.0 0.133 0.952
Z(u) 0.84 0.37 0.88 0.78 0.75 0.88 0.91 0.72 0.91 0.91 1.00 0.81 1.00 0.827
Z(c) 0.88 0.44 0.88 0.81 0.81 0.94 0.94 0.75 0.94 0.94 1.00 0.88 1.00 0.861
                      -----------------

Requirements
Crit  1    2    3    4    5    6    7    8    9    10   11   12   13  TotWt Dev#10
  1  4.0  4.5  5.5  6.0  4.5  5.5  7.0  2.5  6.0  5.5  7.0  4.0  7.0 0.190 0.467
  2  4.0  5.0  2.0  2.0  6.0  3.5  4.5  5.5  4.5  3.5  5.0  0.5  3.0 0.135 0.541
  3  4.5  5.0  1.0  2.0  4.0  1.5  1.5  0.5  0.0  2.0  1.5  1.5  1.0 0.071 0.529
  4  4.5  5.0  3.0  6.5  3.0  2.0  5.0  4.0  5.0  6.0  6.0  3.0  6.0 0.162 0.493
  5  4.5  0.5  5.0  5.0  7.0  4.0  4.0  6.0  3.0  2.5  3.0  7.0  5.0 0.155 0.628
  6  0.0  0.5  0.0  3.0  1.0  0.0  1.0  0.5  1.0  1.0  0.5  3.0  0.0 0.032 0.351
  7  2.0  3.0  7.0  0.0  0.0  7.0  1.0  3.0  2.0  2.0  1.0  5.0  2.0 0.096 0.797
  8  4.5  4.5  4.5  3.5  2.5  4.5  4.0  6.0  6.5  5.5  4.0  4.0  4.0 0.159 0.360
Z(u) 0.43 0.63 0.96 0.81 0.94 0.85 0.76 0.85 0.94 0.60 0.96 0.66 1.00 0.799
Z(c) 0.45 0.65 0.98 0.83 0.95 0.88 0.78 0.88 0.95 0.63 0.98 0.68 1.00 0.815
                      -----------------

Performance
Crit  1    2    3    4    5    6    7    8    9    10   11   12   13  TotWt Dev#10
  1  1.5  1.5  2.0  1.0  1.5  1.5  2.0  2.0  1.0  0.0  2.0  1.5  2.0 0.500 1.849
  2  1.5  0.0  0.5  0.0  0.0  0.5  0.5  1.0  0.0  1.0  1.0  0.0  0.0 0.154 1.662
  3  0.0  1.5  0.5  2.0  1.5  1.0  0.5  0.0  2.0  2.0  0.0  1.5  1.0 0.346 2.486
Z(u) 0.75 0.75 0.75 1.00 0.75 0.25 0.75 1.00 1.00 1.00 1.00 0.75 1.00 0.827
Z(c) 1.00 1.00 1.00 1.00 1.00 0.50 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.962
                      -----------------

Risks
Crit  1    2    3    4    5    6    7    8    9    10   11   12   13  TotWt Dev#10
  1  0.0  0.0  0.0  2.0  2.0  2.0  1.0  0.5  0.5  0.0  0.0  0.0  0.0 0.205 2.708
  2  1.5  2.0  1.0  1.0  0.5  0.5  1.0  2.0  0.5  1.5  1.0  1.5  2.0 0.410 1.804
  3  1.5  1.0  2.0  0.0  0.5  0.5  1.0  0.5  2.0  1.5  2.0  1.5  1.0 0.385 2.107
Z(u) 0.75 1.00 1.00 1.00 0.75 0.75 0.00 0.75 0.75 0.75 1.00 0.75 1.00 0.788
Z(c) 1.00 1.00 1.00 1.00 1.00 1.00 0.00 1.00 1.00 1.00 1.00 1.00 1.00 0.923
                      -----------------

Logistics
Crit  1    2    3    4    5    6    7    8    9    10   11   12   13  TotWt Dev#10
  1  0.0  1.0  1.0  0.0  0.0  1.0  1.5  0.5  2.0  1.0  2.0  0.0  1.0 0.282 2.301
  2  1.5  0.0  0.0  1.0  1.0  0.0  0.0  0.5  0.5  0.0  0.0  1.0  0.0 0.141 1.710
  3  1.5  2.0  2.0  2.0  2.0  2.0  1.5  2.0  0.5  2.0  1.0  2.0  2.0 0.577 1.549
Z(u) 0.75 1.00 1.00 1.00 1.00 1.00 0.75 0.75 0.75 1.00 1.00 1.00 1.00 0.923
Z(c) 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.000
                      -----------------
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APPENDIX G: Voting Summary of Priorities

Survivability

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13	TotWt	Dev*10
1	1.0	0.5	4.0	0.5	2.0	0.5	2.5	1.5	1.0	1.0	0.0	5.5	0.0	0.073	0.744
2	3.5	3.0	1.5	0.5	5.0	3.0	3.5	5.5	2.0	0.5	6.0	5.0	3.0	0.154	0.823
3	4.0	2.5	3.5	5.0	0.0	2.5	6.0	0.0	4.5	6.0	3.0	2.5	5.0	0.163	0.895
4	3.5	2.5	1.0	2.0	4.0	1.5	1.5	5.0	4.5	4.5	4.0	3.0	3.0	0.147	0.597
5	0.0	1.5	4.5	3.0	3.0	3.5	2.0	2.5	0.0	3.5	1.5	0.5	1.0	0.097	0.657
6	4.5	5.0	0.5	5.0	1.5	5.0	2.5	2.0	5.0	3.5	1.5	0.5	3.0	0.145	0.800
7	4.5	6.0	6.0	5.0	5.5	5.0	3.0	4.5	4.0	2.0	5.0	4.0	6.0	0.222	0.548
Z(u)	0.68	0.79	0.89	0.91	0.84	0.61	0.46	0.89	0.84	0.82	0.98	0.86	0.93	0.808	
Z(c)	0.71	0.82	0.93	0.93	0.86	0.64	0.50	0.93	0.86	0.86	1.00	0.89	0.93	0.835	

Propellants

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13	TotWt	Dev*10
1	0.0	1.0	0.5	0.0	1.0	2.0	0.0	1.5	0.5	2.0	2.0	2.0	1.0	0.346	2.571
2	1.5	0.0	0.5	2.0	0.0	0.0	1.5	1.0	0.5	0.0	0.0	0.0	0.0	0.179	2.308
3	1.5	2.0	2.0	1.0	2.0	1.0	1.5	0.5	2.0	1.0	1.0	1.0	2.0	0.474	1.710
Z(u)	0.75	1.00	0.75	1.00	1.00	1.00	0.75	0.25	0.75	1.00	1.00	1.00	1.00	0.865	
Z(c)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	0.962	

Maintainability

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13	TotWt	Dev*10
1	0.0	0.5	0.5	0.0	0.0	0.5	0.0	0.0	0.0	3.0	0.0	1.0	0.0	0.071	1.342
2	1.0	0.5	1.5	2.0	2.5	2.0	2.0	3.0	3.0	2.0	2.0	0.0	2.0	0.301	1.407
3	3.0	2.5	3.0	1.0	2.0	3.0	2.0	2.0	2.0	0.0	3.0	2.0	3.0	0.365	1.445
4	2.0	2.5	1.0	3.0	1.5	0.5	2.0	1.0	1.0	1.0	1.0	3.0	1.0	0.263	1.342
Z(u)	1.00	0.75	0.63	1.00	0.63	0.88	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.875	
Z(c)	1.00	1.00	0.75	1.00	0.75	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.923	

Maneuverability

Crit	1	2	3	4	5	6	7	8	9	10	11	12	13	TotWt	Dev*10
1	0.0	0.0	2.0	2.0	0.5	2.0	1.5	2.0	1.0	0.0	2.0	2.0	2.0	0.436	2.815
2	2.0	1.0	1.0	1.0	2.0	0.5	1.5	1.0	2.0	1.5	1.0	0.0	1.0	0.397	1.910
3	1.0	2.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	1.5	0.0	1.0	0.0	0.167	2.168
Z(u)	1.00	1.00	1.00	1.00	0.75	0.75	0.75	1.00	1.00	0.75	1.00	1.00	1.00	0.923	
Z(c)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.000	

APPENDIX H: Anova Results

```
 * * * * * * * *  A N A L Y S I S   O F   V A R I A N C E  * * * * * * * * *
                  CONSIST
               BY JUDGE
                  SIZE
                  CINDEX
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

                                     SUM OF             MEAN             SIGNIF
SOURCE OF VARIATION                 SQUARES    DF      SQUARE       F     OF F

MAIN EFFECTS                           .935    16        .058   1.839     .037
   JUDGE                               .506    11        .046   1.448     .165
   SIZE                                .340     4        .085   2.677     .036
   CINDEX                              .089     1        .089   2.790     .098

2-WAY INTERACTIONS                    2.112    59        .036   1.127     .299
   JUDGE     SIZE                      .906    44        .021    .648     .945
   JUDGE     CINDEX                   1.159    11        .105   3.318     .001
   SIZE      CINDEX                    .046     4        .012    .362     .835

3-WAY INTERACTIONS                     .824    44        .019    .589     .974
   JUDGE     SIZE      CINDEX          .824    44        .019    .589     .974

EXPLAINED                             3.870   119        .033   1.024     .455

RESIDUAL                              3.050    96        .032

TOTAL                                 6.920   215        .032
```

Where: Consist : Zeta and CI Measures of Consistency
Cindex : CI = 1, Zeta = 2
Size : Matrix Dimension (3,4,6,7,8)
Judge : Judge Identifier (1-12)

THE FOLLOWING PAGE 5

APPENDIX I: Initial Survey Data

```
       Survivability
  1       2       3       4       5       6       7     Priority
 1.000   0.143   0.143   1.000   0.143   0.143   0.143   0.02112
 7.000   1.000   1.000   5.000   5.000   0.143   0.143   0.12698
 7.000   1.000   1.000   1.000   5.000   0.143   0.143   0.10922
 1.000   0.200   1.000   1.000   1.000   0.143   0.143   0.04127
 7.000   0.200   0.200   1.000   1.000   1.000   1.000   0.10087
 7.000   7.000   7.000   7.000   1.000   1.000   1.000   0.30027
 7.000   7.000   7.000   7.000   1.000   1.000   1.000   0.30027
lamda(max):  9.2968   C.I.:  0.38280   C.R.:  0.29000


        Propellants
  1       2       3     Priority
 1.000   7.000   7.000   0.76623
 0.143   1.000   0.333   0.07590
 0.143   3.000   1.000   0.15787
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691


      Maintainability
  1       2       3       4     Priority
 1.000   0.143   0.333   1.000   0.08215
 7.000   1.000   0.200   5.000   0.29780
 3.000   5.000   1.000   3.000   0.53430
 1.000   0.200   0.333   1.000   0.08575
lamda(max):  4.7296   C.I.:  0.24319   C.R.:  0.27022


      Maneuverability
  1       2       3     Priority
 1.000   7.000   7.000   0.77778
 0.143   1.000   1.000   0.11111
 0.143   1.000   1.000   0.11111
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000

The Consistency of this hierarchy =  0.4338
```

APPENDIX I: Initial Survey Data

```
  Judge #  6 AHP RESULTS (ORIGINAL SURVEY)
  TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  0.333  7.000  7.000  7.000  0.143  0.18195
 3.000  1.000  7.000  5.000  7.000  1.000  0.27484
 0.143  0.143  1.000  7.000  0.333  0.143  0.06890
 0.143  0.200  0.143  1.000  5.000  0.143  0.05204
 0.143  0.143  3.000  0.200  1.000  0.143  0.04643
 7.000  1.000  7.000  7.000  7.000  1.000  0.37583
lamda(max):  8.2378   C.I.:  0.44755   C.R.:  0.36093


       Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  7.000  7.000  7.000  7.000  9.000  0.200  1.000  0.23927
 0.143  1.000  5.000  5.000  0.200  7.000  0.143  1.000  0.08153
 0.143  0.200  1.000  0.200  1.000  5.000  0.143  0.333  0.03759
 0.143  0.200  5.000  1.000  0.200  5.000  0.143  0.333  0.04766
 0.143  5.000  1.000  5.000  1.000  5.000  0.200  1.000  0.10452
 0.111  0.143  0.200  0.200  0.200  1.000  0.111  1.000  0.02127
 5.000  7.000  7.000  7.000  5.000  9.000  1.000  7.000  0.38756
 1.000  1.000  3.000  3.000  1.000  1.000  0.143  1.000  0.08062
lamda(max):  10.3973   C.I.:  0.34247   C.R.:  0.24289


        Performance
   1      2      3     Priority
 1.000  1.000  7.000  0.56401
 1.000  1.000  0.200  0.17243
 0.143  5.000  1.000  0.26356
lamda(max):  4.5768   C.I.:  0.78839   C.R.:  1.35929


               Risks
   1      2      3     Priority
 1.000  7.000  7.000  0.77778
 0.143  1.000  1.000  0.11111
 0.143  1.000  1.000  0.11111
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


            Logistics
   1      2      3     Priority
 1.000  7.000  0.143  0.20273
 0.143  1.000  0.143  0.05540
 7.000  7.000  1.000  0.74186
lamda(max):  3.4357   C.I.:  0.21784   C.R.:  0.37559
```

APPENDIX I: Initial Survey Data

```
       Survivability
  1      2      3      4      5      6      7     Priority
1.000  0.125  2.000  0.500  1.000  1.000  0.125  0.05306
8.000  1.000  7.000  6.000  1.000  4.000  1.000  0.29515
0.500  0.143  1.000  0.500  0.500  0.500  0.200  0.03938
2.000  0.167  2.000  1.000  3.000  3.000  0.143  0.10657
1.000  1.000  2.000  0.333  1.000  2.000  0.200  0.09408
1.000  0.250  2.000  0.333  0.500  1.000  0.167  0.05140
8.000  1.000  5.000  7.000  5.000  6.000  1.000  0.36036
lamda(max):  7.7748   C.I.:  0.12913   C.R.:  0.09783


        Propellants
  1      2      3     Priority
1.000  2.000  0.500  0.29696
0.500  1.000  0.333  0.16342
2.000  3.000  1.000  0.53961
lamda(max):  3.0092   C.I.:  0.00460   C.R.:  0.00793


     Maintainability
  1      2      3      4     Priority
1.000  0.500  0.500  0.500  0.13567
2.000  1.000  2.000  1.000  0.33998
2.000  0.500  1.000  2.000  0.28734
2.000  1.000  0.500  1.000  0.23701
lamda(max):  4.1855   C.I.:  0.06184   C.R.:  0.06871


     Maneuverability
  1      2      3     Priority
1.000  0.250  1.000  0.16667
4.000  1.000  4.000  0.66667
1.000  0.250  1.000  0.16667
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000

The Consistency of this hierarchy =  0.0499
```

APPENDIX I: Initial Survey Data

```
  Judge #  5 AHP RESULTS (ORIGINAL SURVEY)
  TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  0.500  0.500  3.000  2.000  1.000  0.16626
 2.000  1.000  1.000  2.000  2.000  2.000  0.23371
 2.000  1.000  1.000  3.000  2.000  3.000  0.26772
 0.333  0.500  0.333  1.000  2.000  0.500  0.10131
 0.500  0.500  0.500  0.500  1.000  2.000  0.11420
 1.000  0.500  0.333  2.000  0.500  1.000  0.11679
lamda(max):  6.4121   C.I.:  0.08243   C.R.:  0.06648


        Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  0.333  2.000  3.000  0.250  5.000  4.000  1.000  0.12937
 3.000  1.000  2.000  5.000  0.333  5.000  4.000  4.000  0.21474
 0.500  0.500  1.000  5.000  0.500  5.000  4.000  2.000  0.14009
 0.333  0.200  0.200  1.000  0.200  2.000  2.000  2.000  0.05843
 4.000  3.000  2.000  5.000  1.000  6.000  6.000  5.000  0.32380
 0.200  0.200  0.200  0.500  0.167  1.000  2.000  0.500  0.03649
 0.250  0.250  0.250  0.500  0.167  0.500  1.000  0.500  0.03332
 1.000  0.250  0.500  0.500  0.200  2.000  2.000  1.000  0.06376
lamda(max):  8.6333   C.I.:  0.09047   C.R.:  0.06416


         Performance
   1      2      3     Priority
 1.000  3.000  1.000  0.44343
 0.333  1.000  0.500  0.16920
 1.000  2.000  1.000  0.38737
lamda(max):  3.0183   C.I.:  0.00915   C.R.:  0.01577


               Risks
   1      2      3     Priority
 1.000  3.000  2.000  0.54995
 0.333  1.000  1.000  0.20984
 0.500  1.000  1.000  0.24021
lamda(max):  3.0183   C.I.:  0.00915   C.R.:  0.01577


           Logistics
   1      2      3     Priority
 1.000  0.500  0.333  0.16342
 2.000  1.000  0.500  0.29696
 3.000  2.000  1.000  0.53961
lamda(max):  3.0092   C.I.:  0.00460   C.R.:  0.00793
```

APPENDIX I: Initial Survey Data

```
        Survivability
  1      2      3      4      5      6      7     Priority
1.000  1.000  0.143  0.143  0.200  0.111  0.111  0.01979
1.000  1.000  0.143  0.143  0.143  0.111  0.111  0.01944
7.000  7.000  1.000  7.000  7.000  1.000  1.000  0.25279
7.000  7.000  0.143  1.000  5.000  0.143  0.111  0.08805
5.000  7.000  0.143  0.200  1.000  0.111  0.111  0.04928
9.000  9.000  1.000  7.000  9.000  1.000  1.000  0.27452
9.000  9.000  1.000  9.000  9.000  1.000  1.000  0.29614
lamda(max):  8.1462   C.I.:  0.19103   C.R.:  0.14472


         Propellants
  1      2      3     Priority
1.000  0.200  0.143  0.07030
5.000  1.000  5.000  0.67243
7.000  0.200  1.000  0.25726
lamda(max):  3.4357   C.I.:  0.21784   C.R.:  0.37559


       Maintainability
  1      2      3      4     Priority
1.000  0.111  0.200  0.333  0.05934
9.000  1.000  0.333  0.333  0.19568
5.000  3.000  1.000  0.200  0.24600
3.000  3.000  5.000  1.000  0.49898
lamda(max):  4.9983   C.I.:  0.33276   C.R.:  0.36974


       Maneuverability
  1      2      3     Priority
1.000  7.000  9.000  0.76076
0.143  1.000  7.000  0.19119
0.111  0.143  1.000  0.04805
lamda(max):  3.3276   C.I.:  0.16382   C.R.:  0.28245

The Consistency of this hierarchy =  0.3049
```

APPENDIX I: Initial Survey Data

```
    Judge #  4 AHP RESULTS (ORIGINAL SURVEY)
    TAV Effectiveness
     1       2       3       4       5       6      Priority
  1.000   9.000   9.000   9.000   9.000   9.000   0.60031
  0.111   1.000   5.000   1.000   3.000   3.000   0.12656
  0.111   0.200   1.000   1.000   0.333   0.333   0.03987
  0.111   1.000   1.000   1.000   3.000   3.000   0.10375
  0.111   0.333   3.000   0.333   1.000   5.000   0.08285
  0.111   0.333   3.000   0.333   0.200   1.000   0.04667
lamda(max):   6.9923    C.I.:   0.19846    C.R.:   0.16004


          Requirements
     1       2       3       4       5       6       7       8      Priority
  1.000   9.000   9.000   1.000   1.000   9.000   9.000   9.000   0.25351
  0.111   1.000   1.000   0.200   1.000   0.143   7.000   0.200   0.03998
  0.111   1.000   1.000   0.143   0.143   0.143   5.000   1.000   0.02849
  1.000   5.000   7.000   1.000   7.000   9.000   9.000   9.000   0.33175
  1.000   1.000   7.000   0.143   1.000   7.000   9.000   9.000   0.18296
  0.111   7.000   7.000   0.111   0.143   1.000   9.000   0.143   0.06652
  0.111   0.143   0.200   0.111   0.111   0.111   1.000   0.111   0.01108
  0.111   5.000   1.000   0.111   0.111   7.000   9.000   1.000   0.08570
lamda(max):   11.2589    C.I.:   0.46555    C.R.:   0.33018


           Performance
     1       2       3      Priority
  1.000   7.000   0.143   0.19119
  0.143   1.000   0.111   0.04805
  7.000   9.000   1.000   0.76076
lamda(max):   3.3276    C.I.:   0.16382    C.R.:   0.28245


                 Risks
     1       2       3      Priority
  1.000   5.000   9.000   0.72193
  0.200   1.000   7.000   0.22706
  0.111   0.143   1.000   0.05101
lamda(max):   3.2085    C.I.:   0.10423    C.R.:   0.17971


             Logistics
     1       2       3      Priority
  1.000   0.143   0.111   0.04805
  7.000   1.000   0.143   0.19119
  9.000   7.000   1.000   0.76076
lamda(max):   3.3276    C.I.:   0.16382    C.R.:   0.28245
```

APPENDIX I: Initial Survey Data

```
        Survivability
  1      2      3      4      5      6      7     Priority
 1.000  7.000  3.000  7.000  0.333  5.000  0.200  0.19766
 0.143  1.000  0.333  3.000  0.200  1.000  0.200  0.05889
 0.333  3.000  1.000  3.000  1.000  3.000  0.200  0.09939
 0.143  0.333  0.333  1.000  5.000  3.000  0.143  0.10797
 3.000  5.000  1.000  0.200  1.000  5.000  0.333  0.14531
 0.200  1.000  0.333  0.333  0.200  1.000  0.143  0.02839
 5.000  5.000  5.000  7.000  3.000  7.000  1.000  0.36239
lamda(max):  9.7479   C.I.:  0.45799   C.R.:  0.34696


         Propellants
  1      2      3     Priority
 1.000  1.000  0.333  0.20000
 1.000  1.000  0.333  0.20000
 3.000  3.000  1.000  0.60000
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


      Maintainability
  1      2      3      4     Priority
 1.000  3.000  5.000  1.000  0.42458
 0.333  1.000  3.000  1.000  0.21320
 0.200  0.333  1.000  0.333  0.08024
 1.000  1.000  3.000  1.000  0.28198
lamda(max):  4.1155   C.I.:  0.03849   C.R.:  0.04276


      Maneuverability
  1      2      3     Priority
 1.000  5.000  7.000  0.71471
 0.200  1.000  5.000  0.21849
 0.143  0.200  1.000  0.06680
lamda(max):  3.1828   C.I.:  0.09138   C.R.:  0.15756

The Consistency of this hierarchy =  0.3026
```

APPENDIX I: Initial Survey Data

```
Judge #  3 AHP RESULTS (ORIGINAL SURVEY)
TAV Effectiveness
  1      2      3      4      5      6     Priority
 1.000  1.000  1.000  3.000  5.000  7.000  0.25874
 1.000  1.000  1.000  3.000  5.000  7.000  0.25874
 1.000  1.000  1.000  3.000  7.000  7.000  0.27401
 0.333  0.333  0.333  1.000  5.000  7.000  0.13252
 0.200  0.200  0.143  0.200  1.000  3.000  0.04795
 0.143  0.143  0.143  0.143  0.333  1.000  0.02803
lamda(max):  6.2805   C.I.:  0.05609   C.R.:  0.04524


       Requirements
  1      2      3      4      5      6      7      8     Priority
 1.000  7.000  3.000  5.000  5.000  9.000  0.333  1.000  0.21555
 0.143  1.000  3.000  0.333  0.200  5.000  0.200  0.200  0.06215
 0.333  0.333  1.000  0.333  0.143  5.000  0.200  0.200  0.05313
 0.200  3.000  3.000  1.000  0.200  5.000  0.200  0.333  0.07881
 0.200  5.000  7.000  5.000  1.000  0.143  0.333  0.333  0.10977
 0.111  0.200  0.200  0.200  7.000  1.000  0.143  0.333  0.07951
 3.000  5.000  5.000  5.000  3.000  7.000  1.000  3.000  0.25519
 1.000  5.000  5.000  3.000  3.000  3.000  0.333  1.000  0.14590
lamda(max):  12.5234   C.I.:  0.64621   C.R.:  0.45830


        Performance
  1      2      3     Priority
 1.000  5.000  3.000  0.65864
 0.200  1.000  1.000  0.15618
 0.333  1.000  1.000  0.18517
lamda(max):  3.0291   C.I.:  0.01453   C.R.:  0.02505


               Risks
  1      2      3     Priority
 1.000  0.200  0.143  0.06680
 5.000  1.000  0.200  0.21849
 7.000  5.000  1.000  0.71471
lamda(max):  3.1828   C.I.:  0.09138   C.R.:  0.15756


           Logistics
  1      2      3     Priority
 1.000  0.200  0.200  0.07589
 5.000  1.000  0.143  0.19834
 5.000  7.000  1.000  0.72578
lamda(max):  3.4357   C.I.:  0.21784   C.R.:  0.37559
```

APPENDIX I: Initial Survey Data

```
        Survivability
  1       2       3       4       5       6       7     Priority
 1.000   0.333   0.333   0.200   1.000   0.200   0.143   0.03468
 3.000   1.000   1.000   2.000   1.000   0.200   0.143   0.07781
 3.000   1.000   1.000   1.000   1.000   0.200   0.143   0.06584
 5.000   0.500   1.000   1.000   3.000   0.333   0.200   0.09161
 1.000   1.000   1.000   0.333   1.000   0.333   0.200   0.05596
 5.000   5.000   5.000   3.000   3.000   1.000   0.200   0.21440
 7.000   7.000   7.000   5.000   5.000   5.000   1.000   0.45970
lamda(max):  7.6524   C.I.:  0.10874   C.R.:  0.08238


         Propellants
  1       2       3     Priority
 1.000   5.000   0.333   0.28720
 0.200   1.000   0.167   0.07796
 3.000   6.000   1.000   0.63484
lamda(max):  3.0940   C.I.:  0.04701   C.R.:  0.08105


      Maintainability
  1       2       3       4     Priority
 1.000   1.000   0.200   0.200   0.09082
 1.000   1.000   0.333   0.333   0.11701
 5.000   3.000   1.000   1.000   0.39608
 5.000   3.000   1.000   1.000   0.39608
lamda(max):  4.0328   C.I.:  0.01093   C.R.:  0.01215


      Maneuverability
  1       2       3     Priority
 1.000   0.500   0.200   0.10884
 2.000   1.000   0.167   0.16258
 5.000   6.000   1.000   0.72858
lamda(max):  3.0858   C.I.:  0.04288   C.R.:  0.07394

The Consistency of this hierarchy =  0.0472
```

APPENDIX I: Initial Survey Data

```
  Judge #  2 AHP RESULTS (ORIGINAL SURVEY)
  TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  1.000  1.000  3.000  1.000  0.500  0.15858
 1.000  1.000  2.000  3.000  1.000  1.000  0.20296
 1.000  0.500  1.000  1.000  1.000  1.000  0.14235
 0.333  0.333  1.000  1.000  0.333  0.200  0.06935
 1.000  1.000  1.000  3.000  1.000  0.333  0.15131
 2.000  1.000  1.000  5.000  3.000  1.000  0.27545
lamda(max):  6.3120   C.I.:  0.06240   C.R.:  0.05032


        Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  1.000  1.000  0.500  7.000  7.000  2.000  1.000  0.16379
 1.000  1.000  1.000  1.000  7.000  7.000  3.000  1.000  0.18690
 1.000  1.000  1.000  1.000  7.000  7.000  2.000  1.000  0.17486
 2.000  1.000  1.000  1.000  7.000  7.000  1.000  1.000  0.18265
 0.143  0.143  0.143  0.143  1.000  1.000  0.333  0.333  0.02867
 0.143  0.143  0.143  0.143  1.000  1.000  0.333  0.333  0.02867
 0.500  0.333  0.500  1.000  3.000  3.000  1.000  1.000  0.09942
 1.000  1.000  1.000  1.000  3.000  3.000  1.000  1.000  0.13503
lamda(max):  8.2550   C.I.:  0.03643   C.R.:  0.02584


          Performance
   1      2      3     Priority
 1.000  3.000  1.000  0.42857
 0.333  1.000  0.333  0.14286
 1.000  3.000  1.000  0.42857
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


                 Risks
   1      2      3     Priority
 1.000  0.143  0.333  0.08795
 7.000  1.000  3.000  0.66942
 3.000  0.333  1.000  0.24264
lamda(max):  3.0070   C.I.:  0.00351   C.R.:  0.00605


            Logistics
   1      2      3     Priority
 1.000  3.000  0.333  0.25828
 0.333  1.000  0.200  0.10473
 3.000  5.000  1.000  0.63699
lamda(max):  3.0385   C.I.:  0.01926   C.R.:  0.03320
```

APPENDIX I: Initial Survey Data

```
        Survivability
  1      2      3      4      5      6      7    Priority
1.000  0.333  0.333  0.333  3.000  0.200  0.200  0.06006
3.000  1.000  1.000  1.000  3.000  1.000  0.333  0.14434
3.000  1.000  1.000  1.000  3.000  1.000  1.000  0.16399
3.000  1.000  1.000  1.000  3.000  0.333  1.000  0.14434
0.333  0.333  0.333  0.333  1.000  0.333  0.333  0.04927
5.000  1.000  1.000  3.000  3.000  1.000  1.000  0.21900
5.000  3.000  1.000  1.000  3.000  1.000  1.000  0.21900
lamda(max):  7.4316   C.I.:  0.07193   C.R.:  0.05449


         Propellants
  1      2      3    Priority
1.000  0.333  0.333  0.14286
3.000  1.000  1.000  0.42857
3.000  1.000  1.000  0.42857
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


      Maintainability
  1      2      3      4    Priority
1.000  0.333  0.333  0.333  0.09393
3.000  1.000  0.333  0.500  0.17614
3.000  3.000  1.000  3.000  0.48268
3.000  2.000  0.333  1.000  0.24725
lamda(max):  4.2153   C.I.:  0.07175   C.R.:  0.07973


      Maneuverability
  1      2      3    Priority
1.000  0.200  0.333  0.10065
5.000  1.000  4.000  0.67381
3.000  0.250  1.000  0.22554
lamda(max):  3.0858   C.I.:  0.04288   C.R.:  0.07394

The Consistency of this hierarchy =  0.0209
```

APPENDIX I: Initial Survey Data

```
Judge #  1 AHP RESULTS (ORIGINAL SURVEY)
TAV Effectiveness
  1      2      3      4      5      6     Priority
1.000  3.000  3.000  5.000  1.000  3.000  0.31320
0.333  1.000  1.000  3.000  0.333  3.000  0.14129
0.333  1.000  1.000  3.000  1.000  3.000  0.16696
0.200  0.333  0.333  1.000  0.333  0.333  0.05134
1.000  3.000  1.000  3.000  1.000  3.000  0.24440
0.333  0.333  0.333  3.000  0.333  1.000  0.08280
lamda(max):   6.3457   C.I.:  0.06913   C.R.:  0.05575


       Requirements
  1      2      3      4      5      6      7      8     Priority
1.000  1.000  1.000  1.000  1.000  5.000  1.000  1.000  0.13448
1.000  1.000  1.000  1.000  1.000  5.000  1.000  1.000  0.13448
1.000  1.000  1.000  1.000  1.000  5.000  3.000  1.000  0.15496
1.000  1.000  1.000  1.000  1.000  5.000  3.000  1.000  0.15496
1.000  1.000  1.000  1.000  1.000  5.000  3.000  1.000  0.15496
0.200  0.200  0.200  0.200  0.200  1.000  0.200  0.200  0.02690
1.000  1.000  0.333  0.333  0.333  5.000  1.000  0.333  0.08431
1.000  1.000  1.000  1.000  1.000  5.000  3.000  1.000  0.15496
lamda(max):   8.2359   C.I.:  0.03370   C.R.:  0.02390


        Performance
  1      2      3     Priority
1.000  1.000  3.000  0.42857
1.000  1.000  3.000  0.42857
0.333  0.333  1.000  0.14286
lamda(max):   3.0000   C.I.:  0.00000   C.R.:  0.00000


              Risks
  1      2      3     Priority
1.000  0.200  0.200  0.09091
5.000  1.000  1.000  0.45455
5.000  1.000  1.000  0.45455
lamda(max):   3.0000   C.I.:  0.00000   C.R.:  0.00000


          Logistics
  1      2      3     Priority
1.000  0.333  0.333  0.14286
3.000  1.000  1.000  0.42857
3.000  1.000  1.000  0.42857
lamda(max):   3.0000   C.I.:  0.00000   C.R.:  0.00000
```

APPENDIX H: Anova Results

```
* * * * * * * * *   A N A L Y S I S   O F   V A R I A N C E  * * * * * * * *
                ZETA
             BY JUDGE
                SIZE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


                                        SUM OF              MEAN            SIGNIF
SOURCE OF VARIATION                    SQUARES     DF     SQUARE      F      OF F

MAIN EFFECTS                              .480     15       .032  1.205      .274
   JUDGE                                  .436     11       .040  1.492      .139
   SIZE                                   .044      4       .011   .415      .798

2-WAY INTERACTIONS                        .544     44       .012   .466      .998
   JUDGE     SIZE                         .544     44       .012   .466      .998

EXPLAINED                                1.024     59       .017   .653      .969

RESIDUAL                                 4.143    156       .027

TOTAL                                    5.167    215       .024

* * * * * * * * *   A N A L Y S I S   O F   V A R I A N C E  * * * * * * * *
                ZETA
             BY SIZE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


                                        SUM OF              MEAN            SIGNIF
SOURCE OF VARIATION                    SQUARES     DF     SQUARE      F      OF F

MAIN EFFECTS                              .050      4       .013   .581      .677
   SIZE                                   .050      4       .013   .581      .677

EXPLAINED                                 .050      4       .013   .581      .677

RESIDUAL                                 5.345    247       .022

TOTAL                                    5.395    251       .021

* * * * * * * * *   A N A L Y S I S   O F   V A R I A N C E  * * * * * * * *
                ZETA
             BY JUDGE
* * * * * * * * * * * * * * * * * * * * * * * , * * * * * * * * * * * * * *


                                        SUM OF              MEAN            SIGNIF
SOURCE OF VARIATION                    SQUARES     DF     SQUARE      F      OF F

MAIN EFFECTS                              .436     11       .040  1.708      .073
   JUDGE                                  .436     11       .040  1.708      .073

EXPLAINED                                 .436     11       .040  1.708      .073

RESIDUAL                                 4.731    204       .023

TOTAL                                    5.167    215       .024
```

APPENDIX H: Anova Results

```
* * * * * * * * *  A N A L Y S I S   O F   V A R I A N C E  * * * * * * * * *
        CI
     BY JUDGE
        SIZE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


                                          SUM OF              MEAN              SIGNIF
SOURCE OF VARIATION                      SQUARES     DF      SQUARE       F       OF F

MAIN EFFECTS                                .546     15        .036    1.856     .032
   JUDGE                                    .397     11        .036    1.840     .052
   SIZE                                     .149      4        .037    1.900     .113

2-WAY INTERACTIONS                          .321     44        .007     .372     .999
   JUDGE     SIZE                           .321     44        .007     .372     .999

EXPLAINED                                   .867     59        .015     .749     .898

RESIDUAL                                   3.059    156        .020

TOTAL                                      3.926    215        .018
* * * * * * * * *  A N A L Y S I S   O F   V A R I A N C E  * * * * * * * * *
        CI
     BY SIZE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


                                          SUM OF              MEAN              SIGNIF
SOURCE OF VARIATION                      SQUARES     DF      SQUARE       F       OF F

MAIN EFFECTS                                .150      4        .037    2.361     .054
   SIZE                                     .150      4        .037    2.361     .054

EXPLAINED                                   .150      4        .037    2.361     .054

RESIDUAL                                   3.919    247        .016

TOTAL                                      4.069    251        .016


* * * * * * * * *  A N A L Y S I S   O F   V A R I A N C E  * * * * * * * * *
        CI
     BY JUDGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


                                          SUM OF              MEAN              SIGNIF
SOURCE OF VARIATION                      SQUARES     DF      SQUARE       F       OF F

MAIN EFFECTS                                .397     11        .036    2.086     .023
   JUDGE                                    .397     11        .036    2.086     .023

EXPLAINED                                   .397     11        .036    2.086     .023

RESIDUAL                                   3.529    204        .017

TOTAL                                      3.926    215        .018
```

APPENDIX I: Initial Survey Data

```
  Judge #  7 AHP RESULTS (ORIGINAL SURVEY)
  TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  9.000  9.000  9.000  9.000  9.000  0.61070
 0.111  1.000  7.000  3.000  7.000  1.000  0.14880
 0.111  0.143  1.000  0.333  0.333  0.200  0.02581
 0.111  0.333  3.000  1.000  5.000  1.000  0.08300
 0.111  0.143  3.000  0.200  1.000  0.333  0.03740
 0.111  1.000  5.000  1.000  3.000  1.000  0.09429
lamda(max):  6.7372   C.I.:  0.14744   C.R.:  0.11890


        Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  5.000  9.000  5.000  5.000  9.000  9.000  3.000  0.41035
 0.200  1.000  5.000  1.000  1.000  5.000  5.000  1.000  0.12081
 0.111  0.200  1.000  0.111  0.333  1.000  1.000  1.000  0.03642
 0.200  1.000  9.000  1.000  3.000  9.000  5.000  1.000  0.17448
 0.200  1.000  3.000  0.333  1.000  7.000  5.000  1.000  0.10501
 0.111  0.200  1.000  0.111  0.143  1.000  1.000  0.333  0.02656
 0.111  0.200  1.000  0.200  0.200  1.000  1.000  0.333  0.02906
 0.333  1.000  1.000  1.000  1.000  3.000  3.000  1.000  0.09732
lamda(max):  8.6076   C.I.:  0.08680   C.R.:  0.06156


         Performance
   1      2      3     Priority
 1.000  3.000  3.000  0.60000
 0.333  1.000  1.000  0.20000
 0.333  1.000  1.000  0.20000
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


              Risks
   1      2      3     Priority
 1.000  1.000  1.000  0.33333
 1.000  1.000  1.000  0.33333
 1.000  1.000  1.000  0.33333
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


           Logistics
   1      2      3     Priority
 1.000  5.000  1.000  0.45455
 0.200  1.000  0.200  0.09091
 1.000  5.000  1.000  0.45455
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000
```

APPENDIX I: Initial Survey Data

```
       Survivability
   1      2      3      4      5      6      7     Priority
 1.000  1.000  0.111  1.000  1.000  1.000  1.000  0.06320
 1.000  1.000  0.111  5.000  7.000  1.000  1.000  0.12804
 9.000  9.000  1.000  9.000  9.000  9.000  9.000  0.56878
 1.000  0.200  0.111  1.000  0.333  1.000  1.000  0.04548
 1.000  0.143  0.111  3.000  1.000  1.000  0.333  0.05423
 1.000  1.000  0.111  1.000  1.000  1.000  1.000  0.06320
 1.000  1.000  0.111  1.000  3.000  1.000  1.000  0.07706
lamda(max):  7.8232   C.I.:  0.13721   C.R.:  0.10394


        Propellants
   1      2      3    Priority
 1.000  0.200  0.200  0.09091
 5.000  1.000  1.000  0.45455
 5.000  1.000  1.000  0.45455
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


      Maintainability
   1      2      3      4    Priority
 1.000  0.143  0.143  0.143  0.04545
 7.000  1.000  1.000  1.000  0.31818
 7.000  1.000  1.000  1.000  0.31818
 7.000  1.000  1.000  1.000  0.31818
lamda(max):  4.0000   C.I.:  0.00000   C.R.:  0.00000


      Maneuverability
   1      2      3    Priority
 1.000  1.000  5.000  0.45455
 1.000  1.000  5.000  0.45455
 0.200  0.200  1.000  0.09091
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000

The Consistency of this hierarchy =  0.0510
```

APPENDIX I: Initial Survey Data

```
  Judge #  8 AHP RESULTS (ORIGINAL SURVEY)
  TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  1.000  1.000  3.000  2.000  3.000  0.21393
 1.000  1.000  1.000  5.000  3.000  5.000  0.27528
 1.000  1.000  1.000  5.000  1.000  5.000  0.22128
 0.333  0.200  0.200  1.000  0.200  0.200  0.03972
 0.500  0.333  1.000  5.000  1.000  5.000  0.17696
 0.333  0.200  0.200  5.000  0.200  1.000  0.07285
lamda(max):  6.5540   C.I.:  0.11080   C.R.:  0.08935


       Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  0.200  9.000  1.000  0.333  9.000  0.200  0.200  0.07520
 5.000  1.000  9.000  3.000  1.000  9.000  3.000  0.333  0.20769
 0.111  0.111  1.000  0.143  0.143  1.000  0.143  0.143  0.01785
 1.000  0.333  7.000  1.000  0.333  9.000  3.000  1.000  0.12949
 3.000  1.000  7.000  3.000  1.000  9.000  3.000  1.000  0.20471
 0.111  0.111  1.000  0.111  0.111  1.000  0.111  0.111  0.01547
 5.000  0.333  7.000  0.333  0.333  9.000  1.000  0.333  0.11116
 5.000  3.000  7.000  1.000  1.000  9.000  3.000  1.000  0.23842
lamda(max):  9.0988   C.I.:  0.15697   C.R.:  0.11133


        Performance
   1      2      3     Priority
 1.000  5.000  5.000  0.68542
 0.200  1.000  5.000  0.23441
 0.200  0.200  1.000  0.08017
lamda(max):  3.2948   C.I.:  0.14739   C.R.:  0.25412


              Risks
   1      2      3     Priority
 1.000  0.143  1.000  0.13151
 7.000  1.000  3.000  0.69406
 1.000  0.333  1.000  0.17443
lamda(max):  3.0803   C.I.:  0.04015   C.R.:  0.06922


           Logistics
   1      2      3     Priority
 1.000  1.000  0.200  0.13356
 1.000  1.000  0.143  0.11939
 5.000  7.000  1.000  0.74705
lamda(max):  3.0126   C.I.:  0.00630   C.R.:  0.01086
```

APPENDIX I: Initial Survey Data

```
        Survivability
  1      2      3      4      5      6      7    Priority
 1.000  0.143  3.000  0.143  0.333  1.000  0.143  0.03863
 7.000  1.000  7.000  1.000  7.000  5.000  5.000  0.36441
 0.333  0.143  1.000  0.143  0.143  0.143  0.143  0.02152
 7.000  1.000  7.000  1.000  3.000  7.000  1.000  0.23819
 3.000  0.143  7.000  0.333  1.000  1.000  0.200  0.07296
 1.000  0.200  7.000  0.143  1.000  1.000  0.200  0.05997
 7.000  0.200  7.000  1.000  5.000  5.000  1.000  0.20431
lamda(max):  7.8369   C.I.:  0.13948   C.R.:  0.10567


         Propellants
  1      2      3    Priority
 1.000  9.000  1.000  0.59052
 0.111  1.000  7.000  0.26108
 1.000  0.143  1.000  0.14841
lamda(max):  5.2304   C.I.:  1.11519   C.R.:  1.92274


      Maintainability
  1      2      3    Priority
 1.000  0.143  0.200  0.07193
 7.000  1.000  3.000  0.64912
 5.000  0.333  1.000  0.27895
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594


      Maneuverability
  1      2      3    Priority
 1.000  5.000  7.000  0.70149
 0.200  1.000  7.000  0.23991
 0.143  0.143  1.000  0.05860
lamda(max):  3.2948   C.I.:  0.14739   C.R.:  0.25412

The Consistency of this hierarchy =  0.1600
```

APPENDIX I: Initial Survey Data

```
  Judge # 9 AHP RESULTS (ORIGINAL SURVEY)
  TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  0.143  0.333  0.200  0.333  0.333  0.03973
 7.000  1.000  3.000  3.000  1.000  3.000  0.32302
 3.000  0.333  1.000  0.333  0.333  0.333  0.07399
 5.000  0.333  3.000  1.000  3.000  4.000  0.26985
 3.000  1.000  3.000  0.333  1.000  3.000  0.18997
 3.000  0.333  3.000  0.250  0.333  1.000  0.10344
lamda(max):  6.6031   C.I.:  0.12063   C.R.:  0.09728


       Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  5.000  7.000  3.000  3.000  7.000  3.000  0.333  0.24621
 0.200  1.000  7.000  1.000  3.000  7.000  3.000  0.333  0.13203
 0.143  0.143  1.000  0.143  0.200  0.333  0.200  0.143  0.01926
 0.333  1.000  7.000  1.000  3.000  5.000  3.000  1.000  0.15014
 0.333  0.333  5.000  0.333  1.000  3.000  3.000  0.200  0.07608
 0.143  0.143  3.000  0.200  0.333  1.000  0.200  0.200  0.02964
 0.333  0.333  5.000  0.333  0.333  5.000  1.000  0.200  0.06300
 3.000  3.000  7.000  1.000  5.000  5.000  5.000  1.000  0.28364
lamda(max):  8.9796   C.I.:  0.13994   C.R.:  0.09925


        Performance
   1      2      3     Priority
 1.000  3.000  0.143  0.15787
 0.333  1.000  0.143  0.07590
 7.000  7.000  1.000  0.76623
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691


              Risks
   1      2      3     Priority
 1.000  1.000  0.333  0.20000
 1.000  1.000  0.333  0.20000
 3.000  3.000  1.000  0.60000
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


          Logistics
   1      2      3     Priority
 1.000  3.000  3.000  0.60000
 0.333  1.000  1.000  0.20000
 0.333  1.000  1.000  0.20000
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000
```

APPENDIX I: Initial Survey Data

```
      Survivability
  1      2      3      4      5      6      7     Priority
 1.000  0.333  0.200  0.200  3.000  0.200  0.200  0.04766
 3.000  1.000  0.333  0.333  5.000  0.333  0.333  0.09342
 5.000  3.000  1.000  1.000  3.000  1.000  1.000  0.19353
 5.000  3.000  1.000  1.000  3.000  1.000  1.000  0.19353
 0.333  0.200  0.333  0.333  1.000  0.200  0.200  0.03842
 5.000  3.000  1.000  1.000  5.000  1.000  3.000  0.25204
 5.000  3.000  1.000  1.000  5.000  0.333  1.000  0.18140
lamda(max):  7.5146   C.I.:  0.08576   C.R.:  0.06497
```

```
       Propellants
  1      2      3     Priority
 1.000  1.000  0.143  0.11111
 1.000  1.000  0.143  0.11111
 7.000  7.000  1.000  0.77778
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000
```

```
     Maintainability
  1      2      3      4     Priority
 1.000  0.143  0.143  0.200  0.04496
 7.000  1.000  3.000  3.000  0.51057
 7.000  0.333  1.000  3.000  0.29196
 5.000  0.333  0.333  1.000  0.15251
lamda(max):  4.2281   C.I.:  0.07604   C.R.:  0.08449
```

```
     Maneuverability
  1      2      3     Priority
 1.000  0.200  3.000  0.18839
 5.000  1.000  7.000  0.73064
 0.333  0.143  1.000  0.08096
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594

The Consistency of this hierarchy =  0.0545
```

APPENDIX I: Initial Survey Data

```
  Judge # 10 AHP RESULTS (ORIGINAL SURVEY)
  TAV Effectiveness
  1     2     3     4     5     6    Priority
1.000 3.000 3.000 3.000 3.000 3.000 0.34463
0.333 1.000 3.000 1.000 0.333 0.333 0.09981
0.333 0.333 1.000 3.000 0.333 0.333 0.08445
0.333 1.000 0.333 1.000 0.333 0.333 0.06622
0.333 3.000 3.000 3.000 1.000 0.333 0.16582
0.333 3.000 3.000 3.000 3.000 1.000 0.23906
lamda(max):  6.7049   C.I.:  0.14098   C.R.:  0.11370


        Requirements
  1     2     3     4     5     6     7     8    Priority
1.000 1.000 3.000 1.000 3.000 3.000 3.000 1.000 0.17917
1.000 1.000 1.000 0.333 1.000 3.000 1.000 1.000 0.10828
0.333 1.000 1.000 0.333 1.000 3.000 0.333 0.333 0.07379
1.000 3.000 3.000 1.000 5.000 5.000 3.000 1.000 0.23431
0.333 1.000 1.000 0.200 1.000 1.000 3.000 0.333 0.08176
0.333 0.333 0.333 0.200 1.000 1.000 1.000 0.333 0.05051
0.333 1.000 3.000 0.333 0.333 1.000 1.000 0.200 0.07566
1.000 1.000 3.000 1.000 3.000 3.000 5.000 1.000 0.19652
lamda(max):  8.7258   C.I.:  0.10368   C.R.:  0.07353


         Performance
  1     2     3    Priority
1.000 0.333 0.200 0.09717
3.000 1.000 0.200 0.20212
5.000 5.000 1.000 0.70071
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691


             Risks
  1     2     3    Priority
1.000 0.500 0.500 0.20000
2.000 1.000 1.000 0.40000
2.000 1.000 1.000 0.40000
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


           Logistics
  1     2     3    Priority
1.000 3.000 0.111 0.12952
0.333 1.000 0.111 0.06227
9.000 9.000 1.000 0.80822
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691
```

APPENDIX I: Initial Survey Data

```
      Survivability
  1      2      3      4      5      6      7    Priority
1.000  1.000  0.200  1.000  0.333  0.200  0.200  0.05306
1.000  1.000  0.200  0.333  0.333  0.333  0.333  0.04107
5.000  5.000  1.000  5.000  5.000  5.000  5.000  0.40561
1.000  3.000  0.200  1.000  5.000  3.000  3.000  0.19065
3.000  3.000  0.200  0.200  1.000  1.000  3.000  0.10537
5.000  3.000  0.200  0.333  1.000  1.000  3.000  0.12116
5.000  3.000  0.200  0.333  0.333  0.333  1.000  0.08308
lamda(max):  8.3272   C.I.:  0.22121   C.R.:  0.16758
```

```
       Propellants
  1      2      3    Priority
1.000  7.000  3.000  0.64912
0.143  1.000  0.200  0.07193
0.333  5.000  1.000  0.27895
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594
```

```
    Maintainability
  1      2      3      4    Priority
1.000  7.000  7.000  5.000  0.64484
0.143  1.000  5.000  3.000  0.19210
0.143  0.200  1.000  0.200  0.04425
0.200  0.333  5.000  1.000  0.11881
lamda(max):  4.4868   C.I.:  0.16228   C.R.:  0.18031
```

```
    Maneuverability
  1      2      3    Priority
1.000  0.200  0.333  0.11397
5.000  1.000  1.000  0.48064
3.000  1.000  1.000  0.40539
lamda(max):  3.0291   C.I.:  0.01453   C.R.:  0.02506

The Consistency of this hierarchy =  0.1050
```

APPENDIX I: Initial Survey Data

```
  Judge # 11 AHP RESULTS (ORIGINAL SURVEY)
  TAV Effectiveness
  1      2      3      4      5      6     Priority
 1.000  7.000  7.000  7.000  7.000  7.000  0.49290
 0.143  1.000  7.000  7.000  7.000  7.000  0.25491
 0.143  0.143  1.000  0.200  0.143  0.143  0.01970
 0.143  0.143  5.000  1.000  0.143  0.143  0.03248
 0.143  0.143  7.000  7.000  1.000  7.000  0.13183
 0.143  0.143  7.000  7.000  0.143  1.000  0.06817
lamda(max):  8.2015   C.I.:  0.44031   C.R.:  0.35509


       Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  7.000  9.000  7.000  9.000  9.000  5.000  7.000  0.32068
 0.143  1.000  9.000  0.143  9.000  9.000  9.000  5.000  0.16629
 0.111  0.111  1.000  9.000  7.000  1.000  0.143  0.143  0.11795
 0.143  7.000  0.111  1.000  7.000  9.000  7.000  7.000  0.17245
 0.111  0.111  0.143  0.143  1.000  7.000  7.000  0.143  0.03957
 0.111  0.111  1.000  0.111  0.143  1.000  0.143  0.143  0.01357
 0.111  0.111  7.000  0.143  0.143  7.000  1.000  0.143  0.06265
 0.143  0.200  7.000  0.143  7.000  7.000  7.000  1.000  0.10683
lamda(max):  17.2861   C.I.:  1.32659   C.R.:  0.94084


        Performance
   1      2      3    Priority
 1.000  7.000  7.000  0.74186
 0.143  1.000  7.000  0.20273
 0.143  0.143  1.000  0.05540
lamda(max):  3.4357   C.I.:  0.21784   C.R.:  0.37559


               Risks
   1      2      3    Priority
 1.000  0.200  0.143  0.06292
 5.000  1.000  0.143  0.18397
 7.000  7.000  1.000  0.75311
lamda(max):  3.2948   C.I.:  0.14739   C.R.:  0.25412


             Logistics
   1      2      3    Priority
 1.000  7.000  3.000  0.63299
 0.143  1.000  0.143  0.06270
 0.333  7.000  1.000  0.30431
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691
```

APPENDIX I: Initial Survey Data

```
      Survivability
  1      2      3      4      5      6      7    Priority
1.000  0.111  0.143  0.143  0.143  0.143  0.143  0.01580
9.000  1.000  7.000  5.000  7.000  7.000  7.000  0.44906
7.000  0.143  1.000  0.143  5.000  5.000  0.143  0.07343
7.000  0.200  7.000  1.000  7.000  5.000  0.200  0.14879
7.000  0.143  0.200  0.143  1.000  1.000  0.143  0.03519
7.000  0.143  0.200  0.200  1.000  1.000  0.143  0.03613
7.000  0.143  7.000  5.000  7.000  7.000  1.000  0.24161
lamda(max):  8.9959   C.I.:  0.33265   C.R.:  0.25201


       Propellants
  1      2      3    Priority
1.000  9.000  7.000  0.76076
0.111  1.000  0.143  0.04805
0.143  7.000  1.000  0.19119
lamda(max):  3.3276   C.I.:  0.16382   C.R.:  0.28245


     Maintainability
  1      2      3      4    Priority
1.000  0.143  0.111  0.200  0.03372
7.000  1.000  0.143  5.000  0.20401
9.000  7.000  1.000  9.000  0.68270
5.000  0.200  0.111  1.000  0.07957
lamda(max):  4.5853   C.I.:  0.19511   C.R.:  0.21679


     Maneuverability
  1      2      3    Priority
1.000  7.000  7.000  0.74186
0.143  1.000  7.000  0.20273
0.143  0.143  1.000  0.05540
lamda(max):  3.4357   C.I.:  0.21784   C.R.:  0.37559

The Consistency of this hierarchy =  0.6946
```

APPENDIX I: Initial Survey Data

```
 Judge # 12 AHP RESULTS (ORIGINAL SURVEY)
 TAV Effectiveness
   1      2      3      4      5      6    Priority
 1.000  7.000  1.000  5.000  5.000  5.000  0.35841
 0.143  1.000  1.000  5.000  3.000  3.000  0.16746
 1.000  1.000  1.000  5.000  1.000  0.200  0.14129
 0.200  0.200  0.200  1.000  3.000  3.000  0.10010
 0.200  0.333  1.000  0.333  1.000  7.000  0.12616
 0.200  0.333  5.000  0.333  0.143  1.000  0.10657
lamda(max):  9.3079   C.I.:  0.66157   C.R.:  0.53353
```

```
       Requirements
   1      2      3      4      5      6      7      8    Priority
 1.000  7.000  7.000  5.000  0.143  0.200  0.200  5.000  0.13131
 0.143  1.000  1.000  0.200  0.143  0.200  0.200  5.000  0.05143
 0.143  1.000  1.000  0.200  0.143  0.333  0.143  5.000  0.05147
 0.200  5.000  5.000  1.000  0.143  3.000  0.143  5.000  0.09954
 7.000  7.000  7.000  7.000  1.000  5.000  5.000  3.000  0.28512
 5.000  5.000  3.000  0.333  0.200  1.000  0.143  0.200  0.08547
 5.000  5.000  7.000  7.000  0.200  7.000  1.000  0.200  0.18753
 0.200  0.200  0.200  0.200  0.333  5.000  5.000  1.000  0.10813
lamda(max):  15.1192   C.I.:  1.01703   C.R.:  0.72129
```

```
        Performance
   1      2      3    Priority
 1.000  7.000  1.000  0.48692
 0.143  1.000  0.200  0.07782
 1.000  5.000  1.000  0.43526
lamda(max):  3.0126   C.I.:  0.00630   C.R.:  0.01086
```

```
               Risks
   1      2      3    Priority
 1.000  0.200  0.143  0.07782
 5.000  1.000  1.000  0.43526
 7.000  1.000  1.000  0.48692
lamda(max):  3.0126   C.I.:  0.00630   C.R.:  0.01086
```

```
          Logistics
   1      2      3    Priority
 1.000  0.143  0.143  0.05540
 7.000  1.000  0.143  0.20273
 7.000  7.000  1.000  0.74186
lamda(max):  3.4357   C.I.:  0.21784   C.R.:  0.37559
```

APPENDIX I: Initial Survey Data

```
      Survivability
  1      2      3      4      5      6      7    Priority
1.000  3.000  0.143  1.000  3.000  0.333  3.000  0.16869
0.333  1.000  5.000  7.000  3.000  3.000  3.000  0.25399
7.000  0.200  1.000  1.000  3.000  3.000  0.200  0.17498
1.000  0.143  1.000  1.000  3.000  3.000  0.200  0.07865
0.333  0.333  0.333  0.333  1.000  1.000  0.143  0.03454
3.000  0.333  0.333  0.333  1.000  1.000  0.200  0.07788
0.333  0.333  5.000  5.000  7.000  5.000  1.000  0.21127
lamda(max):  10.6567   C.I.:  0.60946   C.R.:  0.46171


       Propellants
  1      2      3    Priority
1.000  9.000  5.000  0.75343
0.111  1.000  5.000  0.17413
0.200  0.200  1.000  0.07244
lamda(max):  3.5608   C.I.:  0.28042   C.R.:  0.48348


     Maintainability
  1      2      3      4    Priority
1.000  5.000  0.200  0.200  0.11883
0.200  1.000  0.200  0.143  0.04719
5.000  5.000  1.000  0.333  0.29768
5.000  7.000  3.000  1.000  0.53630
lamda(max):  4.3890   C.I.:  0.12968   C.R.:  0.14409


     Maneuverability
  1      2      3    Priority
1.000  7.000  3.000  0.64912
0.143  1.000  0.200  0.07193
0.333  5.000  1.000  0.27895
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594

The Consistency of this hierarchy =  0.5036
```

APPENDIX I: Initial Survey Data

Geometric Mean for 12 Original Surveys

TAV Effectiveness

1	2	3	4	5	6	Priority
1.000	1.754	2.063	3.605	2.928	2.199	0.31191
0.570	1.000	2.367	2.945	2.160	2.205	0.24071
0.485	0.423	1.000	1.615	0.670	0.679	0.10957
0.277	0.340	0.619	1.000	1.178	0.689	0.09067
0.342	0.463	1.492	0.849	1.000	1.629	0.12673
0.455	0.453	1.474	1.452	0.614	1.000	0.12040

lamda(max): 6.1652 C.I.: 0.03304 C.R.: 0.02665

Requirements

1	2	3	4	5	6	7	8	Priority
1.000	2.234	4.620	2.815	1.894	4.453	2.225	1.859	0.26178
0.448	1.000	3.319	1.373	1.382	3.362	1.725	2.016	0.17003
0.216	0.301	1.000	0.632	0.905	1.538	0.396	0.542	0.06429
0.355	0.728	1.582	1.000	1.253	3.637	1.037	1.009	0.11892
0.528	0.724	1.105	0.798	1.000	1.998	2.085	0.850	0.11636
0.225	0.297	0.650	0.275	0.500	1.000	0.371	0.399	0.04549
0.449	0.580	2.526	0.965	0.480	2.698	1.000	0.825	0.10649
0.538	0.496	1.844	0.991	1.176	2.504	1.212	1.000	0.11664

lamda(max): 8.2133 C.I.: 0.03047 C.R.: 0.02161

Performance

1	2	3	Priority
1.000	2.799	1.316	0.47897
0.357	1.000	0.601	0.18570
0.760	1.664	1.000	0.33533

lamda(max): 3.0067 C.I.: 0.00335 C.R.: 0.00578

Risks

1	2	3	Priority
1.000	0.588	0.632	0.23366
1.700	1.000	0.958	0.38235
1.582	1.043	1.000	0.38399

lamda(max): 3.0015 C.I.: 0.00073 C.R.: 0.00126

Logistics

1	2	3	Priority
1.000	1.133	0.350	0.20151
0.882	1.000	0.227	0.15052
2.858	4.402	1.000	0.64797

lamda(max): 3.0104 C.I.: 0.00522 C.R.: 0.00900

APPENDIX I: Initial Survey Data

```
       Survivability
   1       2       3       4       5       6       7     Priority
 1.000   0.496   0.353   0.476   0.632   0.367   0.235   0.05896
 2.017   1.000   0.959   1.678   1.733   0.853   0.590   0.14988
 2.835   1.043   1.000   1.208   2.231   1.125   0.480   0.15592
 2.100   0.596   0.828   1.000   2.779   1.168   0.375   0.13540
 1.582   0.577   0.448   0.360   1.000   0.735   0.293   0.07887
 2.722   1.172   0.888   0.856   1.361   1.000   0.500   0.13732
 4.263   1.696   2.083   2.665   3.411   1.999   1.000   0.28364
lamda(max):  7.1164   C.I.:  0.01940   C.R.:  0.01470


         Propellants
   1       2       3    Priority
 1.000   2.025   0.786  0.37577
 0.494   1.000   0.636  0.21879
 1.272   1.571   1.000  0.40544
lamda(max):  3.0272   C.I.:  0.01362   C.R.:  0.02348


      Maintainability
   1       2       3       4    Priority
 1.000   0.470   0.372   0.490  0.12724
 2.128   1.000   0.719   1.049  0.26523
 2.687   1.391   1.000   1.066  0.33335
 2.042   0.953   0.938   1.000  0.27418
lamda(max):  4.0095   C.I.:  0.00318   C.R.:  0.00354


      Maneuverability
   1       2       3    Priority
 1.000   1.407   2.297  0.45672
 0.711   1.000   2.374  0.36778
 0.435   0.421   1.000  0.17550
lamda(max):  3.0156   C.I.:  0.00778   C.R.:  0.01342

The Consistency of this hierarchy =  0.0154
```

APPENDIX J: AHP Follow-Up Survey Data

```
       Survivability
   1       2       3       4       5       6       7    Priority
 1.000   1.000   0.111   1.000   1.000   1.000   1.000   0.06320
 1.000   1.000   0.111   5.000   7.000   1.000   1.000   0.12804
 9.000   9.000   1.000   9.000   9.000   9.000   9.000   0.56878
 1.000   0.200   0.111   1.000   0.333   1.000   1.000   0.04548
 1.000   0.143   0.111   3.000   1.000   1.000   0.333   0.05423
 1.000   1.000   0.111   1.000   1.000   1.000   1.000   0.06320
 1.000   1.000   0.111   1.000   3.000   1.000   1.000   0.07706
lamda(max):   7.8232    C.I.:  0.13721    C.R.:  0.10394


        Propellants
   1       2       3    Priority
 1.000   0.200   0.200   0.09091
 5.000   1.000   1.000   0.45455
 5.000   1.000   1.000   0.45455
lamda(max):   3.0000    C.I.:  0.00000    C.R.:  0.00000


      Maintainability
   1       2       3       4    Priority
 1.000   0.200   0.200   0.200   0.06250
 5.000   1.000   1.000   1.000   0.31250
 5.000   1.000   1.000   1.000   0.31250
 5.000   1.000   1.000   1.000   0.31250
lamda(max):   4.0000    C.I.:  0.00000    C.R.:  0.00000


      Maneuverability
   1       2       3    Priority
 1.000   1.000   5.000   0.45455
 1.000   1.000   5.000   0.45455
 0.200   0.200   1.000   0.09091
lamda(max):   3.0000    C.I.:  0.00000    C.R.:  0.00000

The Consistency of this hierarchy =  0.0510
```

APPENDIX J: AHP Follow-Up Survey Data

```
       Judge # 7 AHP RESULTS
 TAV Effectiveness
  1      2      3      4      5      6     Priority
1.000  9.000  9.000  9.000  9.000  9.000  0.61070
0.111  1.000  7.000  3.000  7.000  1.000  0.14880
0.111  0.143  1.000  0.333  0.333  0.200  0.02581
0.111  0.333  3.000  1.000  5.000  1.000  0.08300
0.111  0.143  3.000  0.200  1.000  0.333  0.03740
0.111  1.000  5.000  1.000  3.000  1.000  0.09429
lamda(max):  6.7372   C.I.:  0.14744   C.R.:  0.11890


       Requirements
  1      2      3      4      5      6      7      8     Priority
1.000  5.000  9.000  5.000  5.000  9.000  9.000  3.000  0.41035
0.200  1.000  5.000  1.000  1.000  5.000  5.000  1.000  0.12081
0.111  0.200  1.000  0.111  0.333  1.000  1.000  1.000  0.03642
0.200  1.000  9.000  1.000  3.000  9.000  5.000  1.000  0.17448
0.200  1.000  3.000  0.333  1.000  7.000  5.000  1.000  0.10501
0.111  0.200  1.000  0.111  0.143  1.000  1.000  0.333  0.02656
0.111  0.200  1.000  0.200  0.200  1.000  1.000  0.333  0.02906
0.333  1.000  1.000  1.000  1.000  3.000  3.000  1.000  0.09732
lamda(max):  8.6076   C.I.:  0.08680   C.R.:  0.06156


        Performance
  1      2      3     Priority
1.000  3.000  3.000  0.60000
0.333  1.000  1.000  0.20000
0.333  1.000  1.000  0.20000
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


                 Risks
  1      2      3     Priority
1.000  1.000  1.000  0.33333
1.000  1.000  1.000  0.33333
1.000  1.000  1.000  0.33333
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


          Logistics
  1      2      3     Priority
1.000  5.000  1.000  0.45455
0.200  1.000  0.200  0.09091
1.000  5.000  1.000  0.45455
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Survivability
  1       2       3       4       5       6       7     Priority
 1.000   0.143   0.143   1.000   0.143   0.143   0.143   0.02452
 7.000   1.000   1.000   5.000   1.000   0.143   0.111   0.09498
 7.000   1.000   1.000   1.000   1.000   0.143   0.143   0.07408
 1.000   0.200   1.000   1.000   1.000   0.143   0.111   0.04590
 7.000   1.000   1.000   1.000   1.000   1.000   1.000   0.13842
 7.000   7.000   7.000   7.000   1.000   1.000   1.000   0.29405
 7.000   9.000   7.000   9.000   1.000   1.000   1.000   0.32805
lamda(max):  8.2872   C.I.:  0.21453   C.R.:  0.16252


       Propellants
  1       2       3     Priority
 1.000   7.000   7.000   0.76623
 0.143   1.000   0.333   0.07590
 0.143   3.000   1.000   0.15787
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691


     Maintainability
  1       2       3       4     Priority
 1.000   0.143   0.333   1.000   0.07521
 7.000   1.000   0.111   5.000   0.23447
 3.000   9.000   1.000   3.000   0.61253
 1.000   0.200   0.333   1.000   0.07779
lamda(max):  5.1944   C.I.:  0.39815   C.R.:  0.44238


     Maneuverability
  1       2       3     Priority
 1.000   7.000   7.000   0.77778
 0.143   1.000   1.000   0.11111
 0.143   1.000   1.000   0.11111
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000

The Consistency of this hierarchy =  0.3611
```

APPENDIX J: AHP Follow-Up Survey Data

```
          Judge #  6 AHP RESULTS
     TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  0.333  7.000  7.000  7.000  0.143  0.18057
 3.000  1.000  7.000  5.000  7.000  1.000  0.27843
 0.143  0.143  1.000  0.143  5.000  0.143  0.04389
 0.143  0.200  7.000  1.000  1.000  0.143  0.07269
 0.143  0.143  0.200  1.000  1.000  0.143  0.03104
 7.000  1.000  7.000  7.000  7.000  1.000  0.39339
lamda(max):  7.5476   C.I.:  0.30951   C.R.:  0.24961


          Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  7.000  7.000  7.000  7.000  9.000  0.200  1.000  0.23684
 0.143  1.000  5.000  5.000  0.143  7.000  0.143  1.000  0.07532
 0.143  0.200  1.000  0.200  1.000  5.000  0.143  0.333  0.03570
 0.143  0.200  5.000  1.000  0.200  5.000  0.143  0.333  0.04417
 0.143  7.000  1.000  5.000  1.000  5.000  0.200  1.000  0.11454
 0.111  0.143  0.200  0.200  0.200  1.000  0.111  0.143  0.01432
 5.000  7.000  7.000  7.000  5.000  9.000  1.000  7.000  0.38995
 1.000  1.000  3.000  3.000  1.000  7.000  0.143  1.000  0.08916
lamda(max):  10.2223   C.I.:  0.31747   C.R.:  0.22516


           Performance
   1      2      3     Priority
 1.000  1.000  7.000  0.56401
 1.000  1.000  0.200  0.17243
 0.143  5.000  1.000  0.26356
lamda(max):  4.5768   C.I.:  0.78839   C.R.:  1.35929


                Risks
   1      2      3     Priority
 1.000  7.000  7.000  0.77778
 0.143  1.000  1.000  0.11111
 0.143  1.000  1.000  0.11111

lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


             Logistics
   1      2      3     Priority
 1.000  7.000  0.143  0.20273
 0.143  1.000  0.143  0.05541
 7.000  7.000  1.000  0.74186
lamda(max):  3.4357   C.I.:  0.21784   C.R.:  0.37559
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Survivability
  1      2      3      4      5      6      7    Priority
1.000  0.125  2.000  0.500  1.000  1.000  0.125  0.05306
8.000  1.000  7.000  6.000  1.000  4.000  1.000  0.29515
0.500  0.143  1.000  0.500  0.500  0.500  0.200  0.03938
2.000  0.167  2.000  1.000  3.000  3.000  0.143  0.10657
1.000  1.000  2.000  0.333  1.000  2.000  0.200  0.09408
1.000  0.250  2.000  0.333  0.500  1.000  0.167  0.05140
8.000  1.000  5.000  7.000  5.000  6.000  1.000  0.36036
lamda(max):  7.7748   C.I.:  0.12913   C.R.:  0.09783


       Propellants
  1      2      3    Priority
1.000  2.000  0.500  0.29696
0.500  1.000  0.333  0.16342
2.000  3.000  1.000  0.53961
lamda(max):  3.0092   C.I.:  0.00460   C.R.:  0.00793


     Maintainability
  1      2      3      4    Priority
1.000  0.500  0.500  0.500  0.13567
2.000  1.000  2.000  1.000  0.33998
2.000  0.500  1.000  2.000  0.28734
2.000  1.000  0.500  1.000  0.23701
lamda(max):  4.1855   C.I.:  0.06184   C.R.:  0.06871


     Maneuverability
  1      2      3    Priority
1.000  0.250  1.000  0.16667
4.000  1.000  4.000  0.66667
1.000  0.250  1.000  0.16667
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000

The Consistency of this hierarchy =  0.0499
```

APPENDIX J: AHP Follow-Up Survey Data

```
       Judge #  5 AHP RESULTS
   TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  0.500  0.500  3.000  2.000  1.000  0.16626
 2.000  1.000  1.000  2.000  2.000  2.000  0.23371
 2.000  1.000  1.000  3.000  2.000  3.000  0.26772
 0.333  0.500  0.333  1.000  2.000  0.500  0.10131
 0.500  0.500  0.500  0.500  1.000  2.000  0.11420
 1.000  0.500  0.333  2.000  0.500  1.000  0.11679
lamda(max):  6.4121   C.I.:  0.08243   C.R.:  0.06648


       Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  0.333  2.000  3.000  0.250  5.000  4.000  1.000  0.12937
 3.000  1.000  2.000  5.000  0.333  5.000  4.000  4.000  0.21474
 0.500  0.500  1.000  5.000  0.500  5.000  4.000  2.000  0.14009
 0.333  0.200  0.200  1.000  0.200  2.000  2.000  2.000  0.05843
 4.000  3.000  2.000  5.000  1.000  6.000  6.000  5.000  0.32380
 0.200  0.200  0.200  0.500  0.167  1.000  2.000  0.500  0.03649
 0.250  0.250  0.250  0.500  0.167  0.500  1.000  0.500  0.03332
 1.000  0.250  0.500  0.500  0.200  2.000  2.000  1.000  0.06375
lamda(max):  8.6333   C.I.:  0.09047   C.R.:  0.06416


        Performance
   1      2      3     Priority
 1.000  3.000  1.000  0.44743
 0.333  1.000  0.500  0.16520
 1.000  2.000  1.000  0.38737
lamda(max):  3.0183   C.I.:  0.00915   C.R.:  0.01577


             Risks
   1      2      3     Priority
 1.000  3.000  2.000  0.54995
 0.333  1.000  1.000  0.20984
 0.500  1.000  1.000  0.24021
lamda(max):  3.0183   C.I.:  0.00915   C.R.:  0.01577


          Logistics
   1      2      3     Priority
 1.000  0.500  0.333  0.16342
 2.000  1.000  0.500  0.29696
 3.000  2.000  1.000  0.53961
lamda(max):  3.0092   C.I.:  0.00461   C.R.:  0.00795
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Survivability
  1      2      3      4      5      6      7     Priority
1.000  1.000  0.143  0.143  0.200  0.111  0.111  0.01973
1.000  1.000  0.143  0.143  0.143  0.111  0.111  0.01915
7.000  7.000  1.000  7.000  7.000  1.000  1.000  0.25006
7.000  7.000  0.143  1.000  0.200  0.143  0.111  0.05476
5.000  7.000  0.143  5.000  1.000  0.111  0.111  0.08356
9.000  9.000  1.000  7.000  9.000  1.000  1.000  0.27973
9.000  9.000  1.000  9.000  9.000  1.000  1.000  0.29301
lamda(max):  8.2509   C.I.:  0.20848   C.R.:  0.15794


        Propellants
  1      2      3     Priority
1.000  0.200  0.143  0.07030
5.000  1.000  5.000  0.67243
7.000  0.200  1.000  0.25726
lamda(max):  3.4357   C.I.:  0.21794   C.R.:  0.37559


     Maintainability
  1      2      3      4     Priority
1.000  0.111  0.200  0.333  0.05865
9.000  1.000  5.000  0.333  0.34204
5.000  0.200  1.000  0.200  0.12103
3.000  3.000  5.000  1.000  0.47827
lamda(max):  4.7787   C.I.:  0.25956   C.R.:  0.28840


     Maneuverability
  1      2      3     Priority
1.000  7.000  9.000  0.76076
0.143  1.000  7.000  0.19119
0.111  0.143  1.000  0.04805
lamda(max):  3.3276   C.I.:  0.16382   C.R.:  0.28245

The Consistency of this hierarchy =  0.2999
```

APPENDIX J: AHP Follow-Up Survey Data

```
        Judge #  4 AHP RESULTS
    TAV Effectiveness
   1      2      3      4      5      6    Priority
 1.000  9.000  9.000  9.000  9.000  9.000  0.60031
 0.111  1.000  5.000  1.000  3.000  3.000  0.12656
 0.111  0.200  1.000  1.000  0.333  0.333  0.03987
 0.111  1.000  1.000  1.000  3.000  3.000  0.10375
 0.111  0.333  3.000  0.333  1.000  0.200  0.04667
 0.111  0.333  3.000  0.333  5.000  1.000  0.08285
lamda(max):   6.9923   C.I.:  0.19846   C.R.:  0.16004


        Requirements
   1      2      3      4      5      6      7      8    Priority
 1.000  9.000  9.000  1.000  1.000  9.000  9.000  9.000  0.25351
 0.111  1.000  1.000  0.200  1.000  0.143  7.000  0.200  0.03998
 0.111  1.000  1.000  0.143  0.143  0.143  5.000  1.000  0.02849
 1.000  5.000  7.000  1.000  7.000  9.000  9.000  9.000  0.33175
 1.000  1.000  7.000  0.143  1.000  7.000  9.000  9.000  0.18296
 0.111  7.000  7.000  0.111  0.143  1.000  9.000  0.143  0.06652
 0.111  0.143  0.200  0.111  0.111  0.111  1.000  0.111  0.01108
 0.111  5.000  1.000  0.111  0.111  7.000  9.000  1.000  0.08570
lamda(max):   11.2589   C.I.:  0.46555   C.R.:  0.33018


         Performance
   1      2      3    Priority
 1.000  7.000  0.143  0.19119
 0.143  1.000  0.111  0.04805
 7.000  9.000  1.000  0.76076
lamda(max):   3.3276   C.I.:  0.16382   C.R.:  0.28245


               Risks
   1      2      3    Priority
 1.000  5.000  9.000  0.72193
 0.200  1.000  7.000  0.22706
 0.111  0.143  1.000  0.05101
lamda(max):   3.2085   C.I.:  0.10423   C.R.:  0.17971


            Logistics
   1      2      3    Priority
 1.000  0.143  0.111  0.04805
 7.000  1.000  0.143  0.19119
 9.000  7.000  1.000  0.76076
lamda(max):   3.3276   C.I.:  0.16382   C.R.:  0.28245
```

APPENDIX J: AHP Follow-Up Survey Data

Survivability

1	2	3	4	5	6	7	Priority
1.000	7.000	3.000	7.000	0.333	5.000	0.200	0.17865
0.143	1.000	0.333	3.000	0.200	1.000	0.200	0.04804
0.333	3.000	1.000	3.000	1.000	3.000	0.200	0.10180
0.143	0.333	0.333	1.000	0.200	3.000	0.143	0.03947
3.000	5.000	1.000	5.000	1.000	5.000	0.333	0.19958
0.200	1.000	0.333	0.333	0.200	1.000	0.143	0.03310
5.000	5.000	5.000	7.000	3.000	7.000	1.000	0.39935

lamda(max): 7.8842 C.I.: 0.14736 C.R.: 0.11164

Propellants

1	2	3	Priority
1.000	1.000	0.333	0.20000
1.000	1.000	0.333	0.20000
3.000	3.000	1.000	0.60000

lamda(max): 3.0000 C.I.: 0.00000 C.R.: 0.00000

Maintainability

1	2	3	4	Priority
1.000	0.333	0.200	1.000	0.10685
3.000	1.000	0.333	1.000	0.20979
5.000	3.000	1.000	3.000	0.52550
1.000	1.000	0.333	1.000	0.15786

lamda(max): 4.1155 C.I.: 0.03849 C.R.: 0.04276

Maneuverability

1	2	3	Priority
1.000	5.000	7.000	0.71471
0.200	1.000	5.000	0.21849
0.143	0.200	1.000	0.06680

lamda(max): 3.1828 C.I.: 0.09138 C.R.: 0.15756

The Consistency of this hierarchy = 0.0919

APPENDIX J: AHP Follow-Up Survey Data

```
       Judge #  3 AHP RESULTS
    TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  1.000  1.000  3.000  5.000  7.000  0.25874
 1.000  1.000  1.000  3.000  5.000  7.000  0.25874
 1.000  1.000  1.000  3.000  7.000  7.000  0.27401
 0.333  0.333  0.333  1.000  5.000  7.000  0.13252
 0.200  0.200  0.143  0.200  1.000  3.000  0.04795
 0.143  0.143  0.143  0.143  0.333  1.000  0.02803
lamda(max):  6.2805   C.I.:  0.05609   C.R.:  0.04524


       Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  7.000  3.000  5.000  5.000  9.000  0.333  1.000  0.23933
 0.143  1.000  3.000  0.333  0.200  5.000  0.200  0.200  0.04415
 0.333  0.333  1.000  0.333  0.143  3.000  0.200  0.333  0.03548
 0.200  3.000  3.000  1.000  0.200  5.000  0.200  0.333  0.06154
 0.200  5.000  7.000  5.000  1.000  7.000  0.333  3.000  0.17343
 0.111  0.200  0.333  0.200  0.143  1.000  0.111  0.111  0.01610
 3.000  5.000  5.000  5.000  3.000  9.000  1.000  3.000  0.30151
 1.000  5.000  3.000  3.000  0.333  9.000  0.333  1.000  0.12847
lamda(max):  9.2068   C.I.:  0.17241   C.R.:  0.12227


        Performance
   1      2      3     Priority
 1.000  5.000  3.000  0.65864
 0.200  1.000  1.000  0.15618
 0.333  1.000  1.000  0.18517
lamda(max):  3.0291   C.I.:  0.01453   C.R.:  0.02505


              Risks
   1      2      3     Priority
 1.000  0.200  0.143  0.07193
 5.000  1.000  0.333  0.27895
 7.000  3.000  1.000  0.64912
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594


           Logistics
   1      2      3     Priority
 1.000  5.000  0.333  0.27895
 0.200  1.000  0.143  0.07193
 3.000  7.000  1.000  0.64912
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594
```

APPENDIX J: AHP Follow-Up Survey Data

Survivability

1	2	3	4	5	6	7	Priority
1.000	0.333	0.333	0.200	1.000	0.200	0.143	0.03468
3.000	1.000	1.000	2.000	1.000	0.200	0.143	0.07781
3.000	1.000	1.000	1.000	1.000	0.200	0.143	0.06584
5.000	0.500	1.000	1.000	3.000	0.333	0.200	0.09161
1.000	1.000	1.000	0.333	1.000	0.333	0.200	0.05596
5.000	5.000	5.000	3.000	3.000	1.000	0.200	0.21440
7.000	7.000	7.000	5.000	5.000	5.000	1.000	0.45970

lamda(max): 7.6524 C.I.: 0.10874 C.R.: 0.08238

Propellants

1	2	3	Priority
1.000	5.000	0.333	0.28720
0.200	1.000	0.167	0.07796
3.000	6.000	1.000	0.63484

lamda(max): 3.0940 C.I.: 0.04701 C.R.: 0.08105

Maintainability

1	2	3	4	Priority
1.000	1.000	0.200	0.200	0.09082
1.000	1.000	0.333	0.333	0.11701
5.000	3.000	1.000	1.000	0.39608
5.000	3.000	1.000	1.000	0.39608

lamda(max): 4.0328 C.I.: 0.01093 C.R.: 0.01215

Maneuverability

1	2	3	Priority
1.000	0.500	0.200	0.10884
2.000	1.000	0.167	0.16258
5.000	6.000	1.000	0.72858

lamda(max): 3.0858 C.I.: 0.04288 C.R.: 0.07394

The Consistency of this hierarchy = 0.0472

APPENDIX J: AHP Follow-Up Survey Data

```
      Judge #  2 AHP RESULTS
   TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  1.000  1.000  3.000  1.000  0.500  0.15858
 1.000  1.000  2.000  3.000  1.000  1.000  0.20296
 1.000  0.500  1.000  1.000  1.000  1.000  0.14235
 0.333  0.333  1.000  1.000  0.333  0.200  0.06935
 1.000  1.000  1.000  3.000  1.000  0.333  0.15131
 2.000  1.000  1.000  5.000  3.000  1.000  0.27545
lamda(max):  6.3120   C.I.:  0.06240   C.R.:  0.05032
```

```
      Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  1.000  1.000  0.500  7.000  7.000  2.000  1.000  0.16379
 1.000  1.000  1.000  1.000  7.000  7.000  3.000  1.000  0.18690
 1.000  1.000  1.000  1.000  7.000  7.000  2.000  1.000  0.17486
 2.000  1.000  1.000  1.000  7.000  7.000  1.000  1.000  0.18265
 0.143  0.143  0.143  0.143  1.000  1.000  0.333  0.333  0.02867
 0.143  0.143  0.143  0.143  1.000  1.000  0.333  0.333  0.02867
 0.500  0.333  0.500  1.000  3.000  3.000  1.000  1.000  0.09942
 1.000  1.000  1.000  1.000  3.000  3.000  1.000  1.000  0.13503
lamda(max):  8.2550   C.I.:  0.03643   C.R.:  0.02584
```

```
       Performance
   1      2      3     Priority
 1.000  3.000  1.000  0.42857
 0.333  1.000  0.333  0.14286
 1.000  3.000  1.000  0.42857
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000
```

```
              Risks
   1      2      3     Priority
 1.000  0.143  0.333  0.08795
 7.000  1.000  3.000  0.66942
 3.000  0.333  1.000  0.24264
lamda(max):  3.0070   C.I.:  0.00351   C.R.:  0.00605
```

```
         Logistics
   1      2      3     Priority
 1.000  3.000  0.333  0.25828
 0.333  1.000  0.200  0.10473
 3.000  5.000  1.000  0.63699
lamda(max):  3.0385   C.I.:  0.01926   C.R.:  0.03320
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Survivability
  1      2      3      4      5      6      7     Priority
 1.000  0.333  0.333  0.333  3.000  0.200  0.200  0.06006
 3.000  1.000  1.000  1.000  3.000  1.000  0.333  0.14434
 3.000  1.000  1.000  1.000  3.000  1.000  1.000  0.16399
 3.000  1.000  1.000  1.000  3.000  0.333  1.000  0.14434
 0.333  0.333  0.333  0.333  1.000  0.333  0.333  0.04927
 5.000  1.000  1.000  3.000  3.000  1.000  1.000  0.21900
 5.000  3.000  1.000  1.000  3.000  1.000  1.000  0.21900
lamda(max):  7.4316   C.I.:  0.07193   C.R.:  0.05449


       Propellants
  1      2      3     Priority
 1.000  0.333  0.333  0.14286
 3.000  1.000  1.000  0.42857
 3.000  1.000  1.000  0.42857
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


     Maintainability
  1      2      3      4     Priority
 1.000  0.333  0.333  0.333  0.09393
 3.000  1.000  0.333  0.500  0.17614
 3.000  3.000  1.000  3.000  0.48268
 3.000  2.000  0.333  1.000  0.24725
lamda(max):  4.2153   C.I.:  0.07175   C.R.:  0.07973


     Maneuverability
  1      2      3     Priority
 1.000  0.200  0.333  0.10065
 5.000  1.000  4.000  0.67381
 3.000  0.250  1.000  0.22554
lamda(max):  3.0858   C.I.:  0.04288   C.R.:  0.07394

The Consistency of this hierarchy =  0.0209
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Judge #  1 AHP RESULTS
   TAV Effectiveness
  1      2      3      4      5      6     Priority
 1.000  3.000  3.000  5.000  1.000  3.000  0.31320
 0.333  1.000  1.000  3.000  0.333  3.000  0.14129
 0.333  1.000  1.000  3.000  1.000  3.000  0.16696
 0.200  0.333  0.333  1.000  0.333  0.333  0.05134
 1.000  3.000  1.000  3.000  1.000  3.000  0.24440
 0.333  0.333  0.333  3.000  0.333  1.000  0.08280
lamda(max):  6.3457   C.I.:  0.06913   C.R.:  0.05575


      Requirements
  1      2      3      4      5      6      7      8     Priority
 1.000  1.000  1.000  1.000  1.000  5.000  1.000  1.000  0.13448
 1.000  1.000  1.000  1.000  1.000  5.000  1.000  1.000  0.13448
 1.000  1.000  1.000  1.000  1.000  5.000  3.000  1.000  0.15496
 1.000  1.000  1.000  1.000  1.000  5.000  3.000  1.000  0.15496
 1.000  1.000  1.000  1.000  1.000  5.000  3.000  1.000  0.15496
 0.200  0.200  0.200  0.200  0.200  1.000  0.200  0.200  0.02690
 1.000  1.000  0.333  0.333  0.333  5.000  1.000  0.333  0.08431
 1.000  1.000  1.000  1.000  1.000  5.000  3.000  1.000  0.15496
lamda(max):  8.2359   C.I.:  0.03370   C.R.:  0.02390


       Performance
  1      2      3     Priority
 1.000  1.000  3.000  0.42857
 1.000  1.000  3.000  0.42857
 0.333  0.333  1.000  0.14286
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


             Risks
  1      2      3     Priority
 1.000  0.200  0.200  0.09091
 5.000  1.000  1.000  0.45455
 5.000  1.000  1.000  0.45455
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


          Logistics
  1      2      3     Priority
 1.000  0.333  0.333  0.14286
 3.000  1.000  1.000  0.42857
 3.000  1.000  1.000  0.42857
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Judge #  8 AHP RESULTS
   TAV Effectiveness
  1      2      3      4      5      6    Priority
 1.000  1.000  1.000  7.000  1.000  7.000  0.24097
 1.000  1.000  1.000  5.000  3.000  5.000  0.26909
 1.000  1.000  1.000  5.000  1.000  5.000  0.21213
 0.143  0.200  0.200  1.000  0.200  0.200  0.03282
 1.000  0.333  1.000  5.000  1.000  5.000  0.18442
 0.143  0.200  0.200  5.000  0.200  1.000  0.06057
lamda(max):   6.4751   C.I.:  0.09502   C.R.:  0.07663
```

```
       Requirements
  1      2      3      4      5      6      7      8     Priority
 1.000  0.200  9.000  1.000  0.333  9.000  0.200  0.200  0.07520
 5.000  1.000  9.000  3.000  1.000  9.000  3.000  0.333  0.20769
 0.111  0.111  1.000  0.143  0.143  1.000  0.143  0.143  0.01785
 1.000  0.333  7.000  1.000  0.333  9.000  3.000  1.000  0.12949
 3.000  1.000  7.000  3.000  1.000  9.000  3.000  1.000  0.20471
 0.111  0.111  1.000  0.111  0.111  1.000  0.111  0.111  0.01547
 5.000  0.333  7.000  0.333  0.333  9.000  1.000  0.333  0.11116
 5.000  3.000  7.000  1.000  1.000  9.000  3.000  1.000  0.23842
lamda(max):   9.0988   C.I.:  0.15697   C.R.:  0.11133
```

```
        Performance
  1      2      3    Priority
 1.000  5.000  5.000  0.68542
 0.200  1.000  5.000  0.23441
 0.200  0.200  1.000  0.08017
lamda(max):  3.2948   C.I.:  0.14739   C.R.:  0.25412
```

```
            Risks
  1      2      3    Priority
 1.000  0.143  1.000  0.13151
 7.000  1.000  3.000  0.69406
 1.000  0.333  1.000  0.17443
lamda(max):  3.0803   C.I.:  0.04015   C.R.:  0.06922
```

```
         Logistics
  1      2      3    Priority
 1.000  1.000  0.200  0.13356
 1.000  1.000  0.143  0.11939
 5.000  7.000  1.000  0.74705
lamda(max):  3.0126   C.I.:  0.00630   C.R.:  0.01086
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Survivability
   1      2      3      4      5      6      7     Priority
 1.000  0.143  3.000  0.143  0.333  1.000  0.143  0.03863
 7.000  1.000  7.000  1.000  7.000  5.000  5.000  0.36441
 0.333  0.143  1.000  0.143  0.143  0.143  0.143  0.02152
 7.000  1.000  7.000  1.000  3.000  7.000  1.000  0.23819
 3.000  0.143  7.000  0.333  1.000  1.000  0.200  0.07296
 1.000  0.200  7.000  0.143  1.000  1.000  0.200  0.05997
 7.000  0.200  7.000  1.000  5.000  5.000  1.000  0.20431
lamda(max):  7.8369   C.I.:  0.13948   C.R.:  0.10567


       Propellants
   1      2      3    Priority
 1.000  9.000  1.000  0.59052
 0.111  1.000  7.000  0.26108
 1.000  0.143  1.000  0.14841
lamda(max):  5.2304   C.I.:  1.11519   C.R.:  1.92274


     Maintainability
   1      2      3      4    Priority
 1.000  0.143  0.200  0.200  0.04719
 7.000  1.000  3.000  5.000  0.53630
 5.000  0.333  1.000  5.000  0.29768
 5.000  0.200  0.200  1.000  0.11883
lamda(max):  4.3890   C.I.:  0.12968   C.R.:  0.14409


     Maneuverability
   1      2      3    Priority
 1.000  5.000  7.000  0.70149
 0.200  1.000  7.000  0.23991
 0.143  0.143  1.000  0.05860
lamda(max):  3.2948   C.I.:  0.14739   C.R.:  0.25412

The Consistency of this hierarchy =  0.1594
```

APPENDIX J: AHP Follow-Up Survey Data

```
          Judge # 9 AHP RESULTS
      TAV Effectiveness
  1      2      3      4      5      6     Priority
1.000  0.143  0.333  0.200  0.333  0.333  0.03973
7.000  1.000  3.000  3.000  1.000  3.000  0.32302
3.000  0.333  1.000  0.333  0.333  0.333  0.07399
5.000  0.333  3.000  1.000  3.000  4.000  0.26985
3.000  1.000  3.000  0.333  1.000  3.000  0.18997
3.000  0.333  3.000  0.250  0.333  1.000  0.10344
lamda(max):  6.6031   C.I.:  0.12063   C.R.:  0.09728


          Requirements
  1      2      3      4      5      6      7      8     Priority
1.000  5.000  7.000  3.000  3.000  7.000  3.000  0.333  0.24621
0.200  1.000  7.000  1.000  3.000  7.000  3.000  0.333  0.13203
0.143  0.143  1.000  0.143  0.200  0.333  0.200  0.143  0.01926
0.333  1.000  7.000  1.000  3.000  5.000  3.000  1.000  0.15014
0.333  0.333  5.000  0.333  1.000  3.000  3.000  0.200  0.07608
0.143  0.143  3.000  0.200  0.333  1.000  0.200  0.200  0.02964
0.333  0.333  5.000  0.333  0.333  5.000  1.000  0.200  0.06300
3.000  3.000  7.000  1.000  5.000  5.000  5.000  1.000  0.28364
lamda(max):  8.9796   C.I.:  0.13994   C.R.:  0.09925


           Performance
  1      2      3     Priority
1.000  3.000  0.143  0.15787
0.333  1.000  0.143  0.07590
7.000  7.000  1.000  0.76623
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691


                 Risks
  1      2      3     Priority
1.000  1.000  0.800  0.30769
1.000  1.000  0.800  0.30769
1.250  1.250  1.000  0.38462
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


             Logistics
  1      2      3     Priority
1.000  3.000  3.000  0.60000
0.333  1.000  1.000  0.20000
0.333  1.000  1.000  0.20000
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000
```

APPENDIX J: AHP Follow-Up Survey Data

```
        Survivability
  1      2      3      4      5      6      7    Priority
1.000  0.333  0.200  0.200  3.000  0.200  0.200  0.04766
3.000  1.000  0.333  0.333  5.000  0.333  0.333  0.09342
5.000  3.000  1.000  1.000  3.000  1.000  1.000  0.19353
5.000  3.000  1.000  1.000  3.000  1.000  1.000  0.19353
0.333  0.200  0.333  0.333  1.000  0.200  0.200  0.03842
5.000  3.000  1.000  1.000  5.000  1.000  3.000  0.25204
5.000  3.000  1.000  1.000  5.000  0.333  1.000  0.18140
lamda(max):  7.5146   C.I.:  0.08576   C.R.:  0.06497


        Propellants
  1      2      3    Priority
1.000  1.000  0.143  0.11111
1.000  1.000  0.143  0.11111
7.000  7.000  1.000  0.77778
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


       Maintainability
  1      2      3      4    Priority
1.000  0.143  0.143  0.200  0.04496
7.000  1.000  3.000  3.000  0.51057
7.000  0.333  1.000  3.000  0.29196
5.000  0.333  0.333  1.000  0.15251
lamda(max):  4.2281   C.I.:  0.07604   C.R.:  0.08449


       Maneuverability
  1      2      3    Priority
1.000  0.200  3.000  0.18839
5.000  1.000  7.000  0.73064
0.333  0.143  1.000  0.08096
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594

The Consistency of this hierarchy =  0.0545
```

APPENDIX J: AHP Follow-Up Survey Data

```
        Judge # 10 AHP RESULTS
   TAV Effectiveness
   1      2      3      4      5      6     Priority
 1.000  3.000  3.000  3.000  3.000  3.000  0.34463
 0.333  1.000  3.000  1.000  0.333  0.333  0.09981
 0.333  0.333  1.000  3.000  0.333  0.333  0.08445
 0.333  1.000  0.333  1.000  0.333  0.333  0.06622
 0.333  3.000  3.000  3.000  1.000  0.333  0.16582
 0.333  3.000  3.000  3.000  3.000  1.000  0.23906
lamda(max):  6.7049   C.I.:  0.14098   C.R.:  0.11370


        Requirements
   1      2      3      4      5      6      7      8     Priority
 1.000  1.000  3.000  1.000  3.000  3.000  3.000  1.000  0.17917
 1.000  1.000  1.000  0.333  1.000  3.000  1.000  1.000  0.10828
 0.333  1.000  1.000  0.333  1.000  3.000  0.333  0.333  0.07379
 1.000  3.000  3.000  1.000  5.000  5.000  3.000  1.000  0.23431
 0.333  1.000  1.000  0.200  1.000  1.000  3.000  0.333  0.08176
 0.333  0.333  0.333  0.200  1.000  1.000  1.000  0.333  0.05051
 0.333  1.000  3.000  0.333  0.333  1.000  1.000  0.200  0.07566
 1.000  1.000  3.000  1.000  3.000  3.000  5.000  1.000  0.19652
lamda(max):  8.7258   C.I.:  0.10368   C.R.:  0.07353


         Performance
   1      2      3    Priority
 1.000  0.333  0.200  0.09717
 3.000  1.000  0.200  0.20212
 5.000  5.000  1.000  0.70071
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691


                Risks
   1      2      3    Priority
 1.000  0.500  0.500  0.20000
 2.000  1.000  1.000  0.40000
 2.000  1.000  1.000  0.40000
lamda(max):  3.0000   C.I.:  0.00000   C.R.:  0.00000


           Logistics
   1      2      3    Priority
 1.000  3.000  0.111  0.12952
 0.333  1.000  0.111  0.06227
 9.000  9.000  1.000  0.80822
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691
```

APPENDIX J: AHP Follow-Up Survey Data

```
       Survivability
   1      2      3      4      5      6      7     Priority
 1.000  1.000  0.200  1.000  0.333  0.200  0.200  0.05306
 1.000  1.000  0.200  0.333  0.333  0.333  0.333  0.04107
 5.000  5.000  1.000  5.000  5.000  5.000  5.000  0.40561
 1.000  3.000  0.200  1.000  5.000  3.000  3.000  0.19065
 3.000  3.000  0.200  0.200  1.000  1.000  3.000  0.10537
 5.000  3.000  0.200  0.333  1.000  1.000  3.000  0.12116
 5.000  3.000  0.200  0.333  0.333  0.333  1.000  0.08308
lamda(max):  8.3272   C.I.:  0.22121   C.R.:  0.16758
```

```
        Propellants
   1      2      3    Priority
 1.000  7.000  3.000  0.64912
 0.143  1.000  0.200  0.07193
 0.333  5.000  1.000  0.27895
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594
```

```
     Maintainability
   1      2      3      4    Priority
 1.000  7.000  7.000  5.000  0.64484
 0.143  1.000  5.000  3.000  0.19210
 0.143  0.200  1.000  0.200  0.04425
 0.200  0.333  5.000  1.000  0.11881
lamda(max):  4.4868   C.I.:  0.16228   C.R.:  0.18031
```

```
     Maneuverability
   1      2      3    Priority
 1.000  0.200  0.333  0.11397
 5.000  1.000  1.000  0.48064
 3.000  1.000  1.000  0.40539
lamda(max):  3.0291   C.I.:  0.01453   C.R.:  0.02506

The Consistency of this hierarchy =  0.1050
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Judge # 11 AHP RESULTS
  TAV Effectiveness
  1      2      3      4      5      6      Priority
 1.000  2.000  7.000  7.000  7.000  7.000  0.39494
 0.500  1.000  7.000  7.000  7.000  7.000  0.32603
 0.143  0.143  1.000  0.200  0.143  0.143  0.02182
 0.143  0.143  5.000  1.000  0.143  5.000  0.07371
 0.143  0.143  7.000  7.000  1.000  2.000  0.13246
 0.143  0.143  7.000  0.200  0.500  1.000  0.05104
lamda(max):  7.5967   C.I.:  0.31935   C.R.:  0.25754


      Requirements
  1      2      3      4      5      6      7      8      Priority
 1.000  7.000  9.000  7.000  9.000  9.000  9.000  7.000  0.42194
 0.143  1.000  9.000  0.143  9.000  9.000  9.000  5.000  0.14559
 0.111  0.111  1.000  0.143  0.200  1.000  5.000  0.143  0.02372
 0.143  7.000  7.000  1.000  7.000  9.000  7.000  7.000  0.24189
 0.111  0.111  5.000  0.143  1.000  7.000  7.000  0.143  0.04677
 0.111  0.111  1.000  0.111  0.143  1.000  0.143  0.143  0.01344
 0.111  0.111  0.200  0.143  0.143  7.000  1.000  0.143  0.02134
 0.143  0.200  7.000  0.143  7.000  7.000  7.000  1.000  0.08532
lamda(max):  11.0889   C.I.:  0.44127   C.R.:  0.31296


       Performance
  1      2      3      Priority
 1.000  7.000  7.000  0.75311
 0.143  1.000  5.000  0.18397
 0.143  0.200  1.000  0.06292
lamda(max):  3.2948   C.I.:  0.14739   C.R.:  0.25412


             Risks
  1      2      3      Priority
 1.000  0.200  0.143  0.06680
 5.000  1.000  0.200  0.21849
 7.000  5.000  1.000  0.71471
lamda(max):  3.1828   C.I.:  0.09138   C.R.:  0.15756


        Logistics
  1      2      3      Priority
 1.000  7.000  3.000  0.63299
 0.143  1.000  0.143  0.06270
 0.333  7.000  1.000  0.30431
lamda(max):  3.1356   C.I.:  0.06781   C.R.:  0.11691
```

APPENDIX J: AHP Follow-Up Survey Data

```
       Survivability
   1      2      3      4      5      6      7    Priority
 1.000  0.111  0.143  0.143  0.143  0.143  0.143  0.01580
 9.000  1.000  7.000  5.000  7.000  7.000  7.000  0.44906
 7.000  0.143  1.000  0.143  5.000  5.000  0.143  0.07343
 7.000  0.200  7.000  1.000  7.000  5.000  0.200  0.14879
 7.000  0.143  0.200  0.143  1.000  1.000  0.143  0.03519
 7.000  0.143  0.200  0.200  1.000  1.000  0.143  0.03613
 7.000  0.143  7.000  5.000  7.000  7.000  1.000  0.24161
lamda(max):  8.9959   C.I.:  0.33265   C.R.:  0.25201


        Propellants
   1      2      3    Priority
 1.000  9.000  7.000  0.76076
 0.111  1.000  0.143  0.04805
 0.143  7.000  1.000  0.19119
lamda(max):  3.3276   C.I.:  0.16382   C.R.:  0.28245


      Maintainability
   1      2      3      4    Priority
 1.000  0.143  0.111  0.200  0.03372
 7.000  1.000  0.143  5.000  0.20401
 9.000  7.000  1.000  9.000  0.68270
 5.000  0.200  0.111  1.000  0.07957
lamda(max):  4.5853   C.I.:  0.19511   C.R.:  0.21679


      Maneuverability
   1      2      3    Priority
 1.000  7.000  7.000  0.74186
 0.143  1.000  7.000  0.20273
 0.143  0.143  1.000  0.05540
lamda(max):  3.4357   C.I.:  0.21784   C.R.:  0.37559

The Consistency of this hierarchy =  0.2829
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Judge # 12 AHP RESULTS
  TAV Effectiveness
  1      2      3      4      5      6     Priority
1.000  0.143  1.000  5.000  5.000  5.000  0.21111
7.000  1.000  1.000  5.000  3.000  3.000  0.38633
1.000  1.000  1.000  5.000  1.000  5.000  0.18754
0.200  0.200  0.200  1.000  0.333  3.000  0.05058
0.200  0.333  1.000  3.000  1.000  7.000  0.12546
0.200  0.333  0.200  0.333  0.143  1.000  0.03898
lamda(max):  7.2422   C.I.:  0.24843   C.R.:  0.20035


      Requirements
  1      2      3      4      5      6      7      8     Priority
1.000  7.000  7.000  5.000  0.143  0.200  0.200  5.000  0.13624
0.143  1.000  1.000  0.200  0.143  0.200  0.200  0.200  0.01760
0.143  1.000  1.000  0.200  0.143  0.333  0.143  5.000  0.06870
0.200  5.000  5.000  1.000  0.143  3.000  0.143  0.200  0.06332
7.000  7.000  7.000  7.000  1.000  5.000  5.000  3.000  0.29507
5.000  5.000  3.000  0.333  0.200  1.000  0.143  0.200  0.08627
5.000  5.000  7.000  7.000  0.200  7.000  1.000  0.200  0.18520
0.200  5.000  0.200  5.000  0.333  5.000  5.000  1.000  0.14759
lamda(max):  13.8826   C.I.:  0.84036   C.R.:  0.59600


       Performance
  1      2      3    Priority
1.000  7.000  1.000  0.48692
0.143  1.000  0.200  0.07782
1.000  5.000  1.000  0.43526
lamda(max):  3.0126   C.I.:  0.00630   C.R.:  0.01086


             Risks
  1      2      3    Priority
1.000  0.200  0.143  0.07782
5.000  1.000  1.000  0.43526
7.000  1.000  1.000  0.48692
lamda(max):  3.0126   C.I.:  0.00630   C.R.:  0.01086


          Logistics
  1      2      3    Priority
1.000  0.143  0.143  0.05540
7.000  1.000  0.143  0.20273
7.000  7.000  1.000  0.74186
lamda(max):  3.4357   C.I.:  0.21784   C.R.:  0.37559
```

APPENDIX J: AHP Follow-Up Survey Data

```
        Survivability
  1      2      3      4      5      6      7    Priority
1.000  3.000  7.000  1.000  3.000  3.000  3.000  0.29514
0.333  1.000  5.000  7.000  3.000  3.000  3.000  0.26087
0.143  0.200  1.000  1.000  3.000  3.000  0.200  0.06511
1.000  0.143  1.000  1.000  3.000  3.000  0.200  0.09341
0.333  0.333  0.333  0.333  1.000  1.000  0.143  0.04181
0.333  0.333  0.333  0.333  1.000  1.000  0.200  0.04317
0.333  0.333  5.000  5.000  7.000  5.000  1.000  0.20049
lamda(max):  8.4143   C.I.:  0.23572   C.R.:  0.17858


         Propellants
  1      2      3    Priority
1.000  9.000  5.000  0.73519
0.111  1.000  0.200  0.05811
0.200  5.000  1.000  0.20670
lamda(max):  3.1171   C.I.:  0.05855   C.R.:  0.10095


       Maintainability
  1      2      3      4    Priority
1.000  5.000  0.200  0.200  0.11883
0.200  1.000  0.200  0.143  0.04719
5.000  5.000  1.000  0.333  0.29768
5.000  7.000  3.000  1.000  0.53630
lamda(max):  4.3890   C.I.:  0.12968   C.R.:  0.14409


       Maneuverability
  1      2      3    Priority
1.000  7.000  3.000  0.64912
0.143  1.000  0.200  0.07193
0.333  5.000  1.000  0.27895
lamda(max):  3.0649   C.I.:  0.03244   C.R.:  0.05594

The Consistency of this hierarchy =  0.3076
```

APPENDIX J: AHP Follow-Up Survey Data

Geometric Mean for 9 Returned Surveys

TAV Effectiveness

1	2	3	4	5	6	Weight
1.00	1.22	1.87	3.62	2.31	1.87	0.27804
0.82	1.00	2.25	2.84	2.25	2.31	0.26297
0.53	0.44	1.00	1.09	1.11	1.00	0.12311
0.28	0.35	0.92	1.00	1.29	0.76	0.10227
0.43	0.44	0.90	0.77	1.00	0.98	0.10875
0.53	0.43	1.00	1.32	1.02	1.00	0.12486

lamda(max): 6.0563 C.I.: 0.01126 C.R.: 0.00908

Requirements

1	2	3	4	5	6	7	8	Weight	Comp-Wt
1.00	2.08	3.91	2.10	1.89	7.47	1.44	1.07	0.22977	0.0639
0.48	1.00	2.77	1.20	0.84	4.02	1.68	0.64	0.13445	0.0374
0.26	0.36	1.00	0.36	0.44	1.71	0.77	0.55	0.06119	0.0170
0.48	0.84	2.76	1.00	1.02	5.70	1.60	1.08	0.14541	0.0404
0.53	1.20	2.25	0.98	1.00	4.81	1.76	1.28	0.15042	0.0418
0.13	0.25	0.58	0.18	0.21	1.00	0.41	0.20	0.03161	0.0088
0.70	0.59	1.29	0.62	0.57	2.44	1.00	0.59	0.09281	0.0258
0.94	1.56	1.82	0.93	0.78	4.95	1.70	1.00	0.15434	0.0429

lamda(max): 8.1489 C.I.: 0.02128 C.R.: 0.01509

Performance

1	2	3	Weight	Comp-Wt
1.00	2.99	1.39	0.48940	0.1287
0.33	1.00	0.58	0.18062	0.0475
0.72	1.71	1.00	0.32999	0.0868

lamda(max): 3.0043 C.I.: 0.00213 C.R.: 0.00368

Risks

1	2	3	Weight	Comp-Wt
1.00	0.75	1.00	0.30091	0.0308
1.31	1.00	1.37	0.40133	0.0410
1.00	0.73	1.00	0.29776	0.0305

lamda(max): 3.0002 C.I.: 0.00011 C.R.: 0.00019

Logistics

1	2	3	Weight	Comp-Wt
1.00	1.50	0.37	0.23101	0.0251
0.67	1.00	0.27	0.16012	0.0174
2.73	3.67	1.00	0.60888	0.0662

lamda(max): 3.0013 C.I.: 0.00065 C.R.: 0.00112

APPENDIX J: AHP Follow-Up Survey Data

```
      Survivability
  1       2       3       4       5       6       7     Weight   Comp-Wt
 1.00   0.44    0.46    0.46    0.67    0.44    0.19  0.05984  0.0075
 2.26   1.00    0.76    1.52    1.40    0.65    0.39  0.12576  0.0157
 2.18   1.31    1.00    1.34    1.51    0.72    0.47  0.13918  0.0174
 2.17   0.66    0.75    1.00    1.14    0.81    0.33  0.10829  0.0135
 1.48   0.71    0.66    0.88    1.00    0.66    0.27  0.09183  0.0115
 2.27   1.53    1.38    1.24    1.51    1.00    0.52  0.15863  0.0198
 5.26   2.58    2.14    3.00    3.76    1.92    1.00  0.31648  0.0395
lamda(max):  7.0439   C.I.:  0.00732   C.R.:  0.00555

       Propellants
  1       2       3     Weight
 1.00   1.27    0.43  0.26101
 0.79   1.00    0.68  0.25917
 2.31   1.47    1.00  0.47981
lamda(max):  3.0529   C.I.:  0.02643   C.R.:  0.04557

     Maintainability
  1       2       3       4     Weight
 1.00   0.25    0.24    0.35  0.08285
 4.03   1.00    0.90    1.17  0.31238
 4.19   1.12    1.00    1.76  0.36896
 2.82   0.85    0.57    1.00  0.23581 lamda(max):  4.0101   C.I.:  0.00336   C.R.:  0.00373

     Maneuverability
  1       2       3     Weight
 1.00   1.22    2.44  0.43531
 0.82   1.00    3.05  0.40992
 0.41   0.33    1.00  0.15478
lamda(max):  3.0200   C.I.:  0.01000   C.R.:  0.01724

The Consistency of this hierarchy =  0.0097
```

APPENDIX J: AHP Follow-Up Survey Data

```
 Geometric Mean for 12 Revised Surveys (9 Returned)

  TAV Effectiveness
  1      2      3      4      5      6     Weight
1.000  1.143  2.063  3.869  2.764  2.359  0.29743
0.875  1.000  2.367  2.945  2.160  2.205  0.26146
0.485  0.423  1.000  1.168  0.840  0.887  0.11267
0.258  0.340  0.856  1.000  0.858  0.927  0.09372
0.362  0.463  1.190  1.166  1.000  1.122  0.11956
0.424  0.453  1.127  1.079  0.891  1.000  0.11517
lamda(max):  6.0298   C.I.:  0.00596   C.R.:  0.00480

       Requirements
  1      2      3      4      5      6      7      8     Weight   Comp-Wt
1.000  2.397  4.305  2.344  1.803  5.200  1.509  1.412  0.23851  0.0709
0.417  1.000  2.575  0.776  0.893  3.269  1.551  0.715  0.12097  0.0360
0.232  0.388  1.000  0.317  0.405  1.495  0.731  0.566  0.05822  0.0173
0.427  1.289  3.155  1.000  1.159  5.554  1.560  1.090  0.15569  0.0463
0.555  1.120  2.470  0.863  1.000  4.371  2.252  1.021  0.14781  0.0440
0.192  0.306  0.669  0.180  0.229  1.000  0.371  0.204  0.03474  0.0103
0.662  0.645  1.368  0.641  0.444  2.698  1.000  0.438  0.08978  0.0267
0.708  1.399  1.757  0.918  0.979  4.391  2.285  1.000  0.15428  0.0459
lamda(max):  8.1536   C.I.:  0.02194   C.R.:  0.01556

        Performance
  1      2      3     Weight   Comp-Wt
1.000  2.799  1.315  0.47829  0.1251
0.357  1.000  0.584  0.18371  0.0480
0.760  1.711  1.000  0.33799  0.0884
lamda(max):  3.0053   C.I.:  0.00263   C.R.:  0.00454

             Risks
  1      2      3     Weight   Comp-Wt
1.000  0.585  0.680  0.23995  0.0225
1.709  1.000  1.106  0.40200  0.0377
1.470  0.904  1.000  0.35805  0.0336
lamda(max):  3.0002   C.I.:  0.00011   C.R.:  0.00019

          Logistics
  1      2      3     Weight   Comp-Wt
1.000  1.482  0.365  0.28467  0.0267
0.675  1.000  0.227  0.14589  0.0176
2.739  4.402  1.000  0.56944  0.0753
lamda(max):  [illegible]   C.I.:  [illegible]   C.R.:  [illegible]
```

APPENDIX J: AHP Follow-Up Survey Data

```
      Survivability
  1      2      3      4      5      6      7     Weight   Comp-Wt
1.000  0.496  0.488  0.476  0.632  0.441  0.235  0.06425  0.0074
2.017  1.000  0.959  1.678  1.516  0.853  0.577  0.14831  0.0171
2.050  1.043  1.000  1.208  1.951  1.125  0.480  0.14879  0.0171
2.100  0.596  0.828  1.000  1.625  1.168  0.367  0.12467  0.0144
1.582  0.660  0.513  0.615  1.000  0.735  0.293  0.08863  0.0102
2.266  1.172  0.888  0.856  1.361  1.000  0.500  0.13593  0.0157
4.263  1.732  2.083  2.722  3.411  1.999  1.000  0.28942  0.0333
lamda(max):  7.0608   C.I.:  0.01013   C.R.:  0.00767

       Propellants
  1      2      3     Weight
1.000  2.025  0.786  0.36869
0.494  1.000  0.487  0.19631
1.272  2.055  1.000  0.43500
lamda(max):  3.0057   C.I.:  0.00285   C.R.:  0.00491

     Maintainability
  1      2      3      4     Weight
1.000  0.402  0.293  0.402  0.10645
2.485  1.000  0.783  1.200  0.28210
3.417  1.277  1.000  1.464  0.36252
2.488  0.833  0.683  1.000  0.24893
lamda(max):  4.0028   C.I.:  0.00094   C.R.:  0.00105

     Maneuverability
  1      2      3     Weight
1.000  1.407  2.297  0.45672
0.711  1.000  2.374  0.36778
0.435  0.421  1.000  0.17550
lamda(max):  3.0156   C.I.:  0.00778   C.R.:  0.01342

The Consistency of this hierarchy =  0.0100
```

Appendix K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	0.50	0.00	0.50	0.50	0.50	0.50	2.50	0.119
0.50	0.00	0.00	1.00	1.00	0.50	0.50	3.50	0.167
1.00	1.00	0.00	1.00	1.00	1.00	1.00	6.00	0.286
0.50	0.00	0.00	0.00	0.00	0.50	0.50	1.50	0.071
0.50	0.00	0.00	1.00	0.00	0.50	0.00	2.00	0.095
0.50	0.50	0.00	0.50	0.50	0.00	0.50	2.50	0.119
0.50	0.50	0.00	0.50	1.00	0.50	0.00	3.00	0.143

Zeta(u) = 0.4643 Zeta(c) = 0.5000

Propellants

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	0.50	1.50	0.500
1.00	0.50	0.00	1.50	0.500

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	0.00	0.00	0.00	0.00	0.000
1.00	0.00	0.50	0.50	2.00	0.333
1.00	0.50	0.00	0.50	2.00	0.333
1.00	0.50	0.50	0.00	2.00	0.333

Zeta(u) = 0.5000 Zeta(c) = 0.5000

Maneuverability

1	2	3	Total	Weights
0.00	0.50	1.00	1.50	0.500
0.50	0.00	1.00	1.50	0.500
0.00	0.00	0.00	0.00	0.000

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Appendix K: Voting Data

Judge # 7 Results (Voting Matrix)

TAV Effectiveness

1	2	3	4	5	6	Total	Weights
0.00	1.00	1.00	1.00	1.00	1.00	5.00	0.333
0.00	0.00	1.00	1.00	1.00	0.50	3.50	0.233
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
0.00	0.00	1.00	0.00	1.00	0.50	2.50	0.167
0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.067
0.00	0.50	1.00	0.50	1.00	0.00	3.00	0.200

Zeta(u) = 0.9062 Zeta(c) = 0.9375

Requirements

1	2	3	4	5	6	7	8	Total	Weights
0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	7.00	0.250
0.00	0.00	1.00	0.50	0.50	1.00	1.00	0.50	4.50	0.161
0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.50	1.50	0.054
0.00	0.50	1.00	0.00	1.00	1.00	1.00	0.50	5.00	0.179
0.00	0.50	1.00	0.00	0.00	1.00	1.00	0.50	4.00	0.143
0.00	0.00	0.50	0.00	0.00	0.00	0.50	0.00	1.00	0.036
0.00	0.00	0.50	0.00	0.00	0.50	0.00	0.00	1.00	0.036
0.00	0.50	0.50	0.50	0.50	1.00	1.00	0.00	4.00	0.143

Zeta(u) = 0.7625 Zeta(c) = 0.7750

Performance

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	0.50	0.50	0.167
0.00	0.50	0.00	0.50	0.167

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Risks

1	2	3	Total	Weights
0.00	0.50	0.50	1.00	0.333
0.50	0.00	0.50	1.00	0.333
0.50	0.50	0.00	1.00	0.333

Zeta(u) = 0.0000 Zeta(c) = 0.0000

Logistics

1	2	3	Total	Weights
0.00	1.00	0.50	1.50	0.500
0.00	0.00	0.00	0.00	0.000
0.50	1.00	0.00	1.50	0.500

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Appendix K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.50	0.024
1.00	0.00	0.50	1.00	0.50	0.00	0.00	3.00	0.143
1.00	0.50	0.00	0.50	0.50	0.00	0.00	2.50	0.119
0.50	0.00	0.50	0.00	0.50	0.00	0.00	1.50	0.071
1.00	0.50	0.50	0.50	0.00	0.50	0.50	3.50	0.167
1.00	1.00	1.00	1.00	0.50	0.00	0.50	5.00	0.238
1.00	1.00	1.00	1.00	0.50	0.50	0.00	5.00	0.238

Zeta(u) = 0.6071 Zeta(c) = 0.6429

Propellants

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	0.00	0.00	0.000
0.00	1.00	0.00	1.00	0.333

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	0.00	0.00	0.50	0.50	0.083
1.00	0.00	0.00	1.00	2.00	0.333
1.00	1.00	0.00	1.00	3.00	0.500
0.50	0.00	0.00	0.00	0.50	0.083

Zeta(u) = 0.8750 Zeta(c) = 1.0000

Maneuverability

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	0.50	0.50	0.167
0.00	0.50	0.00	0.50	0.167

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Appendix K: Voting Data

Judge # 6 Results (Voting Matrix)

TAV Effectiveness

1	2	3	4	5	6	Total	Weights
0.00	0.00	1.00	1.00	1.00	0.00	3.00	0.200
1.00	0.00	1.00	1.00	1.00	0.50	4.50	0.300
0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.067
0.00	0.00	1.00	0.00	0.50	0.00	1.50	0.100
0.00	0.00	0.00	0.50	0.00	0.00	0.50	0.033
1.00	0.50	1.00	1.00	1.00	0.00	4.50	0.300

Zeta(u) = 0.8750 Zeta(c) = 0.9375

Requirements

1	2	3	4	5	6	7	8	Total	Weights
0.00	1.00	1.00	1.00	1.00	1.00	0.00	0.50	5.50	0.196
0.00	0.00	1.00	1.00	0.00	1.00	0.00	0.50	3.50	0.125
0.00	0.00	0.00	0.00	0.50	1.00	0.00	0.00	1.50	0.054
0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	2.00	0.071
0.00	1.00	0.50	1.00	0.00	1.00	0.00	0.50	4.00	0.143
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	7.00	0.250
0.50	0.50	1.00	1.00	0.50	1.00	0.00	0.00	4.50	0.161

Zeta(u) = 0.8500 Zeta(c) = 0.8750

Performance

1	2	3	Total	Weights
0.00	0.50	1.00	1.50	0.500
0.50	0.00	0.00	0.50	0.167
0.00	1.00	0.00	1.00	0.333

Zeta(u) = 0.2500 Zeta(c) = 0.5000

Risks

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	0.50	0.50	0.167
0.00	0.50	0.00	0.50	0.167

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Logistics

1	2	3	Total	Weights
0.00	1.00	0.00	1.00	0.333
0.00	0.00	0.00	0.00	0.000
1.00	1.00	0.00	2.00	0.667

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Appendix K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	0.00	1.00	0.00	0.50	0.50	0.00	2.00	0.095
1.00	0.00	1.00	1.00	0.50	1.00	0.50	5.00	0.238
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
1.00	0.00	1.00	0.00	1.00	1.00	0.00	4.00	0.190
0.50	0.50	1.00	0.00	0.00	1.00	0.00	3.00	0.143
0.50	0.00	1.00	0.00	0.00	0.00	0.00	1.50	0.071
1.00	0.50	1.00	1.00	1.00	1.00	0.00	5.50	0.262

Zeta(u) = 0.8393 Zeta(c) = 0.8571

Propellants

1	2	3	Total	Weights
0.00	1.00	0.00	1.00	0.333
0.00	0.00	0.00	0.00	0.000
1.00	1.00	0.00	2.00	0.667

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	0.00	0.00	0.00	0.00	0.000
1.00	0.00	1.00	0.50	2.50	0.417
1.00	0.00	0.00	1.00	2.00	0.333
1.00	0.50	0.00	0.00	1.50	0.250

Zeta(u) = 0.6250 Zeta(c) = 0.7500

Maneuverability

1	2	3	Total	Weights
0.00	0.00	0.50	0.50	0.167
1.00	0.00	1.00	2.00	0.667
0.50	0.00	0.00	0.50	0.167

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Appendix K: Voting Data

```
Judge # 5 Results (Voting Matrix)
TAV Effectiveness
   1     2     3     4     5     6    Total Weights
  0.00  0.00  0.00  1.00  1.00  0.50  2.50   0.167
  1.00  0.00  0.50  1.00  1.00  1.00  4.50   0.300
  1.00  0.50  0.00  1.00  1.00  1.00  4.50   0.300
  0.00  0.00  0.00  0.00  1.00  0.00  1.00   0.067
  0.00  0.00  0.00  0.00  0.00  1.00  1.00   0.067
  0.50  0.00  0.00  1.00  0.00  0.00  1.50   0.100
Zeta(u) =  0.7500   Zeta(c) =  0.8125
                  ------------

Requirements
   1     2     3     4     5     6     7     8    Total Weights
  0.00  0.00  1.00  1.00  0.00  1.00  1.00  0.50  4.50   0.161
  1.00  0.00  1.00  1.00  0.00  1.00  1.00  1.00  6.00   0.214
  0.00  0.00  0.00  1.00  0.00  1.00  1.00  1.00  4.00   0.143
  0.00  0.00  0.00  0.00  0.00  1.00  1.00  1.00  3.00   0.107
  1.00  1.00  1.00  1.00  0.00  1.00  1.00  1.00  7.00   0.250
  0.00  0.00  0.00  0.00  0.00  0.00  1.00  0.00  1.00   0.036
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
  0.50  0.00  0.00  0.00  0.00  1.00  1.00  0.00  2.50   0.089
Zeta(u) =  0.9375   Zeta(c) =  0.9500
                  ------------

Performance
   1     2     3    Total Weights
  0.00  1.00  0.50  1.50   0.500
  0.00  0.00  0.00  0.00   0.000
  0.50  1.00  0.00  1.50   0.500
Zeta(u) =  0.7500   Zeta(c) =  1.0000
                  ------------

Risks
   1     2     3    Total Weights
  0.00  1.00  1.00  2.00   0.667
  0.00  0.00  0.50  0.50   0.167
  0.00  0.50  0.00  0.50   0.167
Zeta(u) =  0.7500   Zeta(c) =  1.0000
                  ------------

Logistics
   1     2     3    Total Weights
  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  0.00  1.00   0.333
  1.00  1.00  0.00  2.00   0.667
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                  ------------
```

Appendix K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.50	0.024
0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.024
1.00	1.00	0.00	1.00	1.00	0.50	0.50	5.00	0.238
1.00	1.00	0.00	0.00	0.00	0.00	0.00	2.00	0.095
1.00	1.00	0.00	1.00	0.00	0.00	0.00	3.00	0.143
1.00	1.00	0.50	1.00	1.00	0.00	0.50	5.00	0.238
1.00	1.00	0.50	1.00	1.00	0.50	0.00	5.00	0.238

Zeta(u) = 0.9107 Zeta(c) = 0.9286

Propellants

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	1.00	2.00	0.667
1.00	0.00	0.00	1.00	0.333

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	0.00	0.00	0.00	0.00	0.000
1.00	0.00	1.00	0.00	2.00	0.333
1.00	0.00	0.00	0.00	1.00	0.167
1.00	1.00	1.00	0.00	3.00	0.500

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maneuverability

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	1.00	1.00	0.333
0.00	0.00	0.00	0.00	0.000

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Appendix K: Voting Data

```
Judge #  4 Results (Voting Matrix)
TAV Effectiveness
   1     2     3     4     5     6    Total Weights
  0.00  1.00  1.00  1.00  1.00  1.00  5.00   0.333
  0.00  0.00  1.00  0.50  1.00  1.00  3.50   0.233
  0.00  0.00  0.00  0.50  0.00  0.00  0.50   0.033
  0.00  0.50  0.50  0.00  1.00  1.00  3.00   0.200
  0.00  0.00  1.00  0.00  0.00  0.00  1.00   0.067
  0.00  0.00  1.00  0.00  1.00  0.00  2.00   0.133
Zeta(u) =  0.7813   Zeta(c) =  0.8125
                  ------------

Requirements
   1     2     3     4     5     6     7     8    Total Weights
  0.00  1.00  1.00  0.50  0.50  1.00  1.00  1.00  6.00   0.214
  0.00  0.00  0.50  0.00  0.50  0.00  1.00  0.00  2.00   0.071
  0.00  0.50  0.00  0.00  0.00  0.00  1.00  0.50  2.00   0.071
  0.50  1.00  1.00  0.00  1.00  1.00  1.00  1.00  6.50   0.232
  0.50  0.50  1.00  0.00  0.00  1.00  1.00  1.00  5.00   0.179
  0.00  1.00  1.00  0.00  0.00  0.00  1.00  0.00  3.00   0.107
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
  0.00  1.00  0.50  0.00  0.00  1.00  1.00  0.00  3.50   0.125
Zeta(u) =  0.8125   Zeta(c) =  0.8250
                  ------------

Performance
   1     2     3    Total Weights
  0.00  1.00  0.00  1.00   0.333
  0.00  0.00  0.00  0.00   0.000
  1.00  1.00  0.00  2.00   0.667
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                  ------------

Risks
   1     2     3    Total Weights
  0.00  1.00  1.00  2.00   0.667
  0.00  0.00  1.00  1.00   0.333
  0.00  0.00  0.00  0.00   0.000
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                  ------------

Logistics
   1     2     3    Total Weights
  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  0.00  1.00   0.333
  1.00  1.00  0.00  2.00   0.667
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                  ------------
```

Appendix K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	1.00	1.00	1.00	0.00	1.00	0.00	4.00	0.190
0.00	0.00	0.00	1.00	0.00	0.50	0.00	1.50	0.071
0.00	1.00	0.00	1.00	0.50	1.00	0.00	3.50	0.167
0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.048
1.00	1.00	0.50	1.00	0.00	1.00	0.00	4.50	0.214
0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.50	0.024
1.00	1.00	1.00	1.00	1.00	1.00	0.00	6.00	0.286

Zeta(u) = 0.8929 Zeta(c) = 0.9286

Propellants

1	2	3	Total	Weights
0.00	0.50	0.00	0.50	0.167
0.50	0.00	0.00	0.50	0.167
1.00	1.00	0.00	2.00	0.667

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	0.00	0.00	0.50	0.50	0.083
1.00	0.00	0.00	0.50	1.50	0.250
1.00	1.00	0.00	1.00	3.00	0.500
0.50	0.50	0.00	0.00	1.00	0.167

Zeta(u) = 0.6250 Zeta(c) = 0.7500

Maneuverability

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	1.00	1.00	0.333
0.00	0.00	0.00	0.00	0.000

Zeta(u) = 1.0000 Zeta(c) = 1.0000

APPENDIX K: Voting Data

```
Judge # 3 Results (Voting Matrix)
TAV Effectiveness
  1     2     3     4     5     6    Total Weights
 0.00  0.50  0.50  1.00  1.00  1.00  4.00   0.267
 0.50  0.00  0.50  1.00  1.00  1.00  4.00   0.267
 0.50  0.50  0.00  1.00  1.00  1.00  4.00   0.267
 0.00  0.00  0.00  0.00  1.00  1.00  2.00   0.133
 0.00  0.00  0.00  0.00  0.00  1.00  1.00   0.067
 0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
Zeta(u) =  0.8750   Zeta(c) =  0.8750
                 ------------

Requirements
  1     2     3     4     5     6     7     8    Total Weights
 0.00  1.00  1.00  1.00  1.00  1.00  0.00  0.50  5.50   0.196
 0.00  0.00  1.00  0.00  0.00  1.00  0.00  0.00  2.00   0.071
 0.00  0.00  0.00  0.00  0.00  1.00  0.00  0.00  1.00   0.036
 0.00  1.00  1.00  0.00  0.00  1.00  0.00  0.00  3.00   0.107
 0.00  1.00  1.00  1.00  0.00  1.00  0.00  1.00  5.00   0.179
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
 1.00  1.00  1.00  1.00  1.00  1.00  0.00  1.00  7.00   0.250
 0.50  1.00  1.00  1.00  0.00  1.00  0.00  0.00  4.50   0.161
Zeta(u) =  0.9625   Zeta(c) =  0.9750
                 ------------

Performance
  1     2     3    Total Weights
 0.00  1.00  1.00  2.00   0.667
 0.00  0.00  0.50  0.50   0.167
 0.00  0.50  0.00  0.50   0.167
Zeta(u) =  0.7500   Zeta(c) =  1.0000
                 ------------

Risks
  1     2     3    Total Weights
 0.00  0.00  0.00  0.00   0.000
 1.00  0.00  0.00  1.00   0.333
 1.00  1.00  0.00  2.00   0.667
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                 ------------

Logistics
  1     2     3    Total Weights
 0.00  1.00  0.00  1.00   0.333
 0.00  0.00  0.00  0.00   0.000
 1.00  1.00  0.00  2.00   0.667
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                 ------------
```

APPENDIX K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.50	0.024
1.00	0.00	0.50	1.00	0.50	0.00	0.00	3.00	0.143
1.00	0.50	0.00	0.50	0.50	0.00	0.00	2.50	0.119
1.00	0.00	0.50	0.00	1.00	0.00	0.00	2.50	0.119
0.50	0.50	0.50	0.00	0.00	0.00	0.00	1.50	0.071
1.00	1.00	1.00	1.00	1.00	0.00	0.00	5.00	0.238
1.00	1.00	1.00	1.00	1.00	1.00	0.00	6.00	0.286

Zeta(u) = 0.7857 Zeta(c) = 0.8214

Propellants

1	2	3	Total	Weights
0.00	1.00	0.00	1.00	0.333
0.00	0.00	0.00	0.00	0.000
1.00	1.00	0.00	2.00	0.667

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	0.50	0.00	0.00	0.50	0.083
0.50	0.00	0.00	0.00	0.50	0.083
1.00	1.00	0.00	0.50	2.50	0.417
1.00	1.00	0.50	0.00	2.50	0.417

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Maneuverability

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	0.00	1.00	0.333
1.00	1.00	0.00	2.00	0.667

Zeta(u) = 1.0000 Zeta(c) = 1.0000

APPENDIX K: Voting Data

Judge # 2 Results (Voting Matrix)

TAV Effectiveness

1	2	3	4	5	6	Total	Weights
0.00	0.50	0.50	1.00	0.50	0.00	2.50	0.167
0.50	0.00	1.00	1.00	0.50	0.50	3.50	0.233
0.50	0.00	0.00	0.50	0.50	0.50	2.00	0.133
0.00	0.00	0.50	0.00	0.00	0.00	0.50	0.033
0.50	0.50	0.50	1.00	0.00	0.00	2.50	0.167
1.00	0.50	0.50	1.00	1.00	0.00	4.00	0.267

Zeta(u) = 0.3750 Zeta(c) = 0.4375

Requirements

1	2	3	4	5	6	7	8	Total	Weights
0.00	0.50	0.50	0.00	1.00	1.00	1.00	0.50	4.50	0.161
0.50	0.00	0.50	0.50	1.00	1.00	1.00	0.50	5.00	0.179
0.50	0.50	0.00	0.50	1.00	1.00	1.00	0.50	5.00	0.179
1.00	0.50	0.50	0.00	1.00	1.00	0.50	0.50	5.00	0.179
0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.50	0.018
0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.50	0.018
0.00	0.00	0.00	0.50	1.00	1.00	0.00	0.50	3.00	0.107
0.50	0.50	0.50	0.50	1.00	1.00	0.50	0.00	4.50	0.161

Zeta(u) = 0.6250 Zeta(c) = 0.6500

Performance

1	2	3	Total	Weights
0.00	1.00	0.50	1.50	0.500
0.00	0.00	0.00	0.00	0.000
0.50	1.00	0.00	1.50	0.500

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Risks

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	1.00	2.00	0.667
1.00	0.00	0.00	1.00	0.333

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Logistics

1	2	3	Total	Weights
0.00	1.00	0.00	1.00	0.333
0.00	0.00	0.00	0.00	0.000
1.00	1.00	0.00	2.00	0.667

Zeta(u) = 1.0000 Zeta(c) = 1.0000

APPENDIX K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.048
1.00	0.00	0.50	0.50	1.00	0.50	0.00	3.50	0.167
1.00	0.50	0.00	0.50	1.00	0.50	0.50	4.00	0.190
1.00	0.50	0.50	0.00	1.00	0.00	0.50	3.50	0.167
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
1.00	0.50	0.50	1.00	1.00	0.00	0.50	4.50	0.214
1.00	1.00	0.50	0.50	1.00	0.50	0.00	4.50	0.214

Zeta(u) = 0.6786   Zeta(c) = 0.7143

Propellants

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	0.50	1.50	0.500
1.00	0.50	0.00	1.50	0.500

Zeta(u) = 0.7500   Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	0.00	0.00	0.00	0.00	0.000
1.00	0.00	0.00	0.00	1.00	0.167
1.00	1.00	0.00	1.00	3.00	0.500
1.00	1.00	0.00	0.00	2.00	0.333

Zeta(u) = 1.0000   Zeta(c) = 1.0000

Maneuverability

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	1.00	2.00	0.667
1.00	0.00	0.00	1.00	0.333

Zeta(u) = 1.0000   Zeta(c) = 1.0000

APPENDIX K: Voting Data

```
Judge # 1 Results (Voting Matrix)
TAV Effectiveness
   1     2     3     4     5     6    Total Weights
  0.00  1.00  1.00  1.00  0.50  1.00  4.50   0.300
  0.00  0.00  0.50  1.00  0.00  1.00  2.50   0.167
  0.00  0.50  0.00  1.00  0.50  1.00  3.00   0.200
  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
  0.50  1.00  0.50  1.00  0.00  1.00  4.00   0.267
  0.00  0.00  0.00  1.00  0.00  0.00  1.00   0.067
Zeta(u) =  0.8437   Zeta(c) =  0.8750
                 ------------

Requirements
   1     2     3     4     5     6     7     8    Total Weights
  0.00  0.50  0.50  0.50  0.50  1.00  0.50  0.50  4.00   0.143
  0.50  0.00  0.50  0.50  0.50  1.00  0.50  0.50  4.00   0.143
  0.50  0.50  0.00  0.50  0.50  1.00  1.00  0.50  4.50   0.161
  0.50  0.50  0.50  0.00  0.50  1.00  1.00  0.50  4.50   0.161
  0.50  0.50  0.50  0.50  0.00  1.00  1.00  0.50  4.50   0.161
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
  0.50  0.50  0.00  0.00  0.00  1.00  0.00  0.00  2.00   0.071
  0.50  0.50  0.50  0.50  0.50  1.00  1.00  0.00  4.50   0.161
Zeta(u) =  0.4250   Zeta(c) =  0.4500
                 ------------

Performance
   1     2     3    Total Weights
  0.00  0.50  1.00  1.50   0.500
  0.50  0.00  1.00  1.50   0.500
  0.00  0.00  0.00  0.00   0.000
Zeta(u) =  0.7500   Zeta(c) =  1.0000
                 ------------

Risks
   1     2     3    Total Weights
  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  0.50  1.50   0.500
  1.00  0.50  0.00  1.50   0.500
Zeta(u) =  0.7500   Zeta(c) =  1.0000
                 ------------

Logistics
   1     2     3    Total Weights
  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  0.50  1.50   0.500
  1.00  0.50  0.00  1.50   0.500
Zeta(u) =  0.7500   Zeta(c) =  1.0000
                 ------------
```

```
Judge #  8 Results (Voting Matrix)
TAV Effectiveness
   1     2     3     4     5     6    Total  Weights
  0.00  0.50  0.50  1.00  0.50  1.00  3.50   0.233
  0.50  0.00  0.50  1.00  1.00  1.00  4.00   0.267
  0.50  0.50  0.00  1.00  0.50  1.00  3.50   0.233
  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
  0.50  0.00  0.50  1.00  0.00  1.00  3.00   0.200
  0.00  0.00  0.00  1.00  0.00  0.00  1.00   0.067
Zeta(u) =  0.7188   Zeta(c) =  0.7500
               ------------

Requirements
   1     2     3     4     5     6     7     8    Total  Weights
  0.00  0.00  1.00  0.50  0.00  1.00  0.00  0.00  2.50   0.089
  1.00  0.00  1.00  1.00  0.50  1.00  1.00  0.00  5.50   0.196
  0.00  0.00  0.00  0.00  0.00  0.50  0.00  0.00  0.50   0.018
  0.50  0.00  1.00  0.00  0.00  1.00  1.00  0.50  4.00   0.143
  1.00  0.50  1.00  1.00  0.00  1.00  1.00  0.50  6.00   0.214
  0.00  0.00  0.50  0.00  0.00  0.00  0.00  0.00  0.50   0.018
  1.00  0.00  1.00  0.00  0.00  1.00  0.00  0.00  3.00   0.107
  1.00  1.00  1.00  0.50  0.50  1.00  1.00  0.00  6.00   0.214
Zeta(u) =  0.8500   Zeta(c) =  0.8750
               ------------

Performance
   1     2     3    Total  Weights
  0.00  1.00  1.00  2.00   0.667
  0.00  0.00  1.00  1.00   0.333
  0.00  0.00  0.00  0.00   0.000
Zeta(u) =  1.0000   Zeta(c) =  1.0000
               ------------

Risks
   1     2     3    Total  Weights
  0.00  0.00  0.50  0.50   0.167
  1.00  0.00  1.00  2.00   0.667
  0.50  0.00  0.00  0.50   0.167
Zeta(u) =  0.7500   Zeta(c) =  1.0000
               ------------

Logistics
   1     2     3    Total  Weights
  0.00  0.50  0.00  0.50   0.167
  0.50  0.00  0.00  0.50   0.167
  1.00  1.00  0.00  2.00   0.667
Zeta(u) =  0.7500   Zeta(c) =  1.0000
               ------------
```

Appendix K: Voting Data

```
Survivability
  1     2     3     4     5     6     7    Total Weights
 0.00  0.00  1.00  0.00  0.00  0.50  0.00  1.50   0.071
 1.00  0.00  1.00  0.50  1.00  1.00  1.00  5.50   0.262
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
 1.00  0.50  1.00  0.00  1.00  1.00  0.50  5.00   0.238
 1.00  0.00  1.00  0.00  0.00  0.50  0.00  2.50   0.119
 0.50  0.00  1.00  0.00  0.50  0.00  0.00  2.00   0.095
 1.00  0.00  1.00  0.50  1.00  1.00  0.00  4.50   0.214
Zeta(u) =  0.8929   Zeta(c) =  0.9286
                  ------------

Propellants
  1     2     3    Total Weights
 0.00  1.00  0.50  1.50   0.500
 0.00  0.00  1.00  1.00   0.333
 0.50  0.00  0.00  0.50   0.167
Zeta(u) =  0.2500   Zeta(c) =  0.5000
                  ------------

Maintainability
  1     2     3     4    Total Weights
 0.00  0.00  0.00  0.00  0.00   0.000
 1.00  0.00  1.00  1.00  3.00   0.500
 1.00  0.00  0.00  1.00  2.00   0.333
 1.00  0.00  0.00  0.00  1.00   0.167
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                  ------------

Maneuverability
  1     2     3    Total Weights
 0.00  1.00  1.00  2.00   0.667
 0.00  0.00  1.00  1.00   0.333
 0.00  0.00  0.00  0.00   0.000
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                  ------------
```

Appendix K: Voting Data

```
Judge # 9 Results (Voting Matrix)
TAV Effectiveness
  1    2    3    4    5    6   Total Weights
 0.00 0.00 0.00 0.00 0.00 0.00 0.00  0.000
 1.00 0.00 1.00 1.00 0.50 1.00 4.50  0.300
 1.00 0.00 0.00 0.00 0.00 0.00 1.00  0.067
 1.00 0.00 1.00 0.00 1.00 1.00 4.00  0.267
 1.00 0.50 1.00 0.00 0.00 1.00 3.50  0.233
 1.00 0.00 1.00 0.00 0.00 0.00 2.00  0.133
Zeta(u) =  0.9062   Zeta(c) =  0.9375
               ------------

Requirements
  1    2    3    4    5    6    7    8   Total Weights
 0.00 1.00 1.00 1.00 1.00 1.00 1.00 0.00 6.00  0.214
 0.00 0.00 1.00 0.50 1.00 1.00 1.00 0.00 4.50  0.161
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00  0.000
 0.00 0.50 1.00 0.00 1.00 1.00 1.00 0.50 5.00  0.179
 0.00 0.00 1.00 0.00 0.00 1.00 1.00 0.00 3.00  0.107
 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00 1.00  0.036
 0.00 0.00 1.00 0.00 0.00 1.00 0.00 0.00 2.00  0.071
 1.00 1.00 1.00 0.50 1.00 1.00 1.00 0.00 6.50  0.232
Zeta(u) =  0.9375   Zeta(c) =  0.9500
               ------------

Performance
  1    2    3   Total Weights
 0.00 1.00 0.00 1.00  0.333
 0.00 0.00 0.00 0.00  0.000
 1.00 1.00 0.00 2.00  0.667
Zeta(u) =  1.0000   Zeta(c) =  1.0000
               ------------

Risks
  1    2    3   Total Weights
 0.00 0.50 0.00 0.50  0.167
 0.50 0.00 0.00 0.50  0.167
 1.00 1.00 0.00 2.00  0.667
Zeta(u) =  0.7500   Zeta(c) =  1.0000
               ------------

Logistics
  1    2    3   Total Weights
 0.00 1.00 1.00 2.00  0.667
 0.00 0.00 0.50 0.50  0.167
 0.00 0.50 0.00 0.50  0.167
Zeta(u) =  0.7500   Zeta(c) =  1.0000
               ------------
```

Appendix K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.048
1.00	0.00	0.00	0.00	1.00	0.00	0.00	2.00	0.095
1.00	1.00	0.00	0.50	1.00	0.50	0.50	4.50	0.214
1.00	1.00	0.50	0.00	1.00	0.50	0.50	4.50	0.214
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
1.00	1.00	0.50	0.50	1.00	0.00	1.00	5.00	0.238
1.00	1.00	0.50	0.50	1.00	0.00	0.00	4.00	0.190

Zeta(u) = 0.8393 Zeta(c) = 0.8571

Propellants

1	2	3	Total	Weights
0.00	0.50	0.00	0.50	0.167
0.50	0.00	0.00	0.50	0.167
1.00	1.00	0.00	2.00	0.667

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	0.00	0.00	0.00	0.00	0.000
1.00	0.00	1.00	1.00	3.00	0.500
1.00	0.00	0.00	1.00	2.00	0.333
1.00	0.00	0.00	0.00	1.00	0.167

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maneuverability

1	2	3	Total	Weights
0.00	0.00	1.00	1.00	0.333
1.00	0.00	1.00	2.00	0.667
0.00	0.00	0.00	0.00	0.000

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Appendix K: Voting Data

```
Judge # 10 Results (Voting Matrix)
TAV Effectiveness
   1     2     3     4     5     6    Total Weights
  0.00  1.00  1.00  1.00  1.00  1.00  5.00   0.333
  0.00  0.00  1.00  0.50  0.00  0.00  1.50   0.100
  0.00  0.00  0.00  1.00  0.00  0.00  1.00   0.067
  0.00  0.50  0.00  0.00  0.00  0.00  0.50   0.033
  0.00  1.00  1.00  1.00  0.00  0.00  3.00   0.200
  0.00  1.00  1.00  1.00  1.00  0.00  4.00   0.267
Zeta(u) =  0.9062   Zeta(c) =  0.9375
                    ------------

Requirements
   1     2     3     4     5     6     7     8    Total Weights
  0.00  0.50  1.00  0.50  1.00  1.00  1.00  0.50  5.50   0.196
  0.50  0.00  0.50  0.00  0.50  1.00  0.50  0.50  3.50   0.125
  0.00  0.50  0.00  0.00  0.50  1.00  0.00  0.00  2.00   0.071
  0.50  1.00  1.00  0.00  1.00  1.00  1.00  0.50  6.00   0.214
  0.00  0.50  0.50  0.00  0.00  0.50  1.00  0.00  2.50   0.089
  0.00  0.00  0.00  0.00  0.50  0.00  0.50  0.00  1.00   0.036
  0.00  0.50  1.00  0.00  0.00  0.50  0.00  0.00  2.00   0.071
  0.50  0.50  1.00  0.50  1.00  1.00  1.00  0.00  5.50   0.196
Zeta(u) =  0.6000   Zeta(c) =  0.6250
                    ------------

Performance
   1     2     3    Total Weights
  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  0.00  1.00   0.333
  1.00  1.00  0.00  2.00   0.667
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                    ------------

Risks
   1     2     3    Total Weights
  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  0.50  1.50   0.500
  1.00  0.50  0.00  1.50   0.500
Zeta(u) =  0.7500   Zeta(c) =  1.0000
                    ------------

Logistics
   1     2     3    Total Weights
  0.00  1.00  0.00  1.00   0.333
  0.00  0.00  0.00  0.00   0.000
  1.00  1.00  0.00  2.00   0.667
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                    ------------
```

Appendix K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	0.50	0.00	0.50	0.00	0.00	0.00	1.00	0.048
0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.024
1.00	1.00	0.00	1.00	1.00	1.00	1.00	6.00	0.286
0.50	1.00	0.00	0.00	1.00	1.00	1.00	4.50	0.214
1.00	1.00	0.00	0.00	0.00	0.50	1.00	3.50	0.167
1.00	1.00	0.00	0.00	0.50	0.00	1.00	3.50	0.167
1.00	1.00	0.00	0.00	0.00	0.00	0.00	2.00	0.095

Zeta(u) = 0.8214 Zeta(c) = 0.8571

Propellants

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	0.00	0.00	0.000
0.00	1.00	0.00	1.00	0.333

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	1.00	1.00	1.00	3.00	0.500
0.00	0.00	1.00	1.00	2.00	0.333
0.00	0.00	0.00	0.00	0.00	0.000
0.00	0.00	1.00	0.00	1.00	0.167

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maneuverability

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	0.50	1.50	0.500
1.00	0.50	0.00	1.50	0.500

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Appendix K: Voting Data

```
Judge # 11 Results (Voting Matrix)
TAV Effectiveness
   1    2    3    4    5    6   Total Weights
 0.00 1.00 1.00 1.00 1.00 1.00 5.00   0.333
 0.00 0.00 1.00 1.00 1.00 1.00 4.00   0.267
 0.00 0.00 0.00 0.00 0.00 0.00 0.00   0.000
 0.00 0.00 1.00 0.00 0.00 1.00 2.00   0.133
 0.00 0.00 1.00 1.00 0.00 1.00 3.00   0.200
 0.00 0.00 1.00 0.00 0.00 0.00 1.00   0.067
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                ------------

Requirements
   1    2    3    4    5    6    7    8   Total Weights
 0.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 7.00   0.250
 0.00 0.00 1.00 0.00 1.00 1.00 1.00 1.00 5.00   0.179
 0.00 0.00 0.00 0.00 0.00 0.50 1.00 0.00 1.50   0.054
 0.00 1.00 1.00 0.00 1.00 1.00 1.00 1.00 6.00   0.214
 0.00 0.00 1.00 0.00 0.00 1.00 1.00 0.00 3.00   0.107
 0.00 0.00 0.50 0.00 0.00 0.00 0.00 0.00 0.50   0.018
 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 1.00   0.036
 0.00 0.00 1.00 0.00 1.00 1.00 1.00 0.00 4.00   0.143
Zeta(u) =  0.9625   Zeta(c) =  0.9750
                ------------

Performance
   1    2    3   Total Weights
 0.00 1.00 1.00 2.00   0.667
 0.00 0.00 1.00 1.00   0.333
 0.00 0.00 0.00 0.00   0.000
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                ------------

Risks
   1    2    3   Total Weights
 0.00 0.00 0.00 0.00   0.000
 1.00 0.00 0.00 1.00   0.333
 1.00 1.00 0.00 2.00   0.667
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                ------------

Logistics
   1    2    3   Total Weights
 0.00 1.00 1.00 2.00   0.667
 0.00 0.00 0.00 0.00   0.000
 0.00 1.00 0.00 1.00   0.333
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                ------------
```

Appendix K: Voting Data

```
Survivability
   1     2     3     4     5     6     7    Total  Weights
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  1.00  1.00  1.00  1.00  1.00  6.00   0.286
  1.00  0.00  0.00  0.00  1.00  1.00  0.00  3.00   0.143
  1.00  0.00  1.00  0.00  1.00  1.00  0.00  4.00   0.190
  1.00  0.00  0.00  0.00  0.00  0.50  0.00  1.50   0.071
  1.00  0.00  0.00  0.00  0.50  0.00  0.00  1.50   0.071
  1.00  0.00  1.00  1.00  1.00  1.00  0.00  5.00   0.238
Zeta(u) =  0.9821   Zeta(c) =  1.0000
                    ------------

Propellants
   1     2     3    Total  Weights
  0.00  1.00  1.00  2.00   0.667
  0.00  0.00  0.00  0.00   0.000
  0.00  1.00  0.00  1.00   0.333
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                    ------------

Maintainability
   1     2     3     4    Total  Weights
  0.00  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  0.00  1.00  2.00   0.333
  1.00  1.00  0.00  1.00  3.00   0.500
  1.00  0.00  0.00  0.00  1.00   0.167
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                    ------------

Maneuverability
   1     2     3    Total  Weights
  0.00  1.00  1.00  2.00   0.667
  0.00  0.00  1.00  1.00   0.333
  0.00  0.00  0.00  0.00   0.000
Zeta(u) =  1.0000   Zeta(c) =  1.0000
                    ------------
```

Appendix K: Voting Data

Judge # 12 Results (Voting Matrix)

TAV Effectiveness

1	2	3	4	5	6	Total	Weights
0.00	0.00	0.50	1.00	1.00	1.00	3.50	0.233
1.00	0.00	0.50	1.00	1.00	1.00	4.50	0.300
0.50	0.50	0.00	1.00	0.50	1.00	3.50	0.233
0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.067
0.00	0.00	0.50	1.00	0.00	1.00	2.50	0.167
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000

Zeta(u) = 0.8125 Zeta(c) = 0.8750

Requirements

1	2	3	4	5	6	7	8	Total	Weights
0.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00	4.00	0.143
0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.50	0.018
0.00	0.50	0.00	0.00	0.00	0.00	0.00	1.00	1.50	0.054
0.00	1.00	1.00	0.00	0.00	1.00	0.00	0.00	3.00	0.107
1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	7.00	0.250
1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	3.00	0.107
1.00	1.00	1.00	1.00	0.00	1.00	0.00	0.00	5.00	0.179
0.00	1.00	0.00	1.00	0.00	1.00	1.00	0.00	4.00	0.143

Zeta(u) = 0.6625 Zeta(c) = 0.6750

Performance

1	2	3	Total	Weights
0.00	1.00	0.50	1.50	0.500
0.00	0.00	0.00	0.00	0.000
0.50	1.00	0.00	1.50	0.500

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Risks

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	0.50	1.50	0.500
1.00	0.50	0.00	1.50	0.500

Zeta(u) = 0.7500 Zeta(c) = 1.0000

Logistics

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	0.00	1.00	0.333
1.00	1.00	0.00	2.00	0.667

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Appendix K: Voting Data

Survivability

1	2	3	4	5	6	7	Total	Weights
0.00	1.00	1.00	0.50	1.00	1.00	1.00	5.50	0.262
0.00	0.00	1.00	1.00	1.00	1.00	1.00	5.00	0.238
0.00	0.00	0.00	0.50	1.00	1.00	0.00	2.50	0.119
0.50	0.00	0.50	0.00	1.00	1.00	0.00	3.00	0.143
0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.024
0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.50	0.024
0.00	0.00	1.00	1.00	1.00	1.00	0.00	4.00	0.190

Zeta(u) = 0.8571 Zeta(c) = 0.8929

Propellants

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	0.00	0.00	0.000
0.00	1.00	0.00	1.00	0.333

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maintainability

1	2	3	4	Total	Weights
0.00	1.00	0.00	0.00	1.00	0.167
0.00	0.00	0.00	0.00	0.00	0.000
1.00	1.00	0.00	0.00	2.00	0.333
1.00	1.00	1.00	0.00	3.00	0.500

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Maneuverability

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	0.00	0.00	0.000
0.00	1.00	0.00	1.00	0.333

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Appendix K: Voting Data

Judge # 13 Results (Voting Matrix)

TAV Effectiveness

1	2	3	4	5	6	Total	Weights
0.00	1.00	1.00	1.00	1.00	1.00	5.00	0.333
0.00	0.00	1.00	1.00	1.00	1.00	4.00	0.267
0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.067
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
0.00	0.00	1.00	1.00	0.00	1.00	3.00	0.200
0.00	0.00	1.00	1.00	0.00	0.00	2.00	0.133

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Requirements

1	2	3	4	5	6	7	8	Total	Weights
0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	7.00	0.250
0.00	0.00	1.00	0.00	0.00	1.00	1.00	0.00	3.00	0.107
0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.036
0.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	6.00	0.214
0.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00	5.00	0.179
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	2.00	0.071
0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	4.00	0.143

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Performance

1	2	3	Total	Weights
0.00	1.00	1.00	2.00	0.667
0.00	0.00	0.00	0.00	0.000
0.00	1.00	0.00	1.00	0.333

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Risks

1	2	3	Total	Weights
0.00	0.00	0.00	0.00	0.000
1.00	0.00	1.00	2.00	0.667
1.00	0.00	0.00	1.00	0.333

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Logistics

1	2	3	Total	Weights
0.00	1.00	0.00	1.00	0.333
0.00	0.00	0.00	0.00	0.000
1.00	1.00	0.00	2.00	0.667

Zeta(u) = 1.0000 Zeta(c) = 1.0000

Appendix K: Voting Data

```
Survivability
   1     2     3     4     5     6     7    Total Weights
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  0.00  1.00  1.00  0.00  0.00  3.00   0.143
  1.00  1.00  0.00  1.00  1.00  1.00  0.00  5.00   0.238
  1.00  0.00  0.00  0.00  1.00  1.00  0.00  3.00   0.143
  1.00  0.00  0.00  0.00  0.00  0.00  0.00  1.00   0.048
  1.00  1.00  0.00  0.00  1.00  0.00  0.00  3.00   0.143
  1.00  1.00  1.00  1.00  1.00  1.00  0.00  6.00   0.286
Zeta(u) =   0.9286    Zeta(c) =   0.9286
                   ------------

Propellants
   1     2     3    Total Weights
  0.00  1.00  0.00  1.00   0.333
  0.00  0.00  0.00  0.00   0.000
  1.00  1.00  0.00  2.00   0.667
Zeta(u) =   1.0000    Zeta(c) =   1.0000
                   ------------

Maintainability
   1     2     3     4    Total Weights
  0.00  0.00  0.00  0.00  0.00   0.000
  1.00  0.00  0.00  1.00  2.00   0.333
  1.00  1.00  0.00  1.00  3.00   0.500
  1.00  0.00  0.00  0.00  1.00   0.167
Zeta(u) =   1.0000    Zeta(c) =   1.0000
                   ------------

Maneuverability
   1     2     3    Total Weights
  0.00  1.00  1.00  2.00   0.667
  0.00  0.00  1.00  1.00   0.333
  0.00  0.00  0.00  0.00   0.000
Zeta(u) =   1.0000    Zeta(c) =   1.0000
                   ------------
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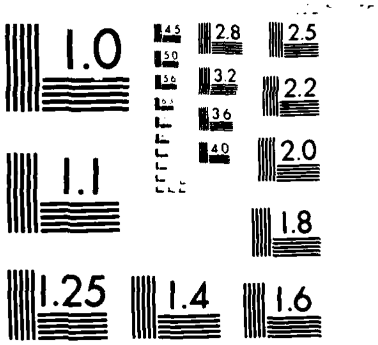

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