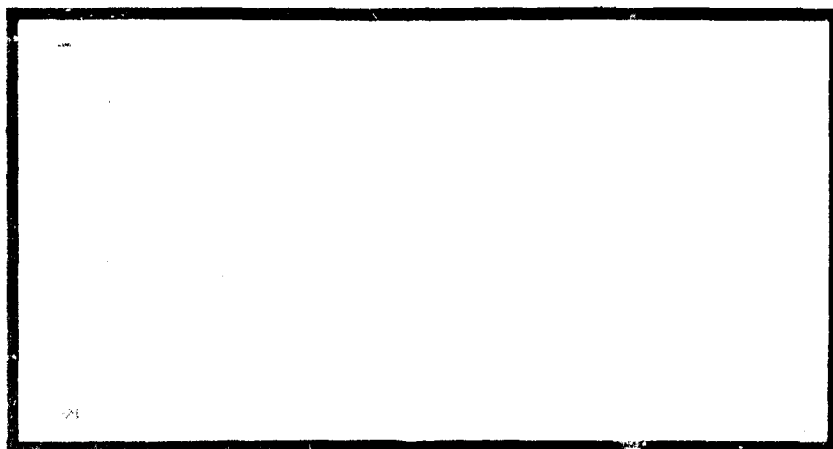


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MADAM:  
MULTIPLE-ATTRIBUTE DECISION ANALYSIS MODEL  
VOLUME I  
THESIS

AFIT/GOR/AA/81D-1-

Wayne A. Stimpson  
2Lt USAFR

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Thesis

MADAM:

MULTIPLE-ATTRIBUTE DECISION ANALYSIS MODEL

Volume I

by

Wayne A. Stimpson  
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Prepared in partial  
fulfillment of  
requirements for a  
Master's Degree

December 1981

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School of Engineering  
Air Force Institute of Technology  
Wright-Patterson Air Force Base  
Ohio

## Preface

I wish to sincerely thank Captain Aaron Dewispelare, and Colonel Donald Stevens. Captain Dewispelare provided a never-ending source of energy and information (as well a pleasant sense of humor) as my advisor. Colonel Stevens offered very solid support and constructive suggestions as my reader. I appreciate the assistance of Dr. Robert Allen and Major Daniel Fox also, and I extend my thanks to them.

From a more personal perspective I wish to express my appreciation of my classmates. They provided the friendship and help necessary to make all of my stay at AFIT very rewarding. I wish to sincerely thank my wife, Judy, whose love and understanding is greatly appreciated.

Finally, I would like to express my appreciation of Mrs. Mickey Miller. Without her patience and superlative administrative skills, this work would have been intolerably difficult to complete.

# Volume I

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Abstract

The complex multifaceted decision situations present today suggest the need for a timely, automated tool. A decision-maker is forced into comparing alternative actions or systems over an entire set of different measures of merit. This effort is an on-line, real-time, computer-based decision aid designed to assist the decision-maker in clarifying preferences in a complex decision environment. It is applicable to problems which may be represented by a hierarchy of objectives to be satisfied. The program is MADAM: Multiple-Attribute Decision Analysis Model, and it is written in FORTRAN V and is implemented on the CYBER 175 system. MADAM is designed to aid the decision-maker as he or she progresses through problem formulation, parameterization, sensitivity analyses, and a decision, including storage of all data and rationales. Deterministic problems are analyzed through Multi-Attribute Utility Theory concepts and an additive value function is utilized for sensitivity analysis. Pairwise preferential independence is tested between attributes. The sensitivity analyses include a cumulative weight analysis, a relative weight analysis, and an attribute level analysis. The analyses may be conducted by fixing an objective to be considered and conducting the analysis across the alternative systems or actions, or conversely by fixing the alternative to be considered and conducting the analysis across a desired set of objectives.

The work is divided into two volumes. Volume I is a theoretical presentation and includes a user's manual. It requires no programming expertise and may be used independently of Volume II. Volume II is a programming manual including the source code. It may not be used independently of Volume I.

# MADAM: Multiple-Attribute Decision Analysis Model

## I. Introduction

The process of decision-making in the context of complex problems is an arduous task at best. Complex problems, especially in societal environments, are compounded by "spill-over" effects which impede the establishment of sharp problem boundaries. As a result, a critical part of decision-making is defining boundaries of the problem (Keeney and Raiffa, 1976). Unfortunately, an all too common occurrence in complex decision-making is a gross imbalance between the amount of effort expended in developing, modifying, and verifying an elaborate model, and the actual choosing of an alternative solution (Keeney and Raiffa, 1976). Often the elaborate output of several measures of merit resulting from the alternative solutions is compressed into a few graphs or tables to be included in a summary report to the decision-maker\* (DM). This situation brings severe criticism to bear on the notion that the DM attempts to make fully informed, rational decisions.

A complete amelioration of ill-informed or irrational decision-making is not possible, however, by simply inundating the DM with relevant data. The introduction of the computer has had a profound impact upon this latter point, and early computer-based decision aiding systems were

\*The term decision-maker is used generically to refer that person (or group of people) who is responsible for making and/or administering the decision.

primarily designed to augment the DM's ability to collect, display, store, and retrieve information. Psychologists are currently in a position to persuasively argue that this is not an adequate approach to a computerized decision support aid. These tools are misdirected in that human DM's are intrinsically slow information processors, and thus they are unable to utilize most of the "available" information (Fischer et al 1978). Thus it is important to recognize the shift in decision-aiding technologies to enhance the information processing function. A significant emphasis has been made to aid the DM in breaking down a complex problem into a system of subproblems which represent the original problem, but which may be considered separately. It is generally accepted that people are more consistent when faced with simple judgments than they are at aggregating large amounts of information to form an overall decision (Fischer et al, 1978). Decision analysis does not provide, and is not intended to provide, a comprehensive calculus of the human psyche. The crux of its development is to provide a DM with a tool which will facilitate rational, consistent decision-making and provide a medium for concise communication and data processing.

This study is an effort to expand an existing decision aid which utilizes the theoretical underpinnings of Multi-Attribute Utility Theory (MAUT) to aid the DM in the resolution of very complex decisions. This decision aid is the extension of the tools developed by Morlan (1979) and Lee (1981). The expansion involves improved processing of information received from the DM, and the extension of the sensitivity analysis to include a system analysis over a set of objectives or attributes. An emphasis is made to address the issue of problem formulation, which includes the formation of an objective hierarchy and the establishment of

a set of attributes capable of measuring achievement of the objectives.

### Background

This discussion centers on those research efforts which deal with decision-making in a riskless environment. An assumption is made that the DM is an individual, although extensions may be made to the group DM case. A decision is classified as riskless if the DM is able to specify with certainty the consequences associated with each alternative action (Fischer et al, 1978). In MAUT, consequences are evaluated in the context of the DM's preference space. The first stage in determining the preference space is to form a hierarchy of objectives. When dividing an objective into subobjectives, it is important that the subobjectives address all facets of the higher level objective. Some of the subobjectives might be so insignificant relative to the others that they may be discarded from the analysis. The analyst must insure, however, that the remaining objectives do not become incomprehensible (Keeney and Raiffa, 1976). Ellis (1970) documented a test of importance which would facilitate proper construction of the objective hierarchy. Unfortunately, a compounding factor in decision analysis is that the objective hierarchy for a particular problem is not unique. Furthermore, the set of attributes which is developed to measure achievement of the objectives is not unique, even for a specific objective hierarchy (Keeney and Raiffa, 1976). As a result, the formulation of the problem, to include developing the objective hierarchy and the attribute set, must be given careful consideration.

In particular, there are several properties of attributes which Keeney and Raiffa (1976) have designated as desirable. Each attribute should have the properties of comprehensiveness and measurability. The

attribute set as a whole, should be complete, operational, decomposable, non-redundant, and of minimum size. In those cases where it is difficult to choose an attribute which directly measures achievement of an objective, it is possible to utilize proxy attributes and direct preference measures. When it is necessary to use proxy attributes, or direct preference measurement, it is important to ascertain exactly what the DM perceives as being measured (Keeney and Raiffa, 1976).

In general, through the process of generating an objective hierarchy and associated attributes, a large set of attributes will be established. This attribute set is large in the sense that the quantified preferences will more accurately reflect the true preferences of the DM when small parts of the overall model can be considered separately by the DM (Keeney and Raiffa, 1976). Thus, a key factor in aiding the DM is to generate those subproblems which, while preserving the original complex decision when taken as a complete set, may be considered individually in order to maximize consistency and understanding in the DM. This process of developing an objective hierarchy and the set of associated attributes is discussed in more detail in Chapter II: Problem Formulation.

After the objectives and attributes are satisfactorily established, it is necessary to assume that any alternative consequences are capable of being compared through a binary preference function, and that the relationships established will be transitive (Keeney and Raiffa, 1976). Practitioners of MAUT attempt to construct a function which maps the alternatives onto the real line in such a manner as to incorporate the DM's implicit preference structure. In particular, under riskless conditions, a value function is sought which has a domain over the consequence space such that

$v(x_1, \dots, x_n) \geq v(x'_1, \dots, x'_n) \iff (x_1, \dots, x_n) \succeq (x'_1, \dots, x'_n)$  where  $\succeq$  is read "is preferred or indifferent to",  $v$  is the value function and  $(x_1, \dots, x_n), (x'_1, \dots, x'_n)$  are elements of the consequence space.

For simplification, this development includes the case where the factor of time is negligible when considering preferences. A treatment of preferences over time is available in the works of Koopmans (1960), Lancaster (1963), Koopmans et al (1964), Pollard (1969), and Bell (1974). While considering simplifying assumptions, it might be noted that confining the development to the riskless case is not totally restrictive. There are cases in which a simple monotonic transformation to a riskless value function will transform space into a utility function for decision-making under risk (Keeney and Raiffa, 1976).

Within the restrictions noted above, it is necessary to establish those conditions under which the complex decision may be decomposed. Leontif (1947 a,b) investigated properties of functions of several variables that provided for separability, i.e. breaking the original function down into one over distinct subsets of the original variables. His results were local rather than global. An important contribution toward separating the assessment of a value function into a number of component parts is the work of Gorman (1968). In particular, he improved the use of the techniques of determining the conditions necessary to imply an additive value function by greatly reducing the number of steps. Ting (1971) also discusses many techniques for decomposing the assessment of preferences, and suggests some guidelines for verifying the assumptions necessary to use the resulting decompositions.

Debreu (1960) provided the first set of axioms implying the existence of an additive value function for greater than two attributes

through an elegant topological proof. An alternative algebraic proof of additivity was given by Luce (1964) when he introduced the concept of conjoint measurement for the two attribute case. It might be noted that most procedures for developing an additive value index assume that the index has the properties of an interval or ratio scale (Fischer et al, 1978). The work of Krantz et al (1971) provides a major extension of the theory of conjoint measurement. Earlier extensions were made by Krantz (1964), Luce (1966), and Tversky (1967).

MAUT is only one of several theories developed under the genre of decision analysis. For example, two other major approaches to decision analysis are multiple objective optimization theory (MacCrimmon, 1973; Dewispelare, 1980) and the work of Bowman (1963), Yntema and Torgerson (1961), and Goldberg (1970) which proposes a statistical analysis. However, MAUT has been used effectively within the context of military management. Some examples of these applications may be found in the works of Chinnis et al (1975) and Allen et al (1977). Chapter III: The Value Function discusses this topic in more detail.

There are several practical difficulties which obscure an objective analysis of the worth of decision aids in applied contexts. Included in the difficulties are the frequent absence of an objective criterion to assess decision quality, the lack of parallel decision channels which facilitate comparative studies, and the unique, non-repetitive nature of the decision-making environment. Despite these problems, some anecdotal evaluations by Kelley (Fischer et al, 1978) reveal that in the military context, decision aids appear to force users to consider both option values and likelihoods explicitly. The benefit of numerical expression of uncertainty as opposed to verbal qualifiers is evident.

The structure and explicit requirements of the decision models appear to facilitate coordinated, efficient action by staff elements. In general, the decision models serve a valuable communicative function. (Fischer et al, 1978).

In light of the apparent success of early attempts to inject decision analysis into the military decision-making environment, concentration may now be directed at refining rather than justifying the decision aids. In particular, Kelley points out that the areas of concern include the requirement that the decision mode facilitate communication and storage of rationale for values, probabilities, and structures. There is a pressing need to enhance decision analyses to include multivariate sensitivity information. Also, there is a significant portion of potential users (about one-third) who require special help from the decision aid to structure the problem and generate options (Fischer et al, 1978).

Computer implementation has been an increasing medium for many approaches to decision analysis. Systems Research, Inc. has several aids on the market (CTREE, QUICKTREE, APLTREE, DECISIONTREE, INFLUENCE-DIAGRAM, and COMPUTERAID). Perceptronics, Inc. has marketed a package which is a group decision aid and its host micro-computer. Decisions and Designs, Inc. under the sponsorship of the Defense Advanced Research Projects Agency have produced several real-time decision aids (DESIGN, TREE, ITREE, HIVAL, PAYOFF, and NEGOTIATIONS). Capt Bruce Morlan (1979) extended some of the products of DDI as a thesis while at the Air Force Institute of Technology. More recently, Capt David Lee (1981) produced an advanced version of Morlan's work. Lee's efforts included enhancing the DM/decision aid interface through the use of colorgraphics, and on improvement of the sensitivity analysis. Lee's decision aid is designed

for a microprocessor, and was built around the APPLE II hardware and software. Although his work does exhibit the feasibility of using a microcomputer as a decision aid, it is highly machine specific and thus does not lend itself to wide application. This thesis is the Multi-Attribute Decision Analysis Model (MADAM). It is an interactive decision aid utilizing the theoretical constructs of MAUT to approach hierarchically structured problems. MADAM combines the increased transportability of Morlan's work with the advantages of Lee's work. A major extension was made to the process of problem formulation and the data structure. The sensitivity analysis has been expanded to include a system analysis over a set of nodes.

In Volume I, the chapters highlight the theoretical aspects of MADAM and the methods used to incorporate these aspects into the model. Chapter II discusses problem formulation: establishing a hierarchy of objectives and an associated attribute set. Chapter III contains information about value functions and their implications. Chapter IV highlights the various sensitivity analyses. Chapter II, III, and IV are divided into two main sections: Theoretical Considerations, and Computer Implementation. This is done for the convenience of those familiar with MAUT, who may skip the Theoretical Considerations and read only the Computer Implementation sections without any loss of continuity. Chapter V provides a detailed prototype decision analysis. Chapter VI contains conclusions and recommendations concerning further work on this model. Appendix A provides a concise glossary of terms which may be unique to the model or unfamiliar. Appendix B is a user's manual which explicitly covers use of MADAM. Volume II is a programming manual including the source code.

## II. Problem Formulation

### Theoretical Consideration

MADAM is designed for a complex decision-making environment. The complexity is exacerbated by the fact that rarely, if ever, are problems of this magnitude neatly laid out or well defined. Unfortunately, the DM is faced with a vague sense of what problem must be addressed. The initial stage of analysis is fraught with ambiguity of objectives and a lack of knowledge about their interrelationships. Thus, a critical phase of the decision analysis is the first stage; problem formulation.

In the context of multi-attribute utility theory (MAUT), this problem formulation phase consists of defining the boundaries of the problem, developing an appropriate set of attributes and objectives to apply to the problem (these terms are defined more precisely in a following paragraph). It is the responsibility of both the DM and the analyst to ensure that proper treatment is given to problem formulation. By-passing careful thought at this stage may temporarily eliminate some difficult trade-offs, but any decision implies such trade-offs. By keeping as many of these trade-offs as explicit as possible, the DM may ascertain that all responses and results reflect true beliefs and values (Fischer et al, 1978).

The DM should be able to place the problem in the typology of problem classifications depicted in Figure 2.1. This step in itself is a potential time-saver in that it will indicate what type of decision analysis is most appropriate, or where time and resources may be conserved by using a simpler analysis technique than was originally hypothesized.

Those problems of Type I and Type II are relatively simple and will not be considered further. Those problems of Type IV are appropriately addressed by MAUT techniques designed to incorporate risk or uncertainty. Type IV problems are, in general, beyond the scope of MADAM except in special cases where risk may be incorporated artificially as an attribute. More generally, MADAM is directed at Type III problems.

| Outcome<br>Under: | Single<br>Attribute | Multiple<br>Attribute |
|-------------------|---------------------|-----------------------|
|                   | Certainty           | Uncertainty           |
| Certainty         | Type I              | Type III              |
| Uncertainty       | Type II             | Type IV               |

Figure 2.1 A Problem Typology

(Adopted from Keeney and  
Raiffa, 1976)

Those problems of Type III and Type IV can be represented by a complex system of objectives, attributes, and alternatives. In MADAM, an assumption is made that the objectives and their relationships may be represented via a hierarchical structure. The ultimate purpose of such an approach is to yield substance and form to the decision environment, and to place an emphasis on interdependencies. Often analysts look at only part of a problem and analyze it separately to reduce the problem to a manageable size. To solve a complex problem, it is necessary to extend the problem boundaries to include the entire relevant system, determine the significance of interdependencies, and thus evaluate their

combined impact (Quade and Boucher, 1968). It is unreasonable to conclude that in the face of increasing occupational specialization, all suboptimization (solution of a restricted problem) may be avoided, but it is highly desirable to insure that the selection of criteria and objectives for each suboptimization be consistent with those appropriate to the full, complex problem. This is one of the critical functions of problem formulation (Quade and Boucher, 1968).

The efforts expended in stating and defining the problem are paid back through a vast clarification of spurious or trivial concerns, and indications of a more direct way to solution (Quade and Boucher, 1968). The process of problem formulation is highly subjective. A predominant force at this stage is to examine what is meaningful and significant to the DM. The problem formulation stage can be concisely described as the phase in which clarification of the objectives, defining the issues of concern, and limiting the problem are paramount (Quade and Boucher, 1968). Within the perceptions of the DM, the questions or issues involved must be isolated, and the context of issue resolution must be established. Along with clarifying the objectives, the operative variables must be discerned, and the relationships among them must be made explicit. All of this is crucial in illustrating the logical structure of the decision analysis (Quade and Boucher, 1968).

The Objective Hierarchy. In MADAM, the process of problem formulation includes constructing a hierarchy of objectives. In this context, an objective is an entity which indicates the general direction in which effort will be exerted. Note that an objective is distinct from a goal, in that a goal is a specific level of some measure which is achieved or not, while an objective denotes no specific level but indicates direction

(Keeney and Raiffa, 1976). Figure 2.2 illustrates a model objective.

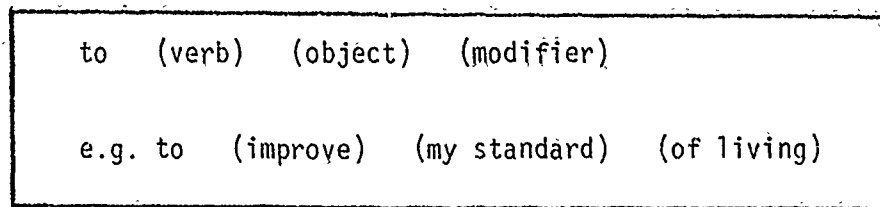


Figure 2.2 A Model Objective

Although the objective hierarchy is not unique for a given problem due to subjectivity and idiosyncrasies of the DM, there are general properties which the objective hierarchy should possess (Keeney and Raiffa, 1976). As one moves up the hierarchy, the subobjectives should indicate the means to an end, where the end is indicated by a parent objective (see Figure 2.3). As a result, the movement up the hierarchy has a natural stopping point at the all-inclusive objective. This objective should give the overall reason for the DM's interest in the problem, and usually, it is too vague for operational purposes (Keeney and Raiffa, 1976). Conversely, as one moves down the hierarchy, the parent objective of a set of subobjectives should indicate the reason for the existence of the subobjectives. Unfortunately, the movement down the hierarchy has no well defined stopping point (Keeney and Raiffa, 1976). The DM must determine the extent of available resources and take a pragmatic attitude toward the amount of detail which is desirable (Quade and Boucher, 1968; Keeney and Raiffa, 1976).

The process of breaking a parent objective into subobjectives is called "specification" (Keeney and Raiffa, 1976). In specification, the objective is divided into subobjectives which provide increased detail. These more detailed subobjectives should be designed to encompass all

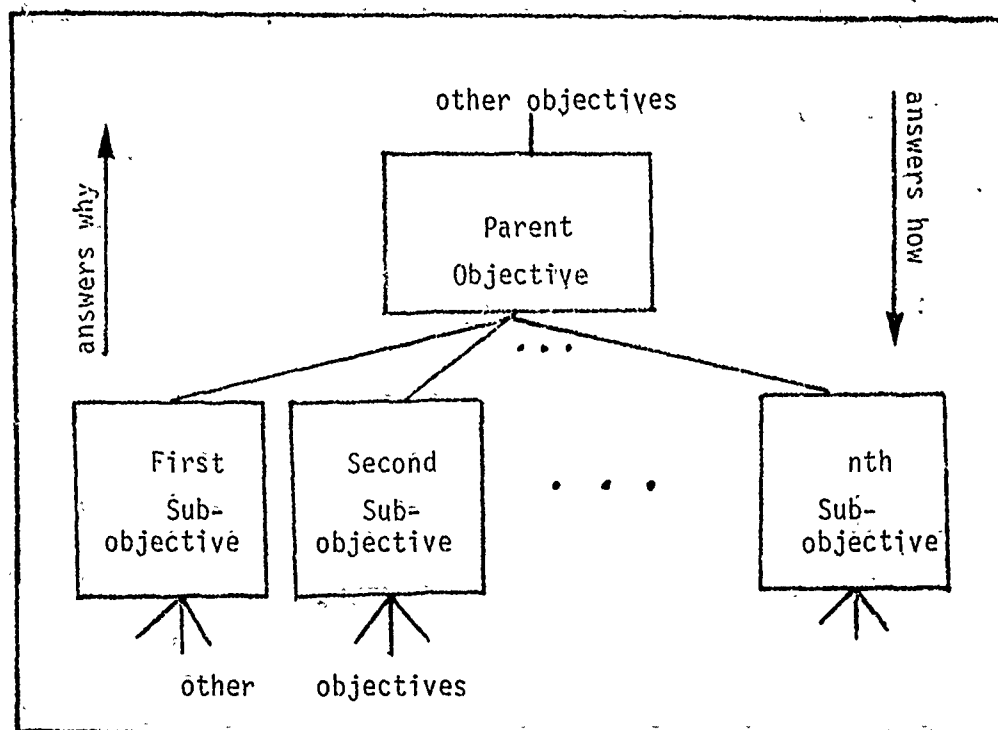


Figure 2.3 A Portion of the Objective Hierarchy

aspects of the parent objective. The complexity of the hierarchy may increase beyond realistic bounds. At each stage of specification, the set of subobjectives should be tested to ascertain whether or not some of the subobjectives may be insignificant relative to the other. If any such subobjectives exist, they may be deleted without hampering the DM's thought process. The analyst and the DM must exercise care when eliminating subobjectives, however, since although the individual subobjectives are negligible, a group of them considered as a whole may be too significant to ignore (if they all pertain to the same basic area of interest) (Keeney and Raiffa, 1976).

The Attribute Set. The process of problem formulation includes the formation of an attribute set. The attribute set provides a means of measuring the extent to which the lowest-level objectives (and thus,



example of a proxy attribute would be to use the attribute "number of work related accidents" to measure how well the objective "to improve job safety" is being met. The last type of attribute is the direct preference measure where the DM indicates on a scale of worth how well an objective is met without using an objective measure of merit. From the standpoint of objectivity, the desirability of normal attributes exceeds that of proxy attributes which in turn exceeds that of the direct preference measure. Some caution must be exercised in that proxy attributes may cause complications, and when small parts of the model are considered implicitly by the DM, the direct preference measure may more accurately reflect the DM's true preferences. Because of this, Hatry (1970) extends a caveat concerning excessive use of proxy attributes in spite of their analytical ease, or easy accessibility. The DM and the analyst should insure that the DM fully understands the ramifications of using any proxy attribute or the direct preference measure. A conscious effort should be made by the DM to consider what each attribute does measure, and is intended to measure (Keeney and Raiffa, 1976).

The attributes should possess certain desirable properties. The individual attributes should be comprehensive and measurable (Keeney and Raiffa, 1976). An attribute is comprehensive if the DM has a clear understanding of the extent to which the associated objective is achieved by knowing the level of the attribute in a particular context. An attribute is measurable if a probability distribution for each alternative over the possible levels of the attribute can be established (since MADAM is concerned with analysis under certainty, a point value must be determined), and the DM's preferences for different levels of the attribute may be determined (Keeney and Raiffa, 1976).

In addition to the properties of an individual attribute, there are desirable properties of the set of attributes as a whole. These properties are that the attribute set be complete, operational, decomposable, non-redundant, and minimal (Keeney and Raiffa, 1976). A set of attributes is complete if the DM is satisfied that an indication of the extent to which the overall objective is satisfied is given by the level of the attributes. Completeness may be achieved when the lowest-level objectives in a hierarchy include all areas of concern, and the attributes associated with them are comprehensive. The property of operability comes from the attributes having meaning to the DM, and having a high communicative value. The attribute set should also be decomposable. This implies that subsets of the whole attribute set may be examined separately from the others due to various types of independence (some of which will be considered in the following chapter). It might be noted that some scientists have developed MAUT analyses which do not utilize (or require determination of) independence conditions (Fishburn, 1978; Farquhar, 1979). The property of non-redundancy means that the attributes should not allow double-counting of consequences. For instance, if two attributes used to determine the quality of the health of a nation are "deaths due to cancer", and "male deaths", one would be double-counting those males who died of cancer. Finally, the attribute set should be kept as small as possible (eliminate some detail in the objective hierarchy) subject to these properties.

The stage of problem formulation is very critical. Some authors have gone as far as suggesting that choosing the "right" objectives may be more important than determining the optimum choice between alternatives (Quade and Boucher, 1968). The essential rationale for such a position

is based on the belief that a near optimum solution to correct problem formulation will be, in general, superior to the optimum solution to an ill-posed problem. The objectives are usually less subject to ephemerality and the ravages of risk/uncertainty. A final point is that the process of problem formulation should continue until the DM is convinced that any further decision analysis would be counter-productive. The DM should feel free, and be encouraged by the analyst, to modify the objective hierarchy or the attribute set based on refined perceptions of the nature of the problem. The DM must be conscious of changes and clarification of perceptions, and incorporate them into the model. Also, operationally significant objectives may arise out of the opportunities which possible alternative solutions offer (Quade and Boucher, 1968). This type of information will occur in intermediate phases of the decision analysis and should be exploited by modifying the problem formulation.

#### Computer Implementation

In order to facilitate the process of problem formulation, MADAM utilizes a data structure which allows storage and manipulation of the objective hierarchy, the attribute set, and the set of alternatives. A detailed, programmer-oriented description is included as a programming manual along with the full program listing in Volume II. For the purposes of this discussion, although references will be made to certain portions of MADAM, every effort will be made not to alienate the users who are not concerned with coding modification. All succeeding chapters will also follow this policy in the "Computer Implementation" sections.

There are two types of storage of "grouped" or similar data: arrays and nodes. An array is simply a list which MADAM recognizes as consisting of elements which should be associated with one another. Thus, for

example, an array is used to store the list of alternatives to be evaluated. A node is a term which denotes a group of associated information which is not a list of similar items. Thus, for example, MADAM uses a single node to store an objective and information about its position in the objective hierarchy. Through the use of these data structures, MADAM is able to obtain an initial problem formulation, and allow the user to modify the problem formulation at a later time in the decision analysis.

As described earlier in this chapter, the key elements of problem formulation for MADAM are formulating the objective hierarchy, establishing the attribute set, and delineating the alternatives. The sequence of routines which accomplish this are accessed when the user calls option **\*\*\*NEW\*\*\***. MADAM will take the user through all of the steps of problem formulation before returning to the main option selection. For notational purposes, all user options will be delineated by asterisks to distinguish them from routines which have the same name or function. While actually using MADAM, these asterisks should be ignored.

The Alternative Set. The first stage of the problem formulation will be to input the current list of alternatives which will be evaluated. MADAM allows the user to input a list of 10 letter mnemonics, each of which signify a particular alternative. This list will be stored but it can be modified later in the decision analysis. This procedure of listing the alternatives is done first so as to exploit the previously mentioned ability of the alternatives to suggest operational objectives by their very nature. The user is encouraged to make any notes concerning objectives which occur at this point. A more precise description of using MADAM is provided by the User's Manual (Appendix B).

The Objective Hierarchy. As the user exits the input of the

alternative set, the next task to be accomplished is the construction of the objective hierarchy. MADAM facilitates formulation of the hierarchy by utilizing the logic shown in Figure 2.5. The user begins forming the objective hierarchy by inputting the overall objective which indicates why the problem is under consideration. The first objective is considered the initial parent objective from which the user specifies the first level of subobjectives (see Figure 2.6 and the Glossary-Appendix A). After the

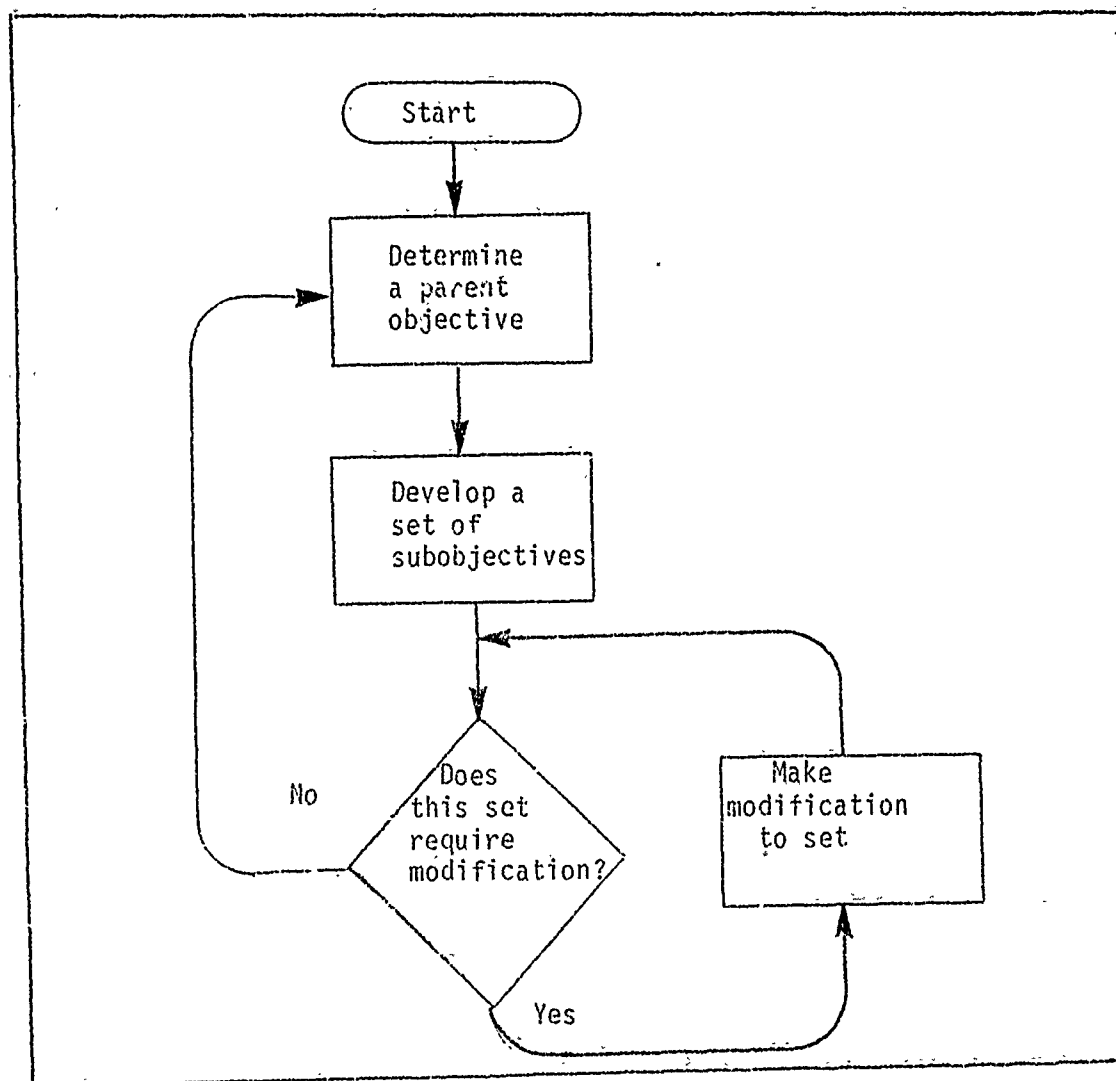


Figure 2.5. Logic Flow of Hierarchy Construction (SPAN)

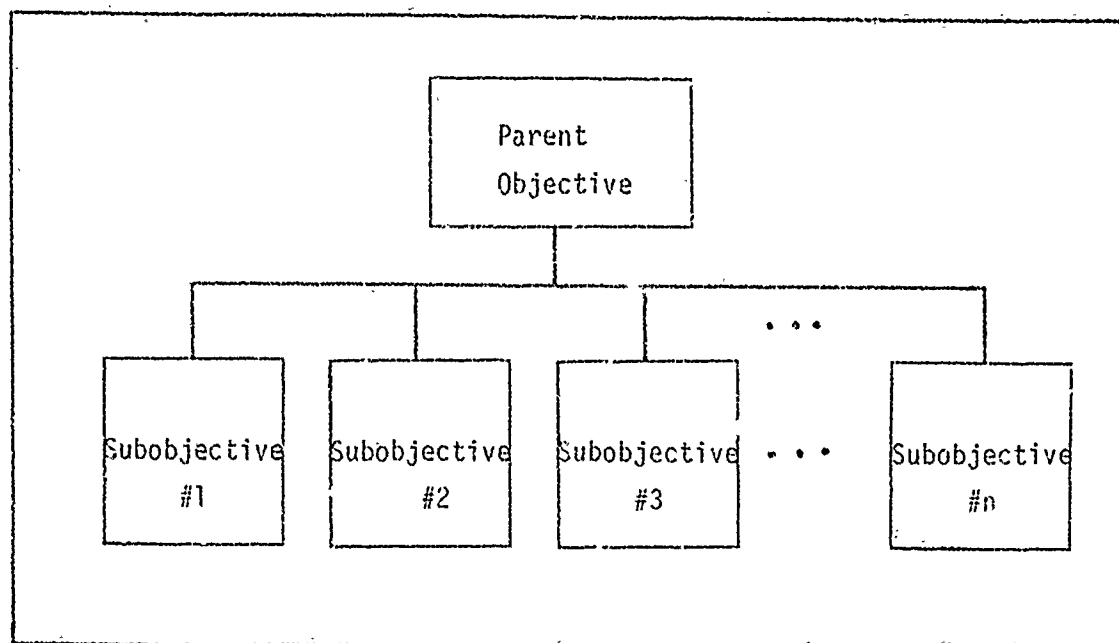


Figure 2.6. A Portion of the Objective Hierarchy

initial set of subobjectives is established, MADAM queries the user as to the existence of several potential sources of problems. If any modification of the set of subobjectives is required, the user is automatically directed into the modification routine (MODIFY, PRUNE) so that the offending subobjectives may be corrected. The user is brought back into the querying phase and this cycle is repeated until an acceptable set of subobjectives is acquired. At this point, the program stores the information (the new subobjectives of the parent objective), and then chooses the first subobjective as the new parent objective. The preceding process is repeated. At the point where the user indicates that a parent node will have no descendant subobjective, that node becomes a data node (an objective which will have an associated attribute), and the current parent node's sibling is chosen as the new parent node. If there are more siblings, MADAM goes back up one level in the hierarchy to look for the nearest sibling. In this manner, the objective hierarchy is developed.

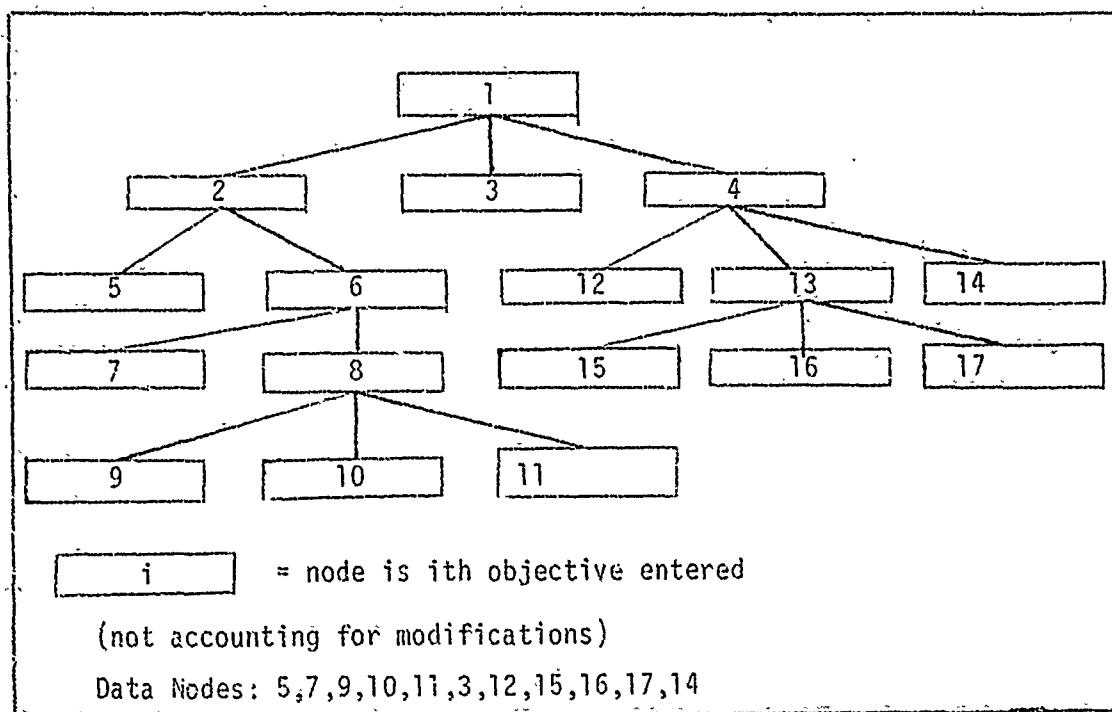


Figure 2.7. An Example of Depth-First Ordering

in a depth-first fashion (see Figure 2.7 above). It is important to note that the subobjective set referred to in the previous discussion that set of subobjectives which specify the single current parent objective. Currently, MADAM allows for up to nine subobjectives for each parent objective and for a total of 500 nodes (objectives) in the entire objective hierarchy. Relatively minor coding modification would allow for a relaxation of these numerical restrictions.

After the objective hierarchy is completed, the user has a local file containing all the input information. This file can be used as temporary storage during the same session, or for permanent storage between sessions. Within a single session MADAM allows the user to work with a file (tree #), and to change files through the option **\*\*\*SEL\*\*\***. The data is stored on a local file, so no information is lost when changing from one file to another. As long as the user exits from the program

normally (\*\*DON\*\*), all objective hierarchies and associated data are stored on separate temporary files. They must be converted to permanent files before disconnecting. This procedure (for the CYBER) is described in the User's Manual. Currently, MADAM allows the use of up to three separate hierarchies (tree #'s) in a single session. This limit may be altered by changing the variable NTREE in the program code.

The Attribute Set. After the entire objective hierarchy has been input, MADAM automatically shifts to the routine which allows input of the attribute set. Through a depth-first search pattern, MADAM finds each data node and allows input of an associated attribute. As each data node is encountered, MADAM allows the input of a 10 letter mnemonic for the attribute to be associated with that node. Several questions are asked to verify the validity of that attribute, and if modifications are required, the cycle is repeated (see Figure 2.8). Once an acceptable attribute is established, the user inputs the best and worst values of this attribute. In this context, best means that level of the attribute which is most preferred, and worst means that level which is least preferred. There is no distinction about which value is numerically greater. For example, if the objective is "to minimize the weight of the radar set" and the associated attribute is WTKILO (weight in kilograms) then the best level might be 10 while the worst level might be 100.

After all of the data nodes have been presented and all of the attribute set obtained, the entire attribute set is reviewed and screened for other problems. Through this screening (and that of the objectives) the desirable properties of the attributes and the attribute set (and the objective hierarchy) are infused into the problem formulation. Following the construction of an appropriate attribute set, the program

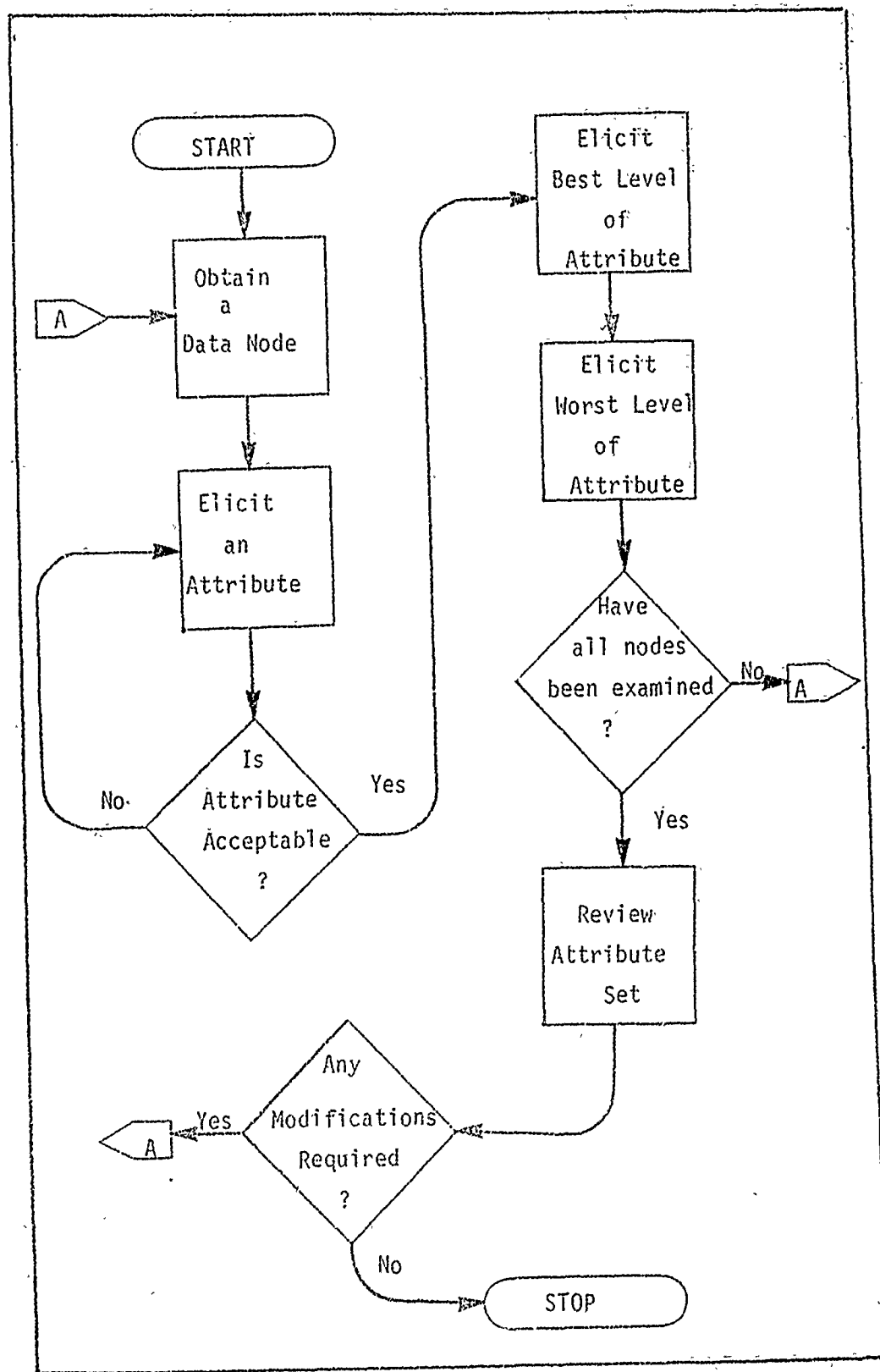


Figure 2.8. Logic Flow to Obtain Attribute Set (RDATT)

branches to the routine which will examine the independence conditions among the attributes (PPI). The process of testing for independence and the implications of the types of independence are the subject of the next chapter: The Value Function.

### III. The Value Function

#### Theoretical Considerations

After formulating the objective hierarchy and the associated attribute set, the next stage of a MAUT decision analysis involves determination of the relationships among the attributes. This is important because these relationships determine the mathematical form of the utility/value function. The mathematical form of the overall utility/value function will determine how changes in the attribute levels will impact the relative ranking of the alternatives. In MAUT, there are essentially four techniques for obtaining the overall utility/value function (Farquhar, 1979). They are the decomposition technique, the multi-valent technique, the approximation technique, and the spanning technique.

The spanning technique is a relatively new approach which uses the concepts of abstract linear algebra. The basic idea involved is to determine a subset of the attributes which "spans" the entire set of attributes. The advantages of this approach are that the DM is not forced to make complex trade-offs between the attributes, and the components of the overall utility/value function is a combination of functions defined over the individual attributes. Because of the novelty of this approach, the theory has not been subjected to external validation through application to practical problems (Farquhar, 1979). For this reason, the spanning technique was not implemented in MADAM.

The multi-valence approach is also a new technique, and it involves determining the ranges over which each attribute has certain independence conditions. This allows more complicated functions to be represented by the use of several simpler functions defined over domains which are subsets

of the original more complicated function (Farquhar, 1979). This approach was discarded for use in MADAM due to the enormous difficulties associated with developing a sensitivity analysis.

The approximation technique was used in DASS, which is the forerunner of MADAM (Morlan, 1979; Lee, 1980). The basic approach is to assume that there are no benefits to be gained by going to a more accurate function, and thus to use a less complicated one. DASS incorporates this approach in that for the purpose of evaluation, the overall value function is assumed to be of the additive form. In addition, the sensitivity analysis further assumes linearity of the individual value functions (functions defined over each attribute separately). In neither case is any attempt made to justify these assumptions for the problem under analysis. The rationale for such an approach is that it significantly decreases the time required for decision analysis by removing almost all of the trade-off analysis between attributes. Theoreticians and practitioners are split as to the validity of such an approach. Some indicate that rarely do problems arise where this is not a good "first-cut" solution (Edwards, 1977), others feel that use of approximation techniques are too misleading to the DM to be of practical value (Keeney and Raiffa, 1976).

The decomposition approach involves specifying the relationship between attributes in order to obtain a true functional form for the overall utility/value function. MADAM lies between an approximation approach and a full decomposition approach. This is because MADAM does test the conditions which are necessary and sufficient conditions for the use of the additive value function but it does not consider all types of relationships among the attributes. Because of an emphasis in efficiency, only the additive decomposition is covered by the model. The individual

value functions are fitted through a least-squares procedure rather than assumed linear for the sensitivity analysis. The rationale behind MADAM is that it must provide enough information so as not to be misleading, but in the interest of time (and practical applicability), it is necessary to restrict the conditional testing.

Conditions of MAUT. Before examining the details of the decomposition approach, it will be necessary to consider some fundamentals of MAUT. The fundamental axiom of MAUT is that an isomorphic mapping exists between alternative actions and the consequence space which in turn, is isomorphic to a set on the real line (see Figure 3.1). The mapping of actions into the consequence space is done by functions which mimic the reality of causation (if-then relationships). The mapping of the outcome space onto the real line is accomplished through the overall value function (only the riskless decision environment will be considered). This mapping into the real line is assumed to represent the DM's true preference structure. That is to say,

$$v(x_1, \dots, x_n) \geq v(x'_1, \dots, x'_n) \Leftrightarrow (x_1, \dots, x_n) \succsim (x'_1, \dots, x'_n)$$

where  $\succsim$  is read as "is preferred or indifferent to"

$(x_1, \dots, x_n), (x'_1, \dots, x'_n)$  are elements of the outcome space and  $v$  is the overall value function.

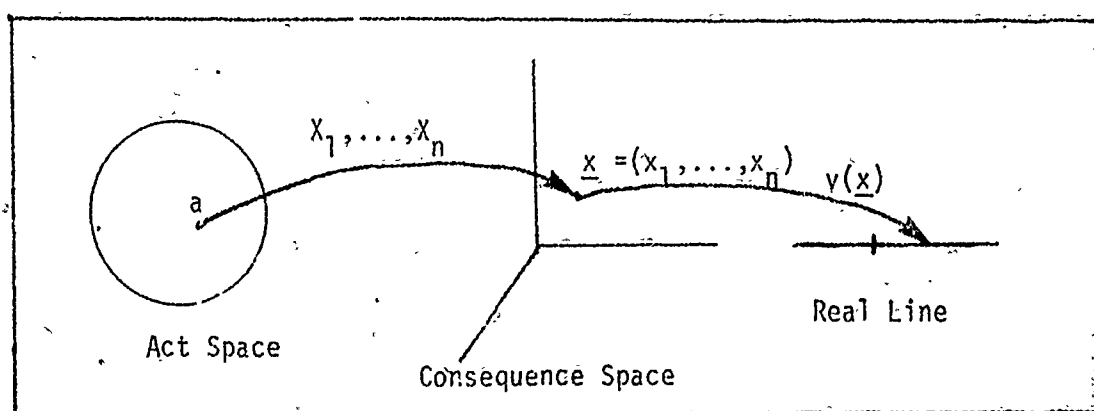


Figure 3.1. Fundamental Relations in MAUT  
(adapted from Keeney and Raiffa, 1976)

MAUT is predicated on the concept of rationality. That is, a decision is to be made in a rational manner. In the context of a riskless environment, a decision strategy is rational if any two consequences may be compared relative to desirability, and all comparisons made are transitive (i.e.  $x_1 \succ x_2, x_2 \succ x_3 \Rightarrow x_1 \succ x_3$ ) (Fischer et al, 1978). Although intuitively appealing, the presence of transitivity has been questioned in some applications, and this stresses the importance of proper problem formulation. Along with the concept of transitivity, a fundamental assumption of MAUT are that the consequence space is topologically dense, and that the attributes are compensatory. These assumptions imply that one can make local changes which preserve indifference about any point in the consequence space, and thus, the indifference curves are continuous (Fishburn, 1977). These assumptions make it meaningful to approach the problems of establishing indifference curves and testing independence assumptions through hypothetical questions which allow the DM to lose (or gain) one attribute for an appropriate gain (or loss) of another attribute. Finally, traditional MAUT assumes that the preference function ( $\succ$ ) is a strict weak order over the consequence space (Fishburn, 1977). A strict weak order is a binary relationship which is:

- i) asymmetric ( $x_1 \succ x_2 \Rightarrow \text{not } x_2 \succ x_1$ )
- and ii) negatively transitive  
( $\text{not } x_1 \succ x_2, \text{not } x_2 \succ x_3 \Rightarrow \text{not } x_1 \succ x_3$ )

The Additive Value Function. With the above information about the assumption of a MAUT decision analysis, it is meaningful to consider what a particular decomposition implies about the relationship between the attributes. Also, the necessary and sufficient conditions for a particular decomposition may be developed. In particular, the decomposition

which will be emphasized is the additive form of the value function (see Figure 3.2). The additive form will be considered in detail because it is the basic decomposition underlying a MADAM decision analysis, and because it is a commonly used decomposition in other decision analytic settings.

Additive Form:

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

Quasi-additive Form:

$$V(\underline{x}) = \sum \{c_{i_1}, \dots, c_{i_r} v_{i_1}(x_{i_1}) \dots v_{i_r}(x_{i_r}) : 1 \leq i_1 < \dots < i_r \leq n, 1 \leq r \leq n\}$$

Multiplication Form:

$$V(\underline{x}) = \sum \{k^{r-1} k_{i_1} \dots k_{i_r} v_{i_1}(x_{i_1}) \dots v_{i_r}(x_{i_r}) : 1 \leq i_1 < \dots < i_r \leq n, 1 \leq r \leq n\}$$

$$\text{Note: } 1 + kv(\underline{x}) = \prod_{i=1}^n (1 + k v_i(x_i))$$

Diagonal Form:

$$V(\underline{x}) = \sum_{i=1}^n c_i v_i(x_i) + \sum \{c_{i_1}, \dots, c_{i_r} f_{i_1}(x_{i_1}) \dots f_{i_r}(x_{i_r}) : 1 \leq i_1 < \dots < i_r \leq n, 2 \leq r \leq n\}$$

Figure 3.2 Some Common Decompositions

In order to derive the necessary and sufficient conditions for the additive value function, it is necessary to introduce the concept of "conditional preference". Let  $A$  be the set of all attributes, and  $X, Y$  are vectors of attributes such that  $X, Y \in A$ ,  $X \cap Y = \emptyset$ . Let  $Z$  represent  $[Z \in A: Z \cap X = \emptyset, Z \cap Y = \emptyset, X \cup Y \cup Z = A]$ . Then two elements of the consequence space  $(x, y)$  and  $(x', y')$  are such that  $(x, y)$  is conditionally preferred to

$(x', y')$  given  $Z$  if and only if the two corresponding elements of the full outcome space  $(x, y, z)$  and  $(x', y', z)$  are such that  $(x, y, z)$  is preferred to  $(x', y', z)$ . (Keeney and Raiffa, 1976). This may be written:

$$(x, y) \succeq_Z (x', y') \iff (x, y, z) \succ (x', y', z)$$

This conditional preference can be extended by defining preferential independence as that condition when the conditional preferences over  $(x, y)$  space do not depend on the level of  $z$  (Keeney and Raiffa, 1976). Regardless of what level of  $z$  is chosen, the DM would indicate the same conditional preferences. This condition is noted by  $\{X, Y\}PI\{Z\}$ . The natural implication of this condition is that trade-offs between  $X$  and  $Y$  may be considered without regard to the level of  $Z$ .

An even stronger independence condition among the attribute is called "mutual preferential independence". The concept of mutual preferential independence (MPI) denotes the condition where every subset of the attribute set is preferentially independent of its complement (Keeney and Raiffa, 1976). That is,

$$\{X, Y\}PI\{Z\}, \forall X, Y, Z \in A \text{ (with above restrictions)}$$

$$\implies \{X_1, \dots, X_n\}MPI, \forall X_i \in A$$

Not only is this condition of MPI more restrictive on the attribute set, but it appears at first that it is necessary to test  $2^n - 2$  different subsets of the attributes in order to verify MPI (Note: PI is not a reflexive operator:  $\{A\}PI\{B\} \not\Rightarrow \{B\}PI\{A\}$ ). Fortunately, there is a theorem which allows the number of cases to be reduced substantially. The theorem states

$$\text{Let } Y \subset A, Z \subset A, Y \cap Z = \emptyset, Y \cup Z = A \quad \{Y\}PI\{A-Y\}, \{Z\}PI\{A-Z\}$$

then

- i)  $Y \cup Z$
- ii)  $Y \cup Z$
- III)  $Y - Z$  and  $Z - Y$
- iv)  $(Y - Z) \cup (Z - Y)$

are each PI of their complements (stated in Keeney and Raiffa, 1976; a formal proof is given in Gorman, 1968).

In particular, the above theorem allows one to equate pairwise preferential independence (PPI) with MPI, where PPI involves testing each pair of attributes against the remaining set. It has been shown that the necessary and sufficient condition for use of the additive value function is that the attributes are MPI, hence it follows that a necessary and sufficient condition for use of the additive value function is that the attributes are PPI (Keeney and Raiffa, 1976). This reduces the testing to  $2^n$  cases, and it is this latter point which MADAM exploits in determining if the additive decomposition is appropriate for the problem at hand.

Linearity. In addition to the decomposition used, a factor which has direct impact on the evaluation of the alternatives is the choice of the individual value functions  $(v_i(x_i))$  for each attribute. In particular, the assumptions made concerning the convexity of the individual value functions carry implicit information about the preferences of the DM (see Figure 3.3). The implications concern the DM's rate of change of preference over changes in the attribute level (see Figure 3.4). It is important to know the form of the individual value functions for a meaningful sensitivity analysis.

In order to save the DM time, DASS (the forerunner of MADAM) assumed that the individual value functions were linear (Morlan, 1979; Lee,

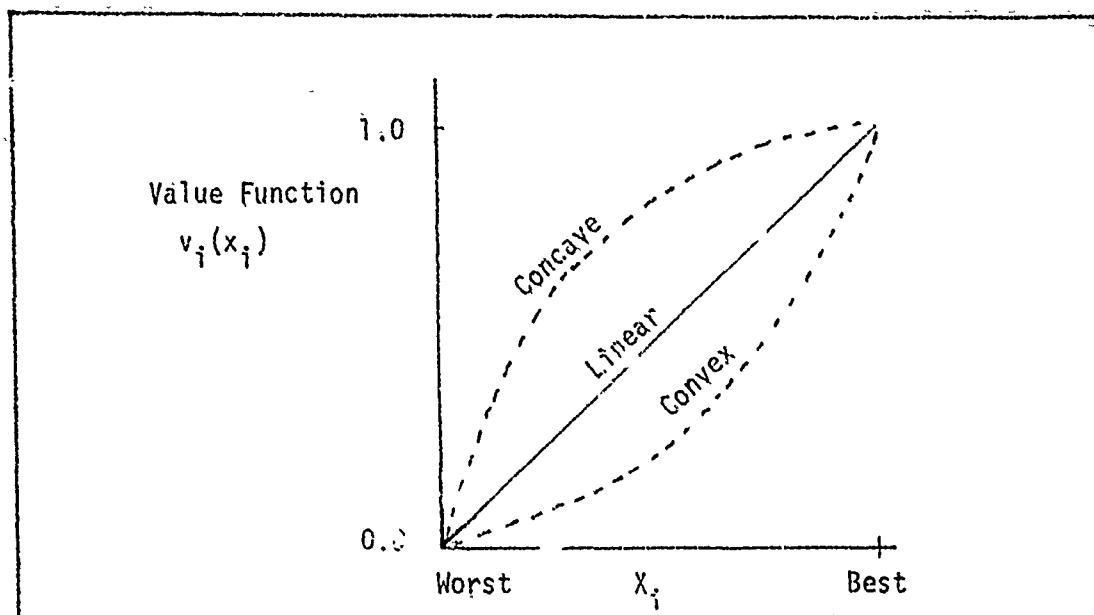


Figure 3.3. Various Forms of an Individual Function

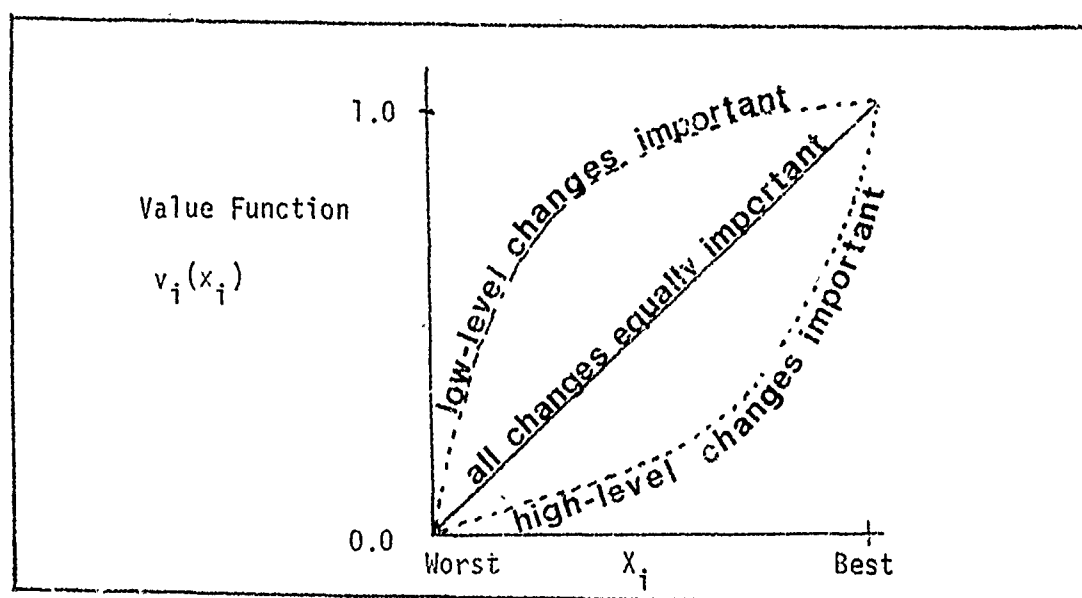


Figure 3.4. Implications Concerning Preferences

1981). MADAM, however, uses a midvalue splitting technique to establish several points of the individual value function. The midvalue splitting technique is an approach where the attribute level having a value (to the DM) halfway between the values of two known levels is solicited. After several points on the curve are obtained, a reasonable approximation to the individual value function may be generated.

#### Computer Implementation.

After obtaining the objective hierarchy and the associated attribute set, it is necessary to test or assume the relationships between the attributes. MADAM automatically takes the user through the routines (PPI, VALUE) which will allow the testing to take place. All testing is done via a hypothetical question approach where the DM is asked to trade-off one attribute for another, or to move between levels of an attribute.

The Additive Value Function. Since MADAM is ultimately concerned with the validity of the additive decomposition, MADAM tests to see if the necessary and sufficient condition of PPI exists. This is done by the routine PPI with the logic flow as shown in Figure 3.5. The user may specify what tolerance is desired to work at, which reflects considerations of time and accuracy in decision analysis. When the tolerance is specified, the user is taken through questions involving trade-offs between two attributes with the other attributes arbitrarily set at the 25% level (25% of the distance between the worst and the best levels). It is assumed that the points established will be on the same indifference curve (which is true if the user understands the questions and the trade-offs involved). MADAM then checks for shifting (in shape) of the indifference curve by moving all the other attributes to the 75% level, and then repeating some hypothetical trade-off questions. This time, however, in

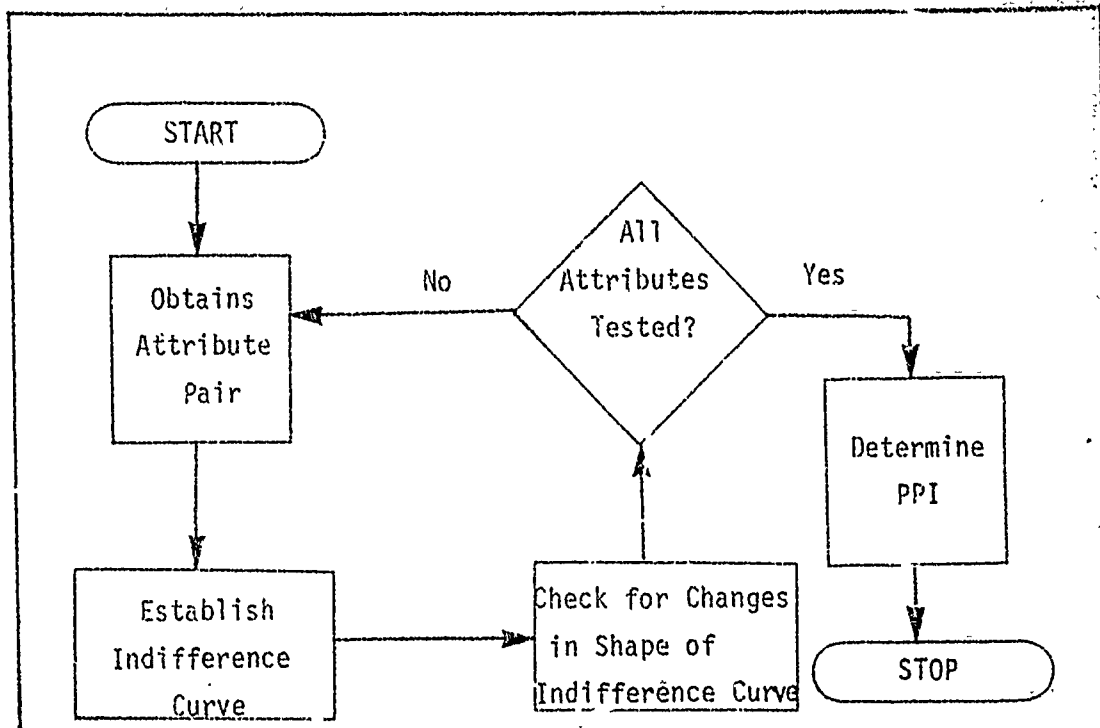


Figure 3.5 Logic Flow of PPI

order to minimize user frustration, the questions are phrased in a yes/no fashion where the user indicates whether the correct level would lie in an interval generated by the program. The length of the interval is a function of the specified tolerance (see Figure 3.6). If it is determined that no significant (out of tolerance) shifts have occurred in the shape of the indifference curve, then the condition of PPI is supported. After all the pairs of attributes have been tested, the final determination of PPI is made.

Currently, MADAM is designed to output any violations of PPI, if any, but it does not handle alternative decompositions. Even if PPI is violated, the user has the option of continuing the analysis with an additive decomposition (with appropriate warnings) so that the program may give the user any desired information.

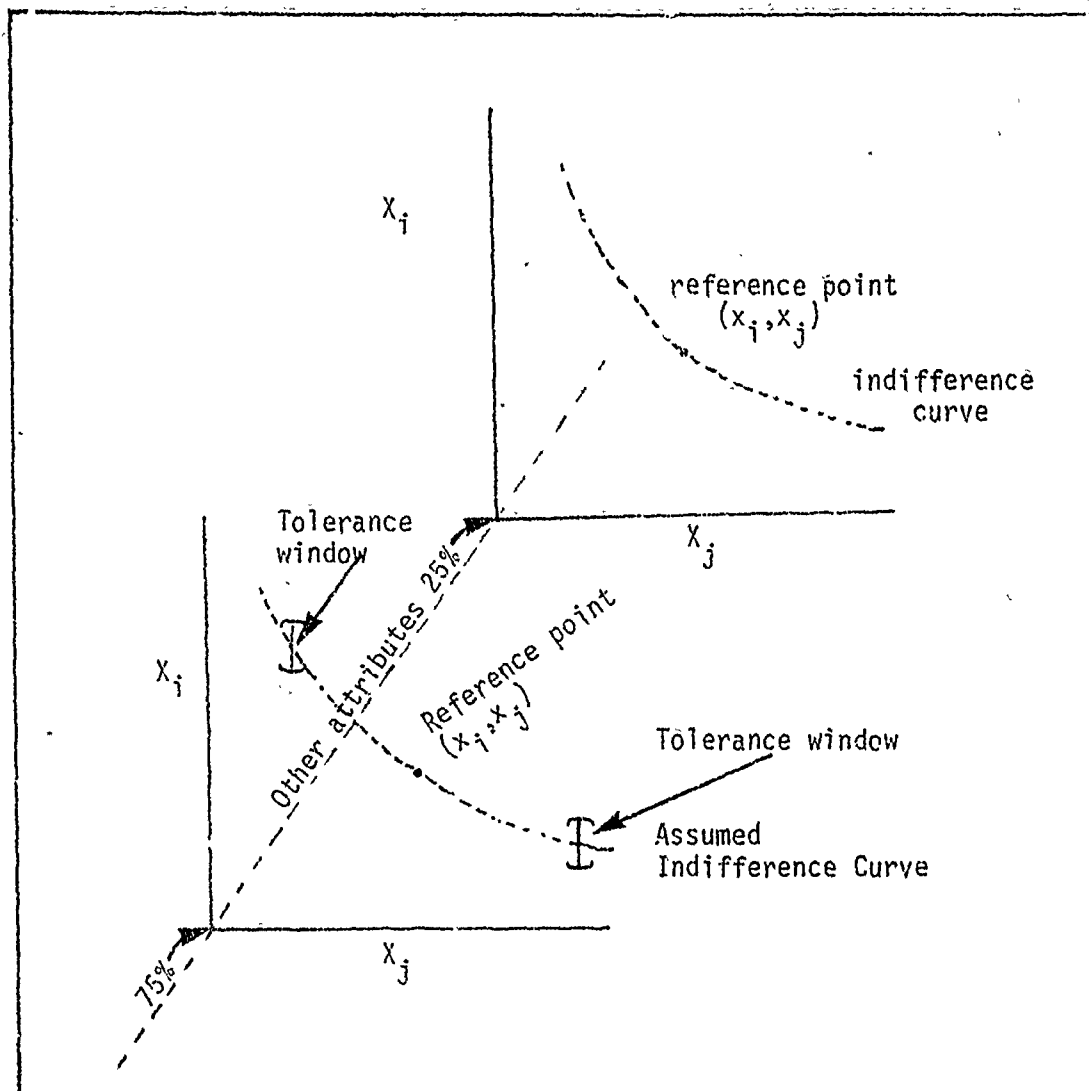


Figure 3.6 Testing for PPI

Linearity. If the condition of PPI is supported, or if the user continues with the analysis, MADAM establishes the nature of the individual value functions. This is done by the routine VALUE, and the logic flow is given in Figure 3.7. For each attribute, the midvalue splitting technique is employed to generate five points on the actual individual value function (Actually, two of these points are given boundary conditions, and three internal points are generated.). By using a least-squares approach, the data is fit to one of five curves based on minimization of the sum of

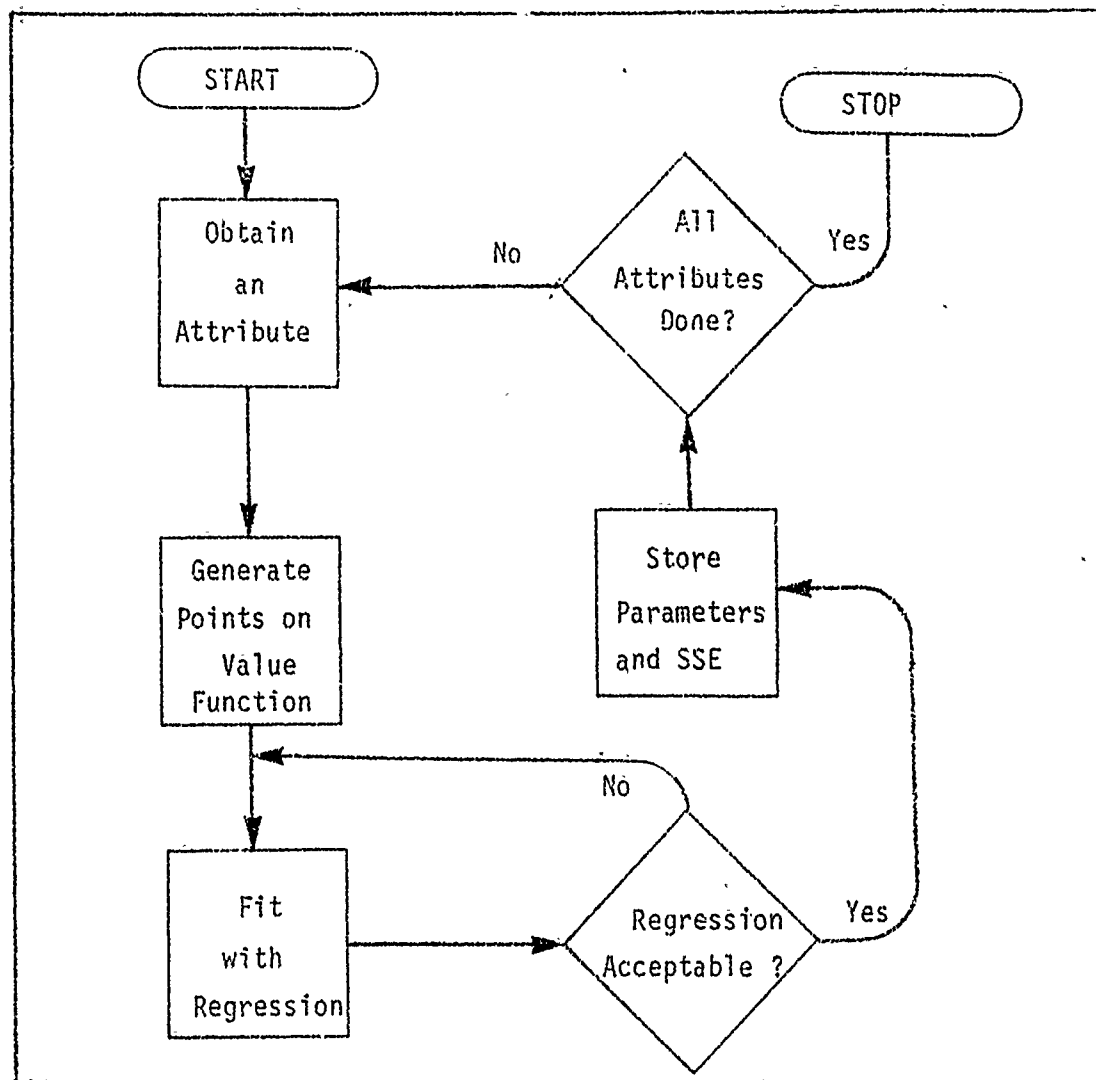
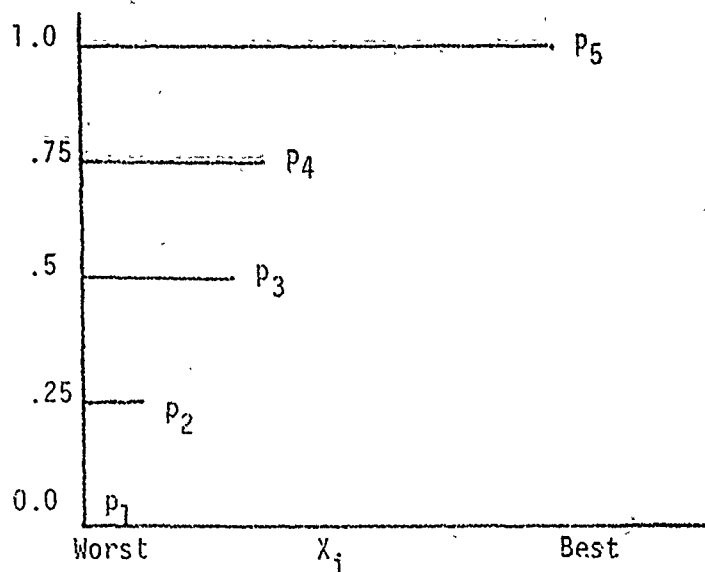


Figure 3.7 Logic Flow of VALUE

squared error (see Figure 3.8). The rationale for this is that the least-squares approach is useful to compare the "goodness of fit" of alternative curves, and that by establishing curves, MADAM may internally generate values based on levels of an attribute without having to bother the user. The curves used to fit the data are

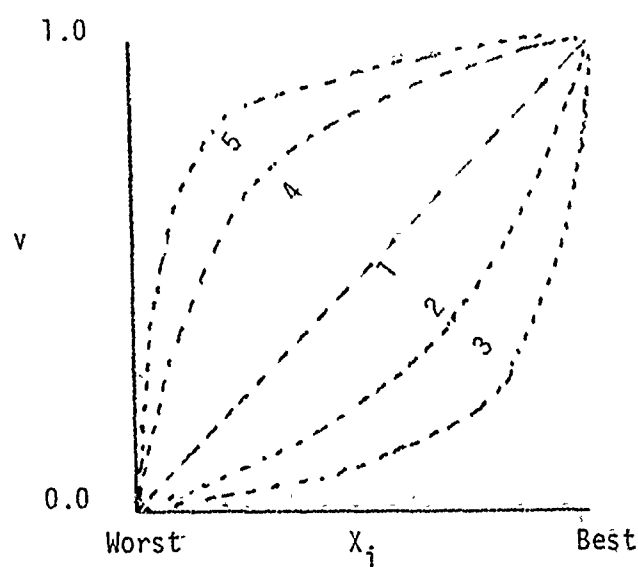
$$v = b_0 + b_1 x$$

$$v = b_0 + b_1 \sqrt{x}$$



$p_1 \dots p_5$  = data points on curve

$p_1, p_5$  = boundary conditions



1  $v = b_0 + b_1 x$

2  $v = b_0 + b_1 x^2$

3  $v = b_0 + b_1 e^x$

4  $v = b_0 + b_1 \sqrt{x}$

5  $v = b_0 + b_1 \ln x$

Figure 3.8 Approximating a Value Function

$$v = b_0 + b_1 x^2$$

$$v = b_0 + b_1 \ln x$$

$$v = b_0 + b_1 e^x$$

where  $v$  is value and  $x$  is a level of the attribute. Although these curves may not fit the data exactly, they do provide an incorporation of the convexity question for the purpose of sensitivity analysis.

As each curve is fit, a graph is output to the user to see if it is realistic. If it is not, the procedure of generating points may be repeated. At all times, the sum of squared error is stored with each parameter set. Since the values are normalized between 0 and 1, it is possible for the DM to provide a cut-off for an acceptable level of the sum of squares error. If all of the regressions exceed this limit, the closest fit is used and a message is generated concerning the problem.

The Overall Value Function. After PPI has been verified, and the individual value functions have been established, the user is returned to the main option selection. At this point the user should enter option \*\*\*WCV\*\*\* in order to enter the weights for the nodes of the objective hierarchy (more detail is given in the User's Manual). The user will be asked to enter relative weights for the descendants of every parent node. These may be entered directly (not necessarily normalized) or indirectly through the use of a pairwise-comparison matrix approach (Saaty, 1980; Williams and Crawford, 1980). When the weights have been entered for the whole hierarchy, MADAM is able to calculate the coefficients ( $w_i$ ) for use in the overall value function. As soon as all of the levels of the attributes for each alternative have been entered, the entire decision analysis is complete except for the sensitivity analysis.

#### IV SENSITIVITY ANALYSIS

##### Theoretical Considerations

An important force behind the development of interactive decision-aids is the realization that a sensitivity analysis of the model parameters may yield important insights to the problem under consideration. Through exploitation of the virtually instantaneous computational capabilities of the computer, the DM may analyze a decision problem quite thoroughly in a matter of several minutes. The insights gained through varying the model parameters may be quite important, and considerably different, than those obtained from a static problem analysis. In the hierarchical type of problems suitable for analysis by MADAM, the critical model parameters to be examined in a sensitivity analysis are the weights assigned to the nodes in the hierarchy, and the attribute levels which describe the alternative systems. MADAM facilitates a thorough problem analysis by allowing a sensitivity analysis over the weight of a particular node relative to its siblings (relative weight), the weight of a particular node relative to the root node (cumulative weight), attribute levels at a particular node, and a particular system relative to a desired set of nodes.

Cumulative Weight Sensitivity (CSA). The crux of the cumulative weight sensitivity is to determine how the overall values of the alternative systems change, relative to each other, when the contribution of a particular node to the hierarchy is modified. For a given alternative system, the overall value (value at the root node) is the summation over all the attributes of the product between the contribution of that attribute and the value of that attribute level assigned to the system.

This can be expressed,

$$V_i = \sum_{\substack{j \\ \text{all} \\ \text{attributes}}}^j (\text{CUMWT}_j) (v_{ij})$$

where  $V_i$  is the overall value of system  $i$

$\text{CUMWT}_j$  is the cumulative weight of the node associated with attribute  $j$

$v_{ij}$  is the value of system  $i$  on attribute  $j$ .

For analysis purposes, the change in  $V_i$  must be determined for given changes in a particular  $\text{CUMWT}_j$ . This change may be determined by deleting the contribution of a particular node to the root node and replacing it with a new contribution. The contribution of a given node to the value of a system at the root node is the product of the cumulative weight of the node and the particular system value at that node.

Unfortunately, simply changing the cumulative weight of a node is not sufficient. When the cumulative weight of a node is modified, the tree structure is no longer normalized. This problem may be ameliorated by introducing a transformation to the tree. This transformation must be such that the modified tree's cumulative weight is equated to one minus the cumulative weight of the perturbed node (Lee, 1981).

This transformation can be incorporated into a single equation so that the desired result is:

$$V_i^* = (v_{ij}) (\text{CUMWT}_j^*) + (1 - \text{CUMWT}_j^*) / (1 - \text{CUMWT}_j) \times (V_i - (v_{ij}) (\text{CUMWT}_j))$$

where

$$V_i^* = \text{new overall value of system } i$$

$V_i$  = old overall value of system i

$v_{ij}$  = value of system i at node j

$CUMWT_j$  = old cumulative weight of node j

$CUMWT_j^*$  = new cumulative weight of node j

The above equation may be used to evaluate the effects of desired changes in the cumulative weight of any one node on the overall system values.

Relative Weight Sensitivity (RSA). In a relative weight sensitivity analysis, the desired information consists of those changes in the overall system values based upon changes in the weight of a given node relative to its siblings. The impact of modifying the relative weight of a given node may be obtained by noting that the value of a system at a particular node is a function of its value at the node's descendants and their relative weights. In particular, the value is given by:

$$v_{ip} = \sum_{\text{span}}^d (\text{RELWT}_d) (v_{id})$$

where  $v_{ip}$  = value of system i at parent node

$\text{RELWT}_d$  = relative weight of a descendant

$v_{id}$  = value of system i at descendant d

Examining the previous equation results in the conclusion that a change in the relative weight of any node will affect only the value of a system at the parent of the given node. Also, the value of a system at a given node is dependent only upon the immediate descendants of the node. Thus, in calculating the change in overall system value based upon perturbations in the relative weight of a given node, the new values of the alternative systems must be computed and substituted for the initial

values. These new values can be directly applied to see how values at the root node are affected, because any nodes contribution to root node values is a function of its cumulative weight (which is constant for this analysis). Combining the preceding concepts, the ramifications of relative weight modifications are given by:

$$V_i^* = V_i - [(CUMWT_p)(v_{ip}) + (CUMWT_p)(v_{ip}^*)]$$

where

$V_i^*$  = new overall value of system i

$V_i$  = old overall value of system i

$CUMWT_p$  = cumulative weight of parent

$v_{ip}$  = old value of system i at parent node

$v_{ip}^*$  = new value of system i at parent node

Since there is some ambiguity as to how to deal with the relative weights of the siblings of the modified node in order to preserve normalization, an arbitrary decision was made to retain the relative weights of the siblings in constant proportions (Lee, 1981). That is, the proportions between the relative weights of the siblings (not including the modified node) would be preserved after modification.

Attribute Level Sensitivity (LSA). The emphasis behind an attribute level sensitivity analysis is to examine the robustness of the "optimal" solution to various changes in the level of a particular attribute. For the purpose of such an analysis, two fundamental assumptions implicit in MADAM are that, first, all the alternatives systems are independent of each other. That is, changes in the attribute levels of one alternative have no influence on the attribute levels associated with the other systems. Second, the relative and cumulative weights of the

nodes are assumed to be unaffected by a modification in a system's attribute levels (Lee, 1981). Under these assumptions, only the perturbed system will experience changes in overall value, and the change experienced is a direct function of the cumulative weight of the node associated with the attribute which is being changed. This may be represented:

$$V_i^* = V_i - (\text{CUMWT}_a) (v_{ia\ell}) + (\text{CUMWT}_a) (v_{ia\ell}^*)$$

where

$V_i^*$  = new overall value of system i

$V_i$  = old overall value of system i

$\text{CUMWT}_a$  = cumulative weight of node a

$v_{ia\ell}$  = old value of system i at a node a with old attribute level  $\ell$

$v_{ia\ell}^*$  = new value of system i at node a with new attribute level  $\ell^*$

System Sensitivity (SSA). As noted in each of the preceding forms of sensitivity analysis, they dealt with the changes in the overall values of all the systems given that a single node was perturbed. Another perspective which yields different but valuable information is to consider how the overall value of a single system changes over perturbations of a set of nodes. Due to limitations on abstraction abilities, it is not very fruitful to consider simultaneous changes over the set of nodes. There is also a severe problem of dealing with an ambiguous rate of change when attempting a simultaneous change of the factor (RELWT, CUMWT, or LEVEL) under consideration. As a result, the system analysis is a concise representation of overall value response to modifications on each node in the desired set taken independently. This approach allows the use of the formulae occurring in the single node analysis while providing the DM with

information concerning the robustness of a possible alternative over changes occurring in a chosen set of nodes.

Since the previous formulae are valid in this approach, it is possible to do a system analysis over changes in cumulative weights, relative weights, and attribute levels corresponding to a desired set of nodes.

#### Computer Implementation.

MADAM allows the user to do all the forms of the sensitivity analysis described in the preceding section. The sensitivity analyses are accessed through the main option **\*\*\*SEN\*\*\***. Use of this option will result in a new set of choices which determine which type of analysis will be conducted. After the data file is complete, either by using options **\*\*\*NEW\*\*\*** and **\*\*\*WVC\*\*\***, or by taking a stored data file and using the appropriate options, there is no limit (subject to computer time restrictions) to the number of analyses which may be performed. The output for all the analysis options are provided in both a tabular and graphical mode (see Figures 4.1 and 4.2).

Cumulative Weight Sensitivity. Utilizing the approach described in the theoretical section of this chapter, MADAM generates a matrix containing overall system values. Each column of the matrix corresponds to an alternative system for a direct CSA, PSA, or LSA. Each column represents a different node for SSA with a CSA suboption. Each row represents a different cumulative weight. This matrix is expressed in a tabular or graphical fashion as shown in Figures 4.1 through 4.4. The dominant alternative system is marked by an asterisk for each cumulative weight (CUMWT) value. The tabular output may be used to ascertain the dominant options over a range of the CUMWT, and the graphical output may be interpreted to see which systems (nodes) are very sensitive to CUMWT.

FOR NODE:

<Associated objective>

CUMWT  
(or  
RELWT  
or  
LEVEL)

|      | <SYS 1> | <SYS 2>    | <SYS n> |
|------|---------|------------|---------|
| X.XX | XX.XX*  | XX.XX ...  | XX.XX   |
| X.XX | XX.XX   | XX.XX* ... | XX.XX   |
| ⋮    | ⋮       | ⋮          | ⋮       |
| X.XX | XX.XX   | XX.XX ...  | XX.XX*  |

(\*indicates dominant alternative)

Figure 4.1. Tabular Output for direct CSA, RSA, or LSA

LEGEND:

SYMBOL = A IS SYSTEM: <SYS 1> SYMBOL = B IS SYSTEM: <SYS 2>

SYMBOL = C IS SYSTEM: < >

CUMWT  
(or  
RELWT  
or  
LEVEL)

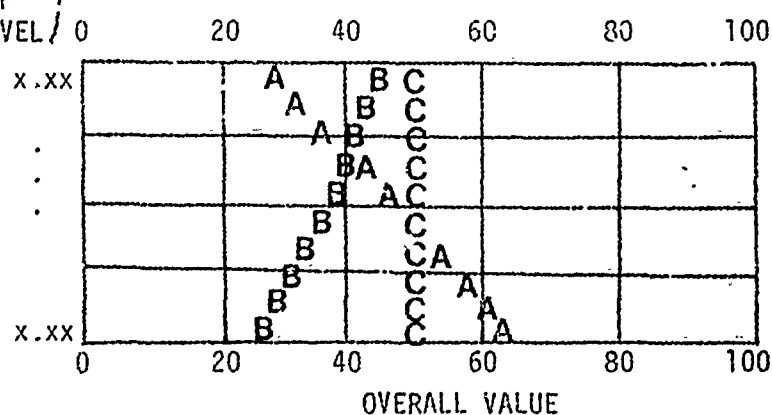


Figure 4.2. Graphical Output for direct CSA, RSA, or LSA  
(expanded option changes x axis)

FOR SYSTEM: <System name>

| CUMWT<br>(or<br>RELWT<br>or<br>VALUE) |  | NODE  | NODE      | NODE  |
|---------------------------------------|--|-------|-----------|-------|
| .xx                                   |  | xx.xx | xx.xx ... | xx.xx |
| .xx                                   |  | xx.xx | xx.xx ... | xx.xx |
| ⋮                                     |  | ⋮     | ⋮         | ⋮     |
| .xx                                   |  | xx.xx | xx.xx     | xx.xx |

Figure 4.3. Tabular Option for SSA with CSA, RSA, or LSA

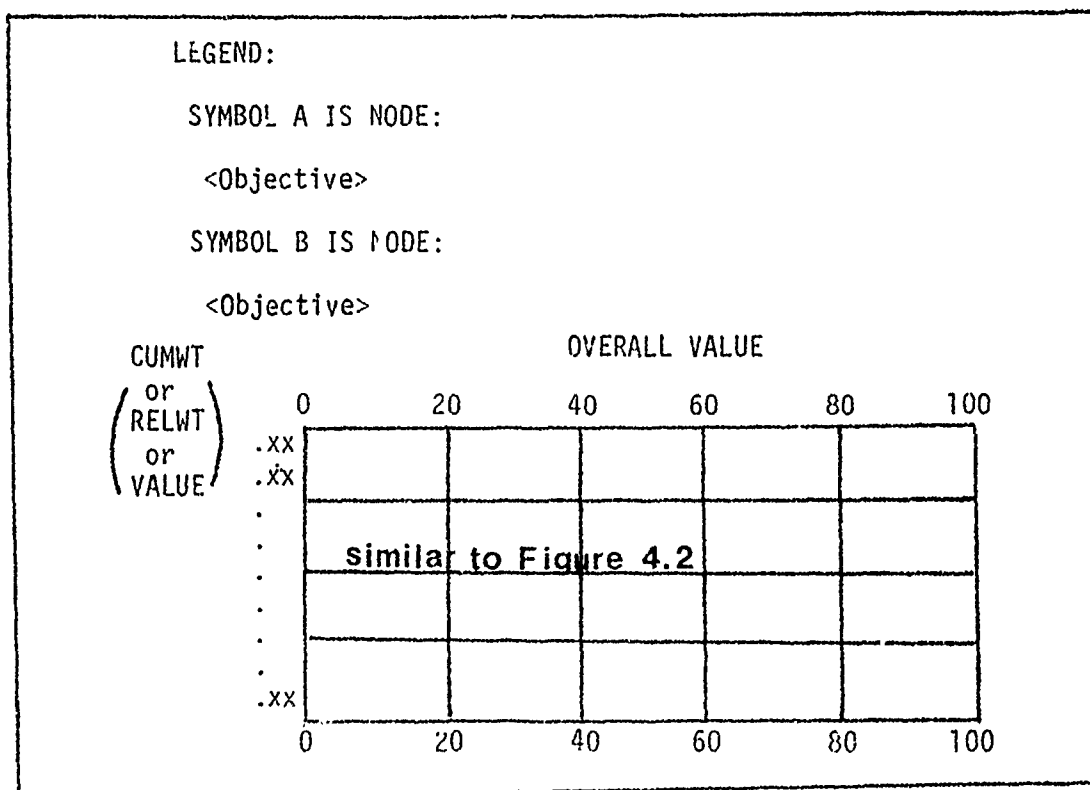


Figure 4.4. Graphical Option for SSA with CSA, RSA, or LSA  
(expanded option affects x axis)

Relative Weight Sensitivity. MADAM utilizes the formula presented in the theoretical section of this chapter for a relative weight sensitivity. A matrix of overall system values is generated where, for the direct RSA, each column corresponds to an alternative system. For the SSA option with the RSA suboption each column represents a different node. Each row corresponds to a different value of relative weight (RELWT). This analysis allows both tabular and graphical output of the data as shown in Figure 4.1 through 4.4. The tabular analysis may be used to readily identify the dominant option at a particular value of the relative weight of the node (nodes) under consideration. For the direct RSA, the graphical analysis will show the relative sensitivities of the alternative system for changes in the relative weight of a given node. The SSA option with RSA suboption will indicate to which nodes the given system is most sensitive based on changes in relative weight.

Attribute Level Sensitivity. Using the formula presented in the theoretical section of this chapter, MADAM allows the user to conduct an attribute level sensitivity. A matrix of overall system values is generated where, for the direct LSA, each column represents an alternative system. For the SSA option with a LSA suboption, each column represents a different node. For the direct LSA, each row represents a different actual level of the associated attribute. For the SSA with a LSA suboption, each row represents a different value where value is an entity into which attribute levels are transformed via the individual value functions. This conversion is made so that a single graph or table may be used to output the data. The output is presented in either a tabular or graphical format as shown in Figure 4.1 through 4.4. The table may be used to identify the dominant system for a given attribute level in the

case of direct LSA. The graphical output may be used to discern relative system sensitivities to changes in a particular attribute for a direct LSA. For SSA with an LSA suboption, the graphical output will yield those nodes to which the given system is most sensitive based on changes in raw value at the individual attribute level.

System Sensitivity. The system analysis allows the user to use one of the prior analyses over a set of nodes as opposed to a single node. In this analysis, however, it is the system (rather than the node) which is fixed, and the columns or symbols represent different nodes as opposed to different systems. For use of this analysis with either the CSA or RSA suboption, the y axis of the output is the same as for the single node option (direct CSA or RSA). When the LSA suboption is involved, the y axis represents raw value rather than actual attribute levels. It would be necessary to convert these raw values to attribute levels using the individual value functions if an interpretation of a particular node is to be made. Since the analysis is made over a single range of the variable, a broad enough range must be chosen so as to include the largest range of interest on any of the individual nodes. There is no restriction to the nodes which may be chosen except that a level (value) analysis is possible only at a data node.

The above sensitivity analyses put a set of powerful analytical tools at the fingertips of the DM. Because of the use of computerization, a very thorough analysis may be generated in a relatively short period of time. This analysis will provide information concerning the robustness of the dominant alternative over a wide range of parameter changes. This is important because the stability of the solution may be more important than its static value, particularly in those decisions where several

parameters are not known precisely. The information generated through sensitivity analyses both enhances and complements the original static analysis.

## V. An Illustrative Example

In order to facilitate discussion about using MADAM, the hierarchy in Figure 5.1 will be used as an example. It is loosely adapted from the example used in the original DASS development (Morlan, 1979; Lee, 1981).

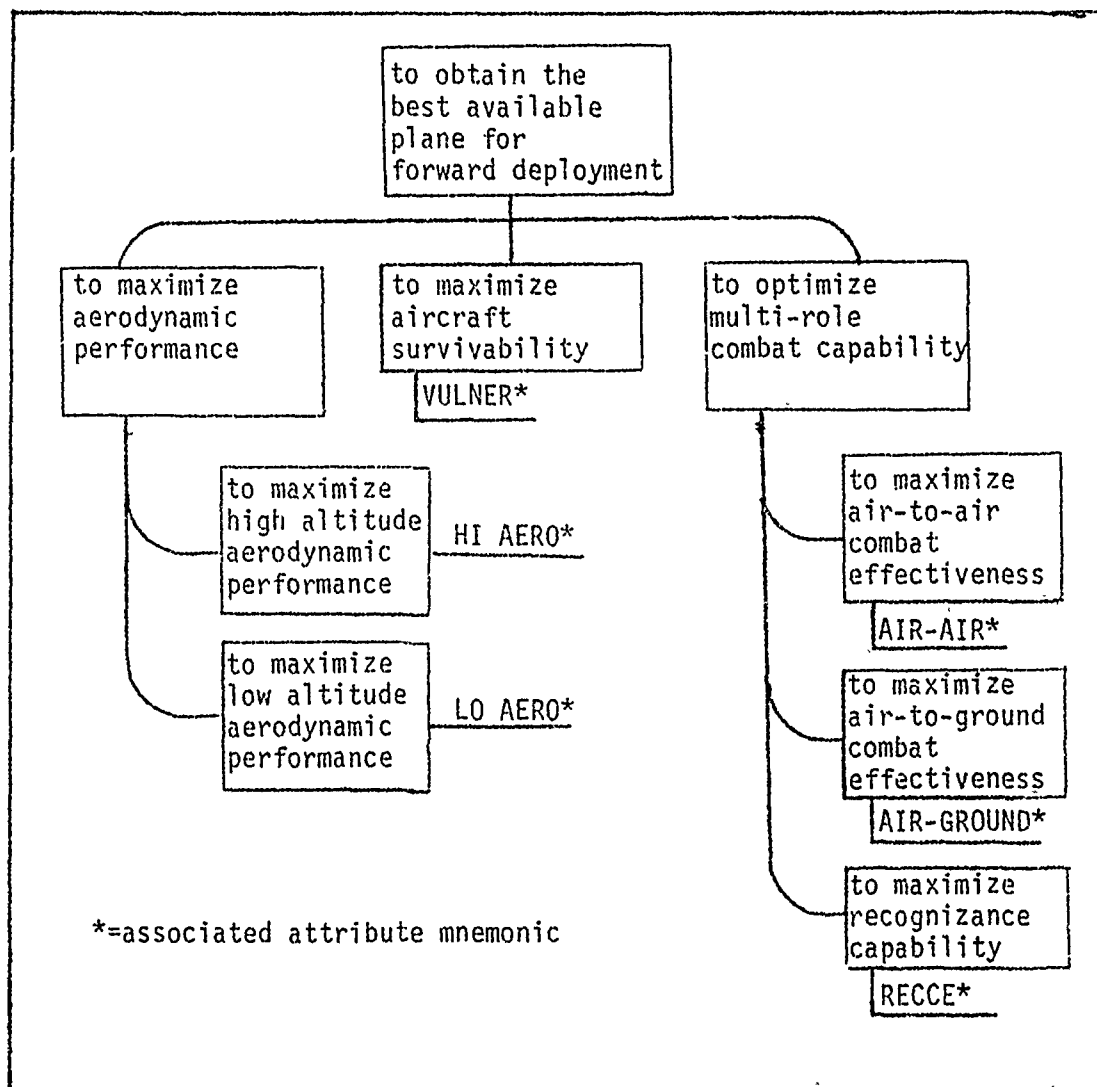


Figure 5.1 A Sample Problem

The sample problem noted above is highly simplified and will serve only to illustrate the mechanics of using MADAM. The following data will be used to generate the necessary tables and graphs. All data is totally hypothetical and no attempt has been made to mimic actual data classified or unclassified (see Table 5.1)

| Mnemonic   | Attribute                                           | Level | System |
|------------|-----------------------------------------------------|-------|--------|
| HI AERO    | objective<br>rating scale<br>(0-10)                 | 4.5   | F-4    |
|            |                                                     | 8.0   | F-15   |
|            |                                                     | 3.0   | F-111  |
| LO AERO    | objective<br>rating scale<br>(0-10)                 | 1.0   | F-4    |
|            |                                                     | .5    | F-15   |
|            |                                                     | 3.0   | F-111  |
| VULNER     | probability of<br>being killed on<br>a model sortie | .2    | F-4    |
|            |                                                     | .1    | F-15   |
|            |                                                     | .25   | F-111  |
| AIR-AIR    | subjective rating<br>(1-5)                          | 4.0   | F-4    |
|            |                                                     | 4.5   | F-15   |
|            |                                                     | 2.0   | F-111  |
| AIR-GROUND | subjective rating<br>(1-5)                          | 2.0   | F-4    |
|            |                                                     | 1.5   | F-15   |
|            |                                                     | 1.75  | F-111  |
| RECCE      | subjective rating                                   | 3.0   | F-4    |
|            |                                                     | 1.25  | F-15   |
|            |                                                     | 3.5   | F-111  |

Table 5.1 Scenario Data

The following pages are an example of how this problem might be analyzed using MADAM. There are intentional errors made during the analysis in order to illustrate the program's graceful recovery capabilities.

U WHAT IS YOUR NAME, PLEASE?

AT CY= 001 SN=AFIT

60000 CM STORAGE USED.

6.740 CP SECONUS COMPILATION TIME. W.STIMPSON

THANK YOU, W.STIMPSON. WE WILL NOW BEGIN THE  
DECISION ANALYSIS.

OPENING FILE NUMBER 1

IS THIS DATA NEW (N) OR STORED (S)?n

W.STIMPSON, YOUR OPTIONS ARE:

ATT COP DIS DON MOD NEW NUM PRO REV SEL

SEN SPA STA SYS TIL WVC

\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?new

THE FOLLOWING INFORMATION WILL ALLOW YOU TO CHOOSE  
AN EXISTING (STORED) DATA FILE, OR TO CONSTRUCT A  
NEW ONE, W.STIMPSON.

THE CURRENT TREE IS NUMBER 1

WITH WHICH TREE WOULD YOU LIKE TO WORK, W.STIMPSON?1

OPENING FILE NUMBER 1

IS THIS DATA NEW (N) OR STORED (S)?s

FILE 1 HAS NO CURRENT TREE STRUCTURE. YOU ARE  
BEING TRANSFERRED TO OPTION \*\*\* NEW \*\*\*.

YOU ARE AT THE POINT WHERE YOU WILL BE ENTERING  
THE ALTERNATIVE SYSTEMS WHICH WILL BE RANKED  
IN TERMS OF PREFERENCE. PLEASE CHOOSE THE  
APPROPRIATE OPTION.

ADD  
?n

DELETE

NEW

EXIT

ENTER...SYSTEM 1 LABEL  
(10 LETTERS OR LESS)  
??-4

ENTER...SYSTEM 2 LABEL  
(10 LETTERS OR LESS)  
??-15

ENTER...SYSTEM 3 LABEL  
(10 LETTERS OR LESS)  
??-111

ENTER...SYSTEM 4 LABEL  
(10 LETTERS OR LESS)  
?

YOU ARE AT THE POINT WHERE YOU WILL BE ENTERING  
THE ALTERNATIVE SYSTEMS WHICH WILL BE RANKED  
IN TERMS OF PREFERENCE. PLEASE CHOOSE THE  
APPROPRIATE OPTION.

ADD      DELETE      NEW      EXIT  
To

ADDING SYSTEM  
LABEL??-105  
USE \*\*\* UVC \*\*\* FOR ENTERING VALUES  
AND RECALCULATING TREE (IF NECESSARY).

YOU ARE AT THE POINT WHERE YOU WILL BE ENTERING  
THE ALTERNATIVE SYSTEMS WHICH WILL BE RANKED  
IN TERMS OF PREFERENCE. PLEASE CHOOSE THE  
APPROPRIATE OPTION.

ADD DELETE NEW EXIT  
?d

CURRENT SYSTEMS...

F-4  
F-15  
F-111  
F-105

ENTER THE SYSTEM TO BE DELETED.  
?f-105

YOU ARE AT THE POINT WHERE YOU WILL BE ENTERING  
THE ALTERNATIVE SYSTEMS WHICH WILL BE RANKED  
IN TERMS OF PREFERENCE. PLEASE CHOOSE THE  
APPROPRIATE OPTION.

ADD DELETE NEW EXIT  
?d

CURRENT SYSTEMS...

F-4  
F-15  
F-111

ENTER THE SYSTEM TO BE DELETED.  
?f-5

SYSTEM F-5 NOT FOUND

YOU ARE AT THE POINT WHERE YOU WILL BE ENTERING  
THE ALTERNATIVE SYSTEMS WHICH WILL BE RANKED  
IN TERMS OF PREFERENCE. PLEASE CHOOSE THE  
APPROPRIATE OPTION.

A(DD      D(DELETE      N(NEW      E(XIT  
    ?e

ENTER A TITLE FOR THIS DATA STRUCTURE...

?this example is intended to illustrate the capabilities of  
?TMADAM; and in no way reflects real data (classified or  
?Unclassified). all preferences and values are hypothetical.  
?Wayne A. Stimpson    19 Nov 1981  
?

SPANNING NODES:      "A"=ALL      "S"=SELECT  
    ?a

DO YOU WISH TO BUILD A NEW TREE, W.STIMPSON?      (Y/N)  
    ?y

DO YOU WISH TO BY-PASS THE BETWEEN NODE CHECK?n  
ADDING DOWNLINKS TO NODE:  
    0

W.STIMPSON. WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?to obtain the best available plane  
PLEASE CONTINUE  
?for forward deployment  
THE LAST SUBOBJECTIVE ENTERED IS:  
TO OBTAIN THE BEST AVAILABLE PLANE  
FOR FORWARD DEPLOYMENT

CURRENT NUMBER OF NODES: 2(MAX 500)  
CURRENT NUMBER OF LEVELS: 2(MAX 20)  
CURRENT NUMBER OF SYSTEMS: 3(MAX 99)  
ADDING DOWNLINKS TO NODE:

1

TO OBTAIN THE BEST AVAILABLE PLANE

FOR FORWARD DEPLOYMENT

W.STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?to maximize aerodynamic performance  
PLEASE CONTINUE

?

THE LAST SUBOBJECTIVE ENTERED IS:  
TO MAXIMIZE AERODYNAMIC PERFORMANCE

WHICH IS SUBOBJECTIVE NUMBER 1  
FOR THE OBJECTIVE:  
TO OBTAIN THE BEST AVAILABLE PLANE

FOR FORWARD DEPLOYMENT

W.STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?to maximize aircraft survivability  
PLEASE CONTINUE

?

THE LAST SUBOBJECTIVE ENTERED IS:  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

WHICH IS SUBOBJECTIVE NUMBER 2  
FOR THE OBJECTIVE:  
TO OBTAIN THE BEST AVAILABLE PLANE

FOR FORWARD DEPLOYMENT

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)

?to optimize multi-role combat

PLEASE CONTINUE

Capability

THE LAST SUBOBJECTIVE ENTERED IS:

TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

WHICH IS SUBOBJECTIVE NUMBER 3

FOR THE OBJECTIVE:

TO OBTAIN THE BEST AVAILABLE PLANE

FOR FORWARD DEPLOYMENT

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)

?

1

oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo

@TO OBTAIN THE BEST AVAILABLE PLANE @

@ @

@FOR FORWARD DEPLOYMENT @

@ @

oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo

@ 1 1

@ @oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo

@ @TO MAXIMIZE AERODYNAMIC PERFORMANCE

@ @

oooooooooooo

@ @

@ @oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo

@ 1 2

@ @oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo

@ @TO MAXIMIZE AIRCRAFT SURVIVABILITY

@ @

oooooooooooo

@ @

@ @oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo

@ 1 3

@ @oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo

@ @TO OPTIMIZE MULTI-ROLE COMBAT

@ @

oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo

@ @

@ @oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo

W.STIMPSON, DO THE SUBOBJECTIVES ADDRESS ALL FACETS  
OF THE PARENT OBJECTIVE? (Y/N)

?w

IS THERE ANY OVERLAP BETWEEN THE COVERAGES OF  
THE SUBOBJECTIVES, W.STIMPSON? (Y/N)

?n

W.STIMPSON, ARE ALL THE SUBOBJECTIVES OPERATIONALLY  
MEANINGFUL TO YOU? (Y/N)

?v

COULD ANY OF THE SUBOBJECTIVES BE IGNORED WITHOUT  
SIGNIFICANTLY IMPACTING YOUR PREFERENCES, W.STIMPSON? (Y/N)

?n

CURRENT NUMBER OF NODES: 5(MAX 500)

CURRENT NUMBER OF LEVELS: 2(MAX 20)

CURRENT NUMBER OF CYCLES: 3(MAX 59)

ADDING DOWNLINKS TO NODE 1

1 1

TO MAXIMIZE AERODYNAMIC PERFORMANCE

W.STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?

(USE NO MORE THAN TWO DO (PARALLEL LINES)

?to maximize high-altitude

PLEASE CONTINUE

?aerodynamic performance

THE LAST SUBOBJECTIVE ENTERED IS:

TO MAXIMIZE HIGH-ALTITUDE

AERODYNAMIC PERFORMANCE

WHICH IS SUBOBJECTIVE NUMBER 1

FOR THE OBJECTIVE?

TO MAXIMIZE AERODYNAMIC PERFORMANCE

W.STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
 (USE NO MORE THAN TWO 80 CHARACTER LINES)  
 ?to maximize low-altitude  
 PLEASE CONTINUE  
 ?aerodynamic performance  
 THE LAST SUBOBJECTIVE ENTERED IS:  
 TO MAXIMIZE LOW-ALTITUDE

AERODYNAMIC PERFORMANCE

WHICH IS SUBOBJECTIVE NUMBER 2  
 FOR THE OBJECTIVE:  
 TO MAXIMIZE AERODYNAMIC PERFORMANCE

W.STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
 (USE NO MORE THAN TWO 80 CHARACTER LINES)  
 ?

```

1      1
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@TO MAXIMIZE AERODYNAMIC PERFORMANCE @
@                                     @
@                                     @
@                                     @
@                                     @
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@                                     1 1 1
@                                     @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@                                     @TO MAXIMIZE HIGH-ALTITUDE
@                                     @
@                                     @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@                                     1 1 2
@                                     @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@                                     @TO MAXIMIZE LOW-ALTITUDE
@                                     @
@                                     @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@                                     @
@                                     @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@

```

W.STIMPSON, DO THE SUBOBJECTIVES ADDRESS ALL FACETS  
 OF THE PARENT OBJECTIVE? (Y/N)

??

IS THERE ANY OVERLAP BETWEEN THE COVERAGES OF  
THE SUBOBJECTIVES, W.STIMPSON? (Y/N)

Tn

W.STIMPSON, ARE ALL THE SUBOBJECTIVES OPERATIONALLY  
MEANINGFUL TO YOU? (Y/N)

Tv

COULD ANY OF THE SUBOBJECTIVES BE IGNORED WITHOUT  
SIGNIFICANTLY IMPACTING YOUR PREFERENCES, W.STIMPSON? (Y/N)

Tn

CURRENT NUMBER OF NODES: 7(MAX 500)  
CURRENT NUMBER OF LEVELS: 3(MAX 20)  
CURRENT NUMBER OF SYSTEMS: 3(MAX 59)  
ADDING DOWNLINKS TO NODE:

1 1 1

TO MAXIMIZE HIGH-ALTITUDE

AERODYNAMIC PERFORMANCE

W.STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?

CURRENT NUMBER OF NODES: 7(MAX 500)  
CURRENT NUMBER OF LEVELS: 3(MAX 20)  
CURRENT NUMBER OF SYSTEMS: 3(MAX 59)  
ADDING DOWNLINKS TO NODE:

1 1 2

TO MAXIMIZE LOW-ALTITUDE

AERODYNAMIC PERFORMANCE

W.STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?

CURRENT NUMBER OF NODES: 7(MAX 500)  
CURRENT NUMBER OF LEVELS: 3(MAX 20)  
CURRENT NUMBER OF SYSTEMS: 3(MAX 59)  
ADDING DOWNLINKS TO NODE:

1 2  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?

CURRENT NUMBER OF NODES: 7(MAX 500)  
CURRENT NUMBER OF LEVELS: 3(MAX 20)  
CURRENT NUMBER OF SYSTEMS: 3(MAX 59)  
ADDING DOWNLINKS TO NODE:

1 3  
TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
To maximize air-to-ground combat

PLEASE CONTINUE

Feasibility

THE LAST SUBOBJECTIVE ENTERED IS:  
TO MAXIMIZE AIR-TO-GROUND COMBAT

CAPABILITY

WHICH IS SUBOBJECTIVE NUMBER 1  
FOR THE OBJECTIVE:  
TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)

?to maximize air-to-ground combat

PLEASE CONTINUE

?effectiveness

THE LAST SUBOBJECTIVE ENTERED IS:

TO MAXIMIZE AIR-TO-GROUND COMBAT

EFFECTIVENESS

WHICH IS SUBOBJECTIVE NUMBER 2

FOR THE OBJECTIVE:

TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?

(USE NO MORE THAN TWO 80 CHARACTER LINES)

?to maximize recce capability

PLEASE CONTINUE

?

THE LAST SUBOBJECTIVE ENTERED IS:

TO MAXIMIZE RECCE CAPABILITY

WHICH IS SUBOBJECTIVE NUMBER 3

FOR THE OBJECTIVE:

TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?

(USE NO MORE THAN TWO 80 CHARACTER LINES)

?

1 3  
 @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  
 @TO OPTIMIZE MULTI-ROLE COMBAT @  
 @ @  
 @CAPABILITY @  
 @ @  
 @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@

@ 1 3 1  
 @ @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  
 @ @TO MAXIMIZE AIR-TO-GROUND COMBAT  
 @ @  
 @@@@@@@@@@@@@CAPABILITY  
 @ @  
 @ @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  
 @ 1 3 2  
 @ @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  
 @ @TO MAXIMIZE AIR-TO-GROUND COMBAT  
 @ @  
 @@@@@@@@@@@@@EFFECTIVENESS  
 @ @  
 @ @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  
 @ 1 3 3  
 @ @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  
 @ @TO MAXIMIZE RECCE CAPABILITY  
 @ @  
 @@@@@@@@@@  
 @ @  
 @ @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@

W. STIMPSON, DO THE SUBOBJECTIVES ADDRESS ALL FACETS  
 OF THE PARENT OBJECTIVE? (Y/N)  
 ?n

YOU ARE NOW ROUTINING THE TREE.

ENTER...NRN?1

3  
 1  
 0

ENTER YOUR SUBOBJECTIVE  
 ?to maximize air-to-air combat  
 PLEASE CONTINUE  
 ?effectiveness

ENTER...NRN?0



CURRENT NUMBER OF NODES: 10(MAX 500)  
CURRENT NUMBER OF LEVELS: 3(MAX 20)  
CURRENT NUMBER OF SYSTEMS: 3(MAX 59)  
ADDING DOWNLINKS TO NODE:

1 3 1

TO MAXIMIZE AIR-TO-AIR COMBAT

EFFECTIVENESS

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?

CURRENT NUMBER OF NODES: 10(MAX 500)  
CURRENT NUMBER OF LEVELS: 3(MAX 20)  
CURRENT NUMBER OF SYSTEMS: 3(MAX 59)  
ADDING DOWNLINKS TO NODE:

1 3 2

TO MAXIMIZE AIR-TO-GROUND COMBAT

EFFECTIVENESS

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?

CURRENT NUMBER OF NODES: 10(MAX 500)  
CURRENT NUMBER OF LEVELS: 3(MAX 20)  
CURRENT NUMBER OF SYSTEMS: 3(MAX 59)  
ADDING DOWNLINKS TO NODE:

1 3 3

TO MAXIMIZE RECCE CAPABILITY

W. STIMPSON, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?

CURRENT NUMBER OF NODES: 10(MAX 500)  
CURRENT NUMBER OF LEVELS: 3(MAX 20)  
CURRENT NUMBER OF SYSTEMS: 3(MAX 59)

W.STIMPSON, PLEASE INPUT AN ATTRIBUTE FOR  
THE DATA NODE WITH THE OBJECTIVE:  
TO MAXIMIZE HIGH-ALTITUDE

AERODYNAMIC PERFORMANCE

(10 LETTERS OR LESS)  
High-aero

IS THE ATTRIBUTE HIGH-AERO  
SUCH THAT BY KNOWING ITS LEVEL,  
THE ATTAINMENT OF THE OBJECTIVE  
IS TOTALLY DETERMINED? (Y/N)  
Y

COULD THE ATTRIBUTE HIGH-AERO  
BE CHANGED SO AS TO IMPROVE  
COMMUNICATING WHAT IS IMPLIED  
IN THE OBJECTIVE? (Y/N)  
Y

WHAT IS THE WORST ACCEPTABLE  
LEVEL (REAL NUMBER) OF HIGH-AERO  
?0  
THE LEVEL STORED WAS 0.

WHAT IS THE BEST (REALISTICALLY)  
LEVEL (REAL NUMBER) OF HIGH-AERO , W.STIMPSON?  
?10  
THE LEVEL STORED WAS 10.

W.STIMPSON, PLEASE INPUT AN ATTRIBUTE FOR  
THE DATA NODE WITH THE OBJECTIVE:  
TO MAXIMIZE LOW-ALTITUDE

AERODYNAMIC PERFORMANCE

(10 LETTERS OR LESS)  
Low-aero

IS THE ATTRIBUTE LOW-AERO  
SUCH THAT BY KNOWING ITS LEVEL,  
THE ATTAINMENT OF THE OBJECTIVE  
IS TOTALLY DETERMINED? (Y/N)

TS

COULD THE ATTRIBUTE LOW-AERO  
BE CHANGED SO AS TO IMPROVE  
COMMUNICATING WHAT IS IMPLIED  
IN THE OBJECTIVE? (Y/N)

TD

WHAT IS THE WORST ACCEPTABLE  
LEVEL (REAL NUMBER) OF LOW-AERO

TO

THE LEVEL STORED WAS 0.

WHAT IS THE BEST (REALISTICALLY)  
LEVEL (REAL NUMBER) OF LOW-AERO , W.STIMPSON?

T10

THE LEVEL STORED WAS 10.

W.STIMPSON, PLEASE INPUT AN ATTRIBUTE FOR  
THE DATA NODE WITH THE OBJECTIVE:  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

(10 LETTERS OR LESS)

Tskill

IS THE ATTRIBUTE SKILL  
SUCH THAT BY KNOWING ITS LEVEL,  
THE ATTAINMENT OF THE OBJECTIVE  
IS TOTALLY DETERMINED? (Y/N)

TS

COULD THE ATTRIBUTE SKILL  
BE CHANGED SO AS TO IMPROVE  
COMMUNICATING WHAT IS IMPLIED  
IN THE OBJECTIVE? (Y/N)

TS

W.STIMPSON, PLEASE INPUT AN ATTRIBUTE FOR  
THE DATA NODE WITH THE OBJECTIVE:  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

(10 LETTERS OR LESS)

Tvulner

IS THE ATTRIBUTE VULNER  
SUCH THAT BY KNOWING ITS LEVEL,  
THE ATTAINMENT OF THE OBJECTIVE  
IS TOTALLY DETERMINED? (Y/N)

?n

COULD THE ATTRIBUTE VULNER  
BE CHANGED SO AS TO IMPROVE  
COMMUNICATING WHAT IS IMPLIED  
IN THE OBJECTIVE? (Y/N)

?n

WHAT IS THE WORST ACCEPTABLE  
LEVEL (REAL NUMBER) OF VULNER

?1

THE LEVEL STORED WAS 1.

WHAT IS THE BEST (REALISTICALLY)  
LEVEL (REAL NUMBER) OF VULNER , W.STIMPSON?

?0

THE LEVEL STORED WAS 0.

W.STIMPSON, PLEASE INPUT AN AIRCRAFT FOR  
THE DATA NODE WITH THE OBJECTIVE:  
TO MAXIMIZE AIR-TO-AIR COMBAT

EFFECTIVENESS

(10 LETTERS OR LESS)

?air-air

IS THE ATTRIBUTE AIR-AIR  
SUCH THAT BY KNOWING ITS LEVEL,  
THE ATTAINMENT OF THE OBJECTIVE  
IS TOTALLY DETERMINED? (Y/N)

?n

COULD THE ATTRIBUTE AIR-AIR  
BE CHANGED SO AS TO IMPROVE  
COMMUNICATING WHAT IS IMPLIED  
IN THE OBJECTIVE? (Y/N)

?n

WHAT IS THE WORST ACCEPTABLE  
LEVEL (REAL NUMBER) OF AIR-AIR

?1

THE LEVEL STORED WAS 1.

WHAT IS THE BEST (REALISTICALLY)  
LEVEL (REAL NUMBER) OF AIR-AIR , W.STIMPSON?

?5

THE LEVEL STORED WAS 5.

W. STIMPSON, PLEASE INPUT AN ATTRIBUTE FOR  
THE DATA NODE WITH THE OBJECTIVE:  
TO MAXIMIZE AIR-TO-GROUND COMBAT

EFFECTIVENESS

(10 LETTERS OR LESS)

?air-ground

IS THE ATTRIBUTE AIR-GROUND  
SUCH THAT BY KNOWING ITS LEVEL,  
THE ATTAINMENT OF THE OBJECTIVE  
IS TOTALLY DETERMINED? (Y/N)

?y

COULD THE ATTRIBUTE AIR-GROUND  
BE CHANGED SO AS TO IMPROVE  
COMMUNICATING WHAT IS IMPLIED  
IN THE OBJECTIVE? (Y/N)

?n

WHAT IS THE WORST ACCEPTABLE  
LEVEL (REAL NUMBER) OF AIR-GROUND

?1

THE LEVEL STORED WAS 1.

WHAT IS THE BEST (REALISTICALLY)  
LEVEL (REAL NUMBER) OF AIR-GROUND, W. STIMPSON?

?5

THE LEVEL STORED WAS 5.

W. STIMPSON, PLEASE INPUT AN ATTRIBUTE FOR  
THE DATA NODE WITH THE OBJECTIVE:  
TO MAXIMIZE RECCF CAPABILITY

(10 LETTERS OR LESS)

?recco

IS THE ATTRIBUTE RECCF  
SUCH THAT BY KNOWING ITS LEVEL,  
THE ATTAINMENT OF THE OBJECTIVE  
IS TOTALLY DETERMINED? (Y/N)

?y

COULD THE ATTRIBUTE RECCF  
BE CHANGED SO AS TO IMPROVE  
COMMUNICATING WHAT IS IMPLIED  
IN THE OBJECTIVE? (Y/N)

?n

WHAT IS THE WORST ACCEPTABLE  
LEVEL (REAL NUMBER) OF RECCF

?1

THE LEVEL STORED WAS 1.

WHAT IS THE BEST (REALISTICALLY)  
LEVEL (REAL NUMBER) OF RECCE , W.STIMPSON?  
75

THE LEVEL STORED WAS 5.  
HIGH-AERO LOW-AERO VULNER AIR-AIR  
AIR-GROUND RECCE

THE ABOVE IS THE CURRENT SET OF ATTRIBUTES, W.STIMPSON.  
IF YOU SEE ANY WHICH ARE REFOUNDING, OR  
WHICH HAVE A DIRECT IMPACT ON ONE ANOTHER  
(E.G. WEIGHT AND THRUST),  
YOU SHOULD REFORM THE ATTRIBUTE SET TO  
REMOVE THESE PROBLEMS.

DO YOU WISH TO REFORM THE ATTRIBUTE SET, W.STIMPSON?  
(Y/N) 76

DO YOU WISH TO BYPASS FREQUENDENCE TESTING? 76

AT WHAT TOLERANCE DO YOU WANT TO CHECK YOUR  
RESPONSES, W.STIMPSON (PLUS OR MINUS X PERCENT)?  
X=702

WE ARE WORKING AT PLUS OR MINUS 2 PERCENT.

SUPPOSE THAT THE FOLLOWING  
ATTRIBUTES ARE AT THESE LEVELS:  
VULNER =.75  
AIR-AIR =2,  
AIR-GROUND=2,  
RECCE =2,  
THAT IS AT THE 25 PERCENT LEVEL.

NOW SUPPOSE THAT YOU HAVE THE INITIAL CONDITIONS:  
HIGH-AERO =5, AND LOW-AERO =5.

IMAGINE THAT LOW-AERO IS CHANGED TO 2.  
WHAT LEVEL OF HIGH-AERO WOULD KEEP YOU AS SATISFIED  
AS YOU WERE UNDER THE INITIAL CONDITIONS?  
(REMEMBER THAT ALL OTHER ATTRIBUTES ARE AT  
THE 25 PERCENT LEVEL)  
77

SUPPOSE THAT YOU ARE STARTING AT  
HIGH-AERO =5, AND LOW-AERO =5.

IMAGINE THAT 2, IN LOW-AERO IS ACHIEVED,  
TO WHAT LEVEL WOULD YOU CHANGE HIGH-AERO, IN ORDER TO  
REMAIN AS SATISFIED AS YOU WERE INITIALLY?  
(REMEMBER THAT ALL OTHER ATTRIBUTES ARE AT THE  
25 PERCENT LEVEL)  
72

W. STIMPSON, SUPPOSE NOW THAT THE FOLLOWING ATTRIBUTES  
ARE SHIFTED TO THESE LEVELS:

VULNER -3.25

AIR-AIR -4.

AIR-GROUND-4.

RECCF -4.

THAT IS AT THE 75 PERCENT LEVEL.

SUPPOSE THAT YOU HAVE

HIGH-AERO =5. AND LOW-AERO =5.

IMAGINE THAT THE LEVEL OF LOW-AERO

IS CHANGED TO 2.

WOULD THE LEVEL OF HIGH-AERO NEED TO REMAIN

AS SATISFIED AS AT THE INITIAL CONDITIONS

LIE BETWEEN 7.1 AND 8.9

(Y/N) ?

SUPPOSE THAT YOU HAVE THE INITIAL CONDITIONS

HIGH-AERO =5. AND LOW-AERO =5.

IMAGINE THAT YOU MUST ACCEPT

A LEVEL OF 8. IN LOW-AERO

WOULD THE LEVEL OF HIGH-AERO

THAT YOU WOULD HAVE TO MOVE TO (IN ORDER TO BE AS

SATISFIED AS UNDER THE INITIAL CONDITIONS) LIE

BETWEEN 7.1 AND 8.9

(Y/N) ?

THERE ARE NO INDEPENDENT PROBLEMS

WITH THE ATTRIBUTES TESTED SO FAR.

DO YOU WISH TO ASSUME PFI FOR THE

REMAINING ATTRIBUTES? (Y/N)

?n

EVEN IF YOU DO NOT WISH TO ASSUME

PFI AMONG THE REMAINING ATTRIBUTES,

DO YOU WANT TO STOP PFI TESTING? (Y/N)

?n

SUPPOSE THAT THE FOLLOWING

ATTRIBUTES ARE AT THESE LEVELS:

LOW-AERO -2.

AIR-AIR -2

AIR-GROUND-2.

RECCF -2.

THAT IS AT THE 25 PERCENT LEVEL

NOW SUPPOSE THAT YOU HAVE THE INITIAL CONDITIONS:

HIGH-AERO =5. AND VULNER =3.5

IMAGINE THAT VULNER IS CHANGED TO .2  
WHAT LEVEL OF HIGH-AERO WOULD KEEP YOU AS SATISFIED  
AS YOU WERE UNDER THE INITIAL CONDITIONS?  
(REMEMBER THAT ALL OTHER ATTRIBUTES ARE AT  
THE 25 PERCENT LEVEL)

T3

SUPPOSE THAT YOU ARE STARTING AT  
HIGH-AERO =5. AND VULNER =.5

IMAGINE THAT .8 IN VULNER IS ACHIEVED.  
TO WHAT LEVEL WOULD YOU CHANGE HIGH-AERO IN ORDER TO  
REMAIN AS SATISFIED AS YOU WERE INITIALLY?  
(REMEMBER THAT ALL OTHER ATTRIBUTES ARE AT THE  
25 PERCENT LEVEL)

T9

W. STIMPSON, SUPPOSE NOW THAT THE FOLLOWING ATTRIBUTES  
ARE SHIFTED TO THESE LEVELS:

LOW-AERO =7.5

AIR-AIR =4.

AIR-GROUND =4.

RECCE =4.

THAT IS AT THE 75 PERCENT LEVEL

SUPPOSE THAT YOU HAVE  
HIGH-AERO =5. AND VULNER =.5

IMAGINE THAT THE LEVEL OF VULNER  
IS CHANGED TO .2.

WOULD THE LEVEL OF HIGH-AERO NEED TO REMAIN  
AS SATISFIED AS AT THE INITIAL CONDITIONS  
LIE BETWEEN 9.1 AND 9.9

(Y/N) T8

SUPPOSE THAT YOU HAVE THE INITIAL CONDITIONS  
HIGH-AERO =5. AND VULNER =.5

IMAGINE THAT YOU MUST ACCEPT  
A LEVEL OF .3 IN VULNER .  
WOULD THE LEVEL OF HIGH-AERO  
THAT YOU WOULD HAVE TO MOVE TO (IN ORDER TO BE AS  
SATISFIED AS UNDER THE INITIAL CONDITIONS) LIE  
BETWEEN 9.1 AND 9.9

(Y/N) T9

THERE ARE NO INDEPENDENCE PROBLEMS  
WITH THE ATTRIBUTES TESTED SO FAR.  
DO YOU WISH TO ASSURE ME FOR THE  
REMAINING ATTRIBUTES? (Y/N)

T10

WHAT LEVEL OF HIGH-AERO  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 0. TO IT, AS FROM THAT LEVEL TO 10.?

75

WHAT LEVEL OF HIGH-AERO  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 0. TO IT, AS FROM THAT LEVEL TO 5.?

73

WHAT LEVEL OF HIGH-AERO  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 10. TO IT, AS FROM THAT LEVEL TO 5.?

77

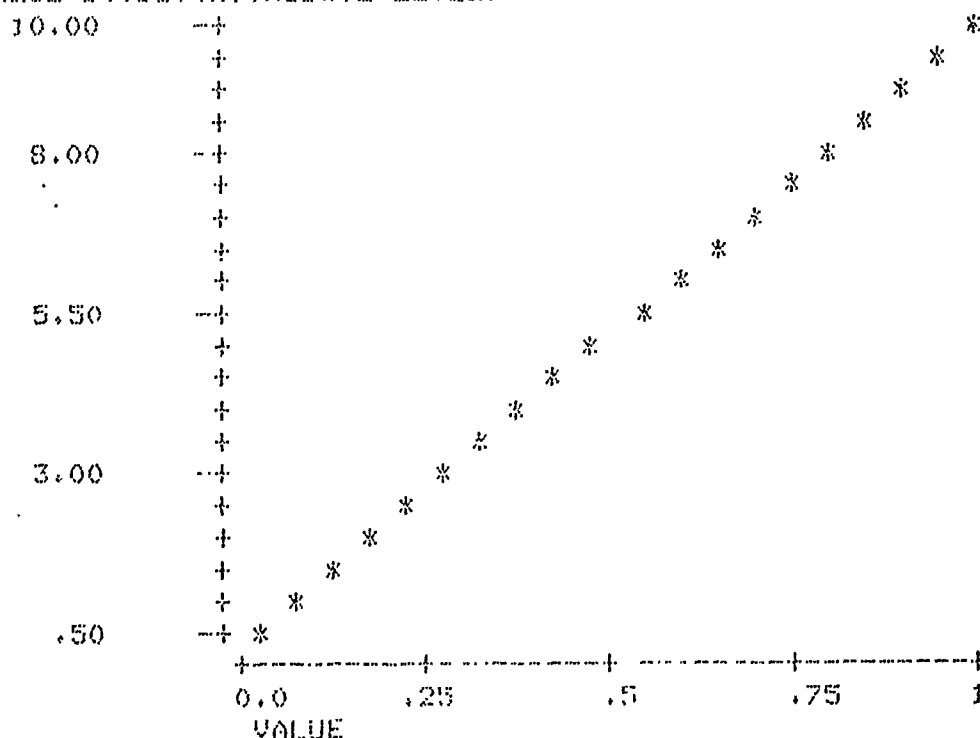
THE ABOVE YIELDS A VALUE FUNCTION FOR HIGH-AERO  
WITH PARAMETERS:

$B_0 = -.01724137931035$   $B_1 = .1034482758621$

SUM OF SQUARED ERROR = .004310344827533

(LINDOR FORM)

VALUE =  $B_0 + B_1 * (\text{ATTRIBUTE LEVEL})$



VALUE FUNCTION FOR HIGH-AERO

( ) DOES THE ABOVE REPRESENTATION APPEAR REASONABLE? (Y/N)

WHAT LEVEL OF LOW-AERO  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 0. TO IT, AS FROM THAT LEVEL TO 10.?   
T3

WHAT LEVEL OF LOW-AERO  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 0. TO IT, AS FROM THAT LEVEL TO 3.?   
T2

WHAT LEVEL OF LOW-AERO  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 10. TO IT, AS FROM THAT LEVEL TO 3.?   
T5

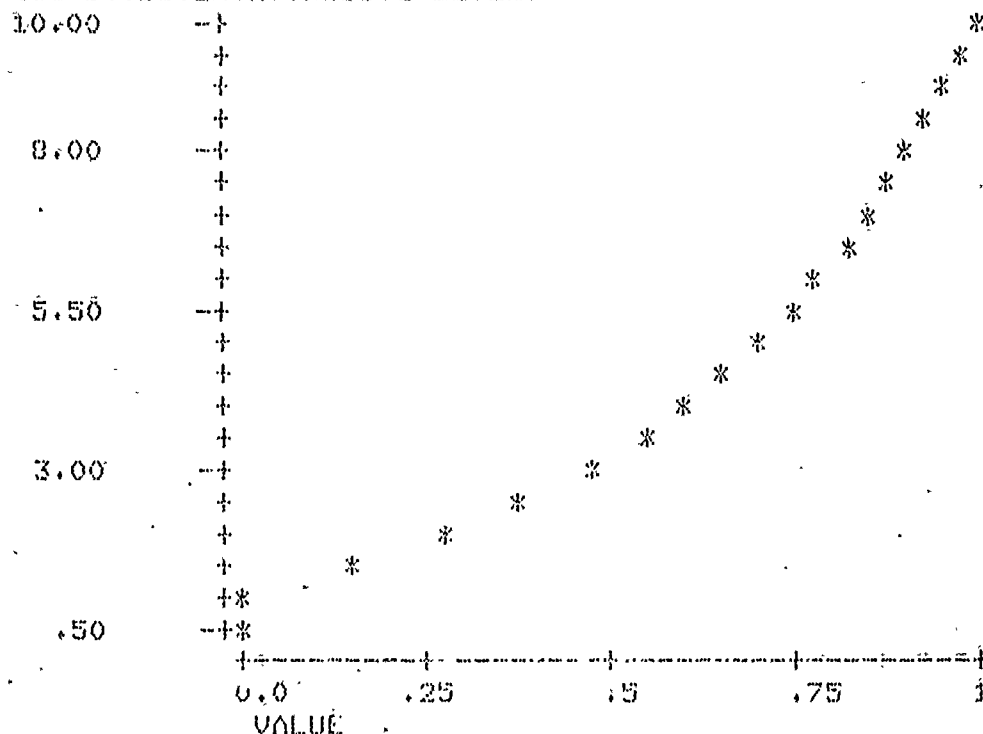
THE ABOVE YIELDS A VALUE FUNCTION FOR LOW-AERO  
WITH PARAMETERS:

B0=-.01242410206834 B1=.4491967429905

SUM OF SQUARED ERROR=.004944434786783

(LOGARITHMIC FORM)

VALUE=B0+B1\*LN(ATTRIBUTE LEVEL)



VALUE FUNCTION FOR LOW-AERO

DOES THE ABOVE REPRESENTATION APPEAR REASONABLE? (Y/N)   
T4

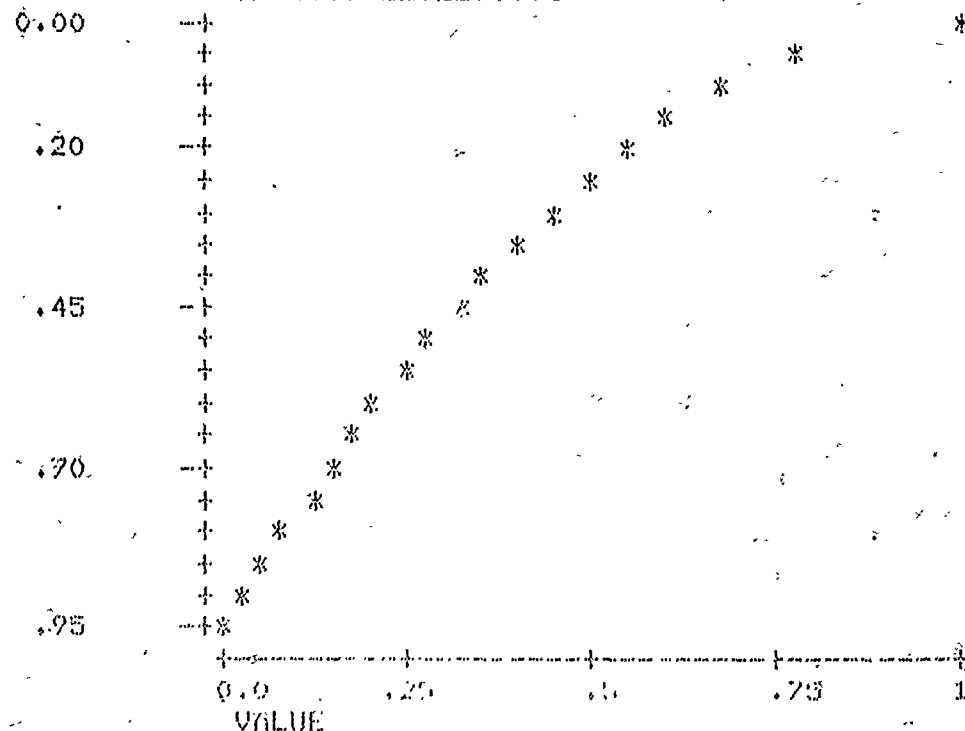
WHAT LEVEL OF VULNER  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 1. TO IT, AS FROM THAT LEVEL TO 0.25  
?.25

WHAT LEVEL OF VULNER  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 1. TO IT, AS FROM THAT LEVEL TO .25?  
?.1  
.1 IS OUTSIDE THE RANGE OF 1. TO .25

WHAT LEVEL OF VULNER  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 1. TO IT, AS FROM THAT LEVEL TO .25?  
?.5

WHAT LEVEL OF VULNER  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 0. TO IT, AS FROM THAT LEVEL TO .25?  
?.1

THE ABOVE YIELDS A VALUE FUNCTION FOR VULNER  
WITH PARAMETERS:  
B0=1.023191314901 R1=-1.03670620188  
SUM OF SQUARED ERROR=.005340224256907  
(SQUARE-ROOT FORM)  
VALUE=B0\*(1-R1\*(ATTRIBUTE LEVEL)\*\*.5



# VALUE FUNCTION FOR VULNER

DOES THE ABOVE REPRESENTATION APPEAR REASONABLE? (Y/N)

?3

WHAT LEVEL OF AIR-AIR

WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 1. TO IT, AS FROM THAT LEVEL TO 5.?

?3.5

WHAT LEVEL OF AIR-AIR

WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 1. TO IT, AS FROM THAT LEVEL TO 3.5?

?3

WHAT LEVEL OF AIR-AIR

WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 5. TO IT, AS FROM THAT LEVEL TO 3.5?

?4.5

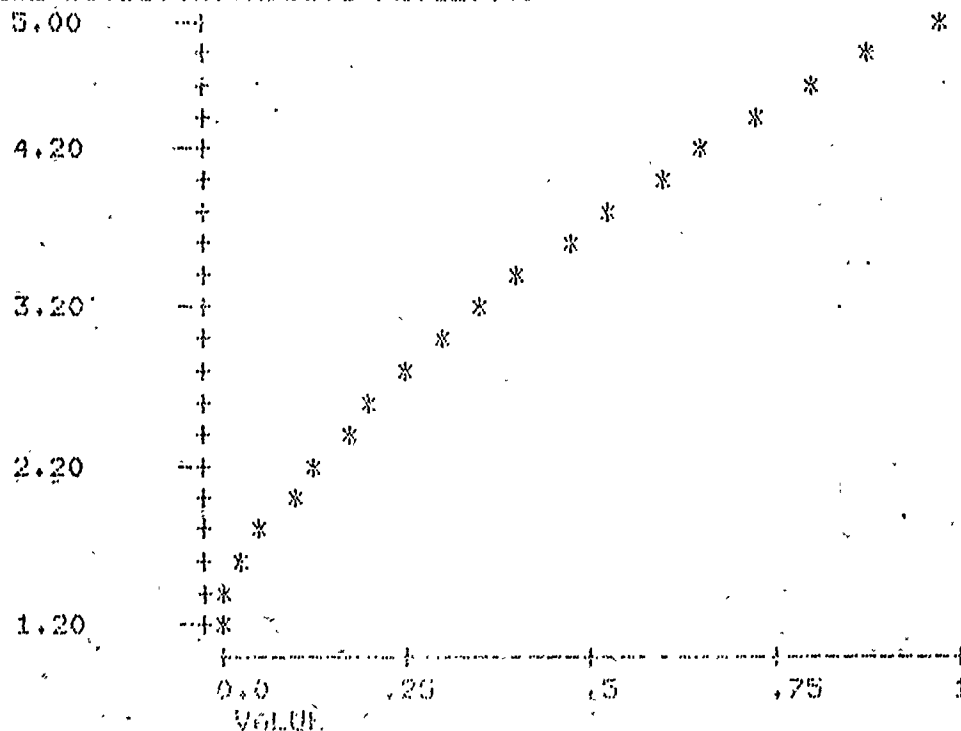
THE ABOVE YIELDS A VALUE FUNCTION FOR AIR-AIR  
WITH PARAMETERS:

$B_0 = -.06190727681138$   $B_1 = .04162276080084$

SUM OF SQUARED ERROR = .008462855637513

(SQUARED FORM)

$VALUE = B_0 + B_1 * (ATTRIBUTE LEVEL) ** 2$



# VALUE FUNCTION FOR AIR-AIR

DOES THE ABOVE REPRESENTATION APPEAR REASONABLE? (Y/N)

?9

WHAT LEVEL OF AIR-GROUND  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 1. TO IT, AS FROM THAT LEVEL TO 5.7

?2

WHAT LEVEL OF AIR-GROUND  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 1. TO IT, AS FROM THAT LEVEL TO 2.7

?1.5

WHAT LEVEL OF AIR-GROUND  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 5. TO IT, AS FROM THAT LEVEL TO 2.7

?2.5

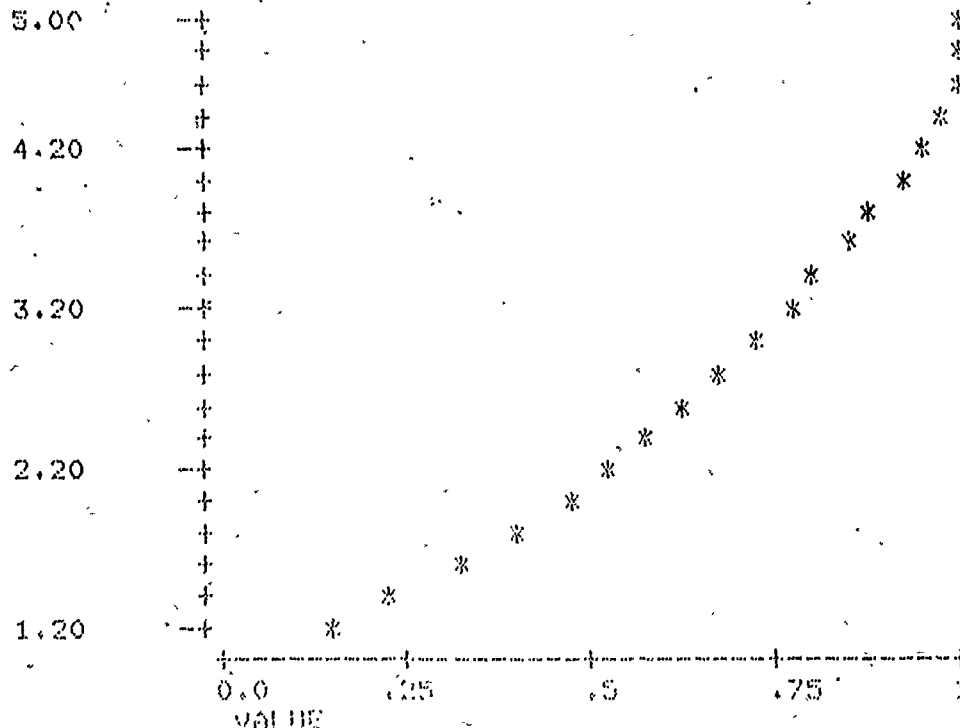
THE ABOVE YIELDS A VALUE FUNCTION FOR AIR-GROUND  
WITH PARAMETERS:

B0=.03308787144949 B1=.6441338400346

SUM OF SQUARED ERROR=.0243932709272

(LOGARITHMIC FORM)

VALUE=B0+B1\*LN(ATTRIBUTE LEVEL)



# VALUE FUNCTION FOR AIR-GROUND

DOES THE ABOVE REPRESENTATION APPEAR REASONABLE? (Y/N)  
?2

WHAT LEVEL OF RECCE  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 1. TO IT, AS FROM THAT LEVEL TO 5.?  
?2.5

WHAT LEVEL OF RECCE  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 1. TO IT, AS FROM THAT LEVEL TO 2.5?  
?2

WHAT LEVEL OF RECCE  
WOULD BE SUCH THAT YOU WOULD FEEL THE SAME  
AMOUNT OF CHANGE IN SATISFACTION IN MOVING  
FROM 5. TO IT, AS FROM THAT LEVEL TO 2.5?  
?4

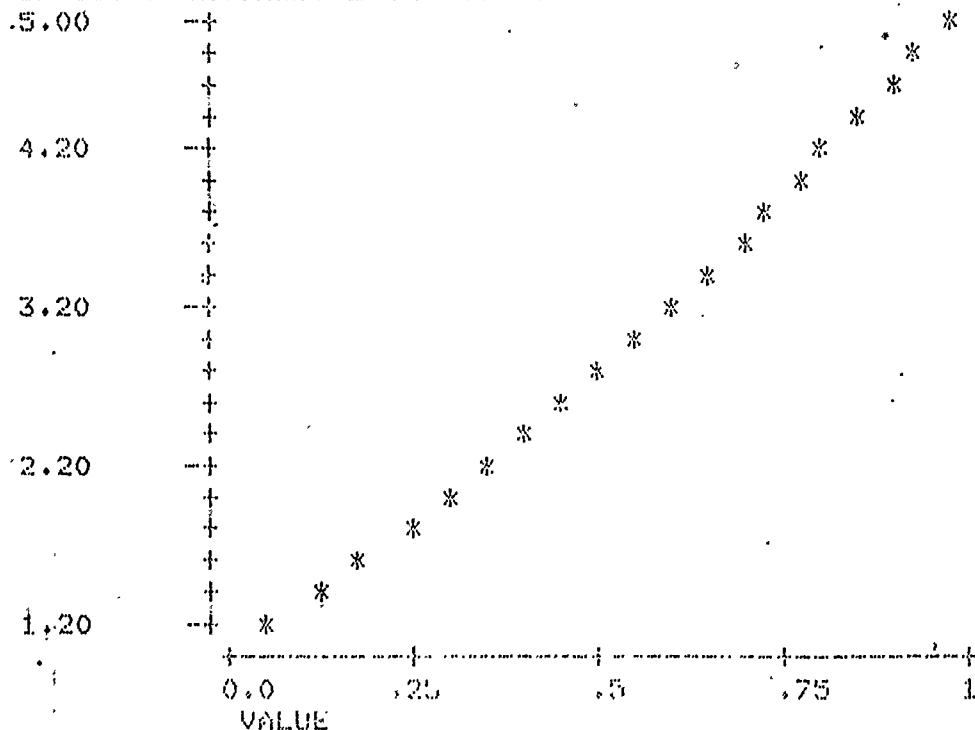
THE ABOVE YIELDS A VALUE FUNCTION FOR RECCE  
WITH PARAMETERS:

$B_0 = -.8265460233373$        $B_1 = .8057819694028$

SUM OF SQUARED ERROR = .006995318047164

(SQUARE-ROOT FORM)

$VALUE = B_0 + B_1 * (ATTRIBUTE LEVEL)^{.5}$



VALUE FUNCTION FOR RECCE

DOES THE ABOVE REPRESENTATION APPEAR REASONABLE? (Y/N)  
?y

OPENING FILE NUMBER 1  
IS THIS DATA NEW (N) OR STORED (S)?s

W.STIMPSON:YOUR OPTIONS ARE:  
ATT COP DIS DON MOD NEW NUM PRU REV SEL  
SEN SPA STA SYS TTL WVC  
\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?rev

HOW MUCH DO YOU WANT TO REVIEW...  
A(ALL S(LECT  
?s

IF ANY MODIFICATIONS HAVE BEEN MADE TO THE TREE  
SINCE IT HAS BEEN CALCULATED, NUMERICAL VALUES  
WILL BE INCORRECT.

(PRESS ANY LETTER TO CONTINUE)  
?d

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

1  
TO OBTAIN THE BEST AVAILABLE PLANE

FOR FORWARD DEPLOYMENT

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

?d

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

1 1  
TO MAXIMIZE AERODYNAMIC PERFORMANCE

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

?d

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

1 1 1  
TO MAXIMIZE HIGH-ALTITUDE  
AERODYNAMIC PERFORMANCE

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

?d

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

1 1 2  
TO MAXIMIZE LOW-ALTITUDE  
AERODYNAMIC PERFORMANCE

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

?d

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

1 2

TO MAXIMIZE AIRCRAFT SURVIVABILITY

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

?d

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

1 3

TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

?d

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

1 3 1

TO MAXIMIZE AIR TO AIR COMBAT

EFFECTIVENESS

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

7d

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.

WAYNE A. STIMPSON 19 NOV 1981

1 3 2

TO MAXIMIZE AIR-TO-GROUND COMBAT

EFFECTIVENESS

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

7d

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.

WAYNE A. STIMPSON 19 NOV 1981

1 3 3

TO MAXIMIZE RECCE CAPABILITY

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

7e

W. STIMPSON, YOUR OPTIONS ARE:

ATT COP DIS DON MOD NEW NUM PRU REV SEL  
SEN SPA STA SYS TTL WVC

\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W. STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON? <sup>help</sup>  
THE FOLLOWING IS A BRIEF EXPLANATION OF THE OPTIONS. FOR  
MORE DETAIL, SEE THE USER'S MANUAL, W.STIMPSON.

\*\*\* ATT \*\*\* ATTRIBUTE LABEL ENTRY  
\*\*\* COP \*\*\* COPIES ONE NODE TO ANOTHER  
\*\*\* DIS \*\*\* DISPLAY OF ONE NODE  
\*\*\* DON \*\*\* DONE WITH WORK, SAVE ALL FILES  
\*\*\* HEL \*\*\* WILL REPEAT THIS INFORMATION  
\*\*\* MOD \*\*\* MODIFIES EXISTING TREE, NODE BY NODE  
\*\*\* NEW \*\*\* NEW TREE BUILDING DRIVER  
\*\*\* NUM \*\*\* SAME AS REV, BUT WITH WEIGHTS AND VALUES

(PRESS ANY LETTER TO CONTINUE)

?d

\*\*\* PRU \*\*\* PRUNES THE TREE NODES  
\*\*\* REV \*\*\* REVIEW PRINT OF TREE  
\*\*\* SEL \*\*\* SELECT TREE FILE (STORED DATA)  
\*\*\* SEN \*\*\* CONDUCT SENSITIVITY ANALYSIS  
\*\*\* SPA \*\*\* ADDS DOWNLINKS TO EXISTING NODES  
\*\*\* STA \*\*\* PROVIDES TREE STATISTICS.  
\*\*\* SYS \*\*\* INPUT ALTERNATIVE SYSTEMS  
\*\*\* TTL \*\*\* DATA FILE TITLE ENTRY  
\*\*\* WVC \*\*\* LOADS WEIGHTS AND VALUES, DOES CALCULATIONS

(PRESS ANY LETTER TO CONTINUE)

?d

W.STIMPSON, YOUR OPTIONS ARE:  
ATT COP DIS DON MOD NEW NUM PRU REV SEL  
SEN SPA STA SYS TTL WVC  
\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?wv6

YOU MAY NOW ENTER WEIGHTS, VALUES, OR (RE)CALCULATE  
THE TREE. CHOOSE YOUR OPTION:

W(EIGHT)      V(ALUES)      C(ALCULATE)      E(XIT)

?w

WEIGHTS      :      ALL      S(ELECT

?a

WE ARE WEIGHTING THE NODE SET:  
TO MAXIMIZE AERODYNAMIC PERFORMANCE

THE ABOVE OBJECTIVE IS FACTOR 1  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

THE ABOVE OBJECTIVE IS FACTOR 2  
TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

THE ABOVE OBJECTIVE IS FACTOR 3

DO YOU WISH TO ENTER THE RELATIVE WEIGHTS DIRECTLY,

(Y/N) ?n

USING THE SCALE:

1-9 AS DEFINED IN THE USER'S MANUAL.

HOW IMPORTANT IS FACTOR 1:

TO MAXIMIZE AERODYNAMIC PERFORMANCE

COMPARED TO FACTOR 2:

TO MAXIMIZE AIRCRAFT SURVIVABILITY

ENTER THE NUMERATOR OF THE RATIO...

?1

ENTER THE DENOMINATOR OF THE RATIO...

?2

USING THE SCALE:  
1-9 AS DEFINED IN THE USER'S MANUAL,  
HOW IMPORTANT IS FACTOR 1:  
TO MAXIMIZE AERODYNAMIC PERFORMANCE

COMPARED TO FACTOR 3:  
TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

ENTER THE NUMERATOR OF THE RATIO...

?1

ENTER THE DENOMINATOR OF THE RATIO...

?4

USING THE SCALE:  
1-9 AS DEFINED IN THE USER'S MANUAL,  
HOW IMPORTANT IS FACTOR 2:  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

COMPARED TO FACTOR 3:  
TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

ENTER THE NUMERATOR OF THE RATIO...

?1

ENTER THE DENOMINATOR OF THE RATIO...

?2

NORMALIZED:14 29 57

ARE YOU HAPPY WITH THESE RELATIVE WEIGHTS? (Y/N)

?y

ENTER COMMENTS ON THESE WEIGHTS

?the weights on nodes 1.1, 1.2, and 1.3 reflect the  
?expected scenarios during alert conditions

WE ARE WEIGHTING THE NODE SET:  
TO MAXIMIZE HIGH-ALTITUDE

AERODYNAMIC PERFORMANCE

THE ABOVE OBJECTIVE IS FACTOR 1  
TO MAXIMIZE LOW-ALTITUDE

AERODYNAMIC PERFORMANCE

THE ABOVE OBJECTIVE IS FACTOR 2

DO YOU WISH TO ENTER THE RELATIVE WEIGHTS DIRECTLY?  
(Y/N) ?9

ENTER THE (UNNORMALIZED) WEIGHTS.

WHAT IS THE WEIGHT FOR FACTOR 1

?3

WHAT IS THE WEIGHT FOR FACTOR 2

?7

NORMALIZED:30 70

ARE YOU HAPPY WITH THESE RELATIVE WEIGHTS? (Y/N)

?9

ENTER COMMENTS ON THESE WEIGHTS

?the weights on nodes 1.1.1 and 1.1.2 reflect increased  
?concern with cas/bai considerations

?1

WE ARE WEIGHTING THE NODE SET:

TO MAXIMIZE AIR-TO-AIR COMBAT

EFFECTIVENESS

THE ABOVE OBJECTIVE IS FACTOR 1

TO MAXIMIZE AIR-TO-GROUND COMBAT

EFFECTIVENESS

THE ABOVE OBJECTIVE IS FACTOR 2

TO MAXIMIZE RECCE CAPABILITY

THE ABOVE OBJECTIVE IS FACTOR 3

DO YOU WISH TO ENTER THE RELATIVE WEIGHTS DIRECTLY,  
(Y/N) ?n

USING THE SCALE:

1-9 AS DEFINED IN THE USER'S MANUAL,

HOW IMPORTANT IS FACTOR 1:

TO MAXIMIZE AIR-TO-AIR COMBAT

EFFECTIVENESS

COMPARED TO FACTOR 2:

TO MAXIMIZE AIR-TO-GROUND COMBAT

EFFECTIVENESS

ENTER THE NUMERATOR OF THE RATIO...

?1

ENTER THE DENOMINATOR OF THE RATIO...

?1

USING THE SCALE:  
1-9 AS DEFINED IN THE USER'S MANUAL,  
HOW IMPORTANT IS FACTOR 1:  
TO MAXIMIZE AIR-TO-AIR COMBAT  
EFFECTIVENESS

COMPARED TO FACTOR 3:  
TO MAXIMIZE RECCE CAPABILITY

ENTER THE NUMERATOR OF THE RATIO...  
?3  
ENTER THE DENOMINATOR OF THE RATIO...  
?1

USING THE SCALE:  
1-9 AS DEFINED IN THE USER'S MANUAL,  
HOW IMPORTANT IS FACTOR 2:  
TO MAXIMIZE AIR-TO-GROUND COMBAT  
EFFECTIVENESS

COMPARED TO FACTOR 3:  
TO MAXIMIZE RECCE CAPABILITY

ENTER THE NUMERATOR OF THE RATIO...  
?3  
ENTER THE DENOMINATOR OF THE RATIO...  
?1  
NORMALIZED:43 43 14

ARE YOU HAPPY WITH THESE RELATIVE WEIGHTS? (Y/N)

?y  
ENTER COMMENTS ON THESE WEIGHTS  
?the weights on nodes 1.3.1, 1.3.2, and 1.3.3 reflect  
?the expectations of a short, fast-moving engagement  
?

YOU MAY NOW ENTER WEIGHTS, VALUES, OR (RE)CALCULATE  
THE TREE. CHOOSE YOUR OPTION:

W(EIGHT) V(ALUES) C(ALCULATE) E(XIT)

?v

VALUES : ALL SELECT  
7a

WE ARE AT THE DATA NODE:  
TO MAXIMIZE HIGH-ALTITUDE

AERODYNAMIC PERFORMANCE

WHICH HAS THE ASSOCIATED ATTRIBUTE HIGH-AERO

THE CURRENT LEVEL OF THE ATTRIBUTE HIGH-AERO  
IS .166666666667 FOR SYSTEM  
F-4

THE RANGE OF THE ATTRIBUTE IS 0. TO 10.

WHAT IS THE NEW LEVEL (REAL NUMBER)?4.5

THE CURRENT LEVEL OF THE ATTRIBUTE HIGH-AERO  
IS .166666666667 FOR SYSTEM  
F-15

THE RANGE OF THE ATTRIBUTE IS 0. TO 10.

WHAT IS THE NEW LEVEL (REAL NUMBER)?8.0

THE CURRENT LEVEL OF THE ATTRIBUTE HIGH-AERO  
IS .166666666667 FOR SYSTEM  
F-111

THE RANGE OF THE ATTRIBUTE IS 0. TO 10.

WHAT IS THE NEW LEVEL (REAL NUMBER)?3.0

ENTER COMMENTS ON THESE ENTRIES.  
Thish-aero ratings reflect data from field  
Texercises conducted over the past three years  
?

WE ARE AT THE DATA NODE:  
TO MAXIMIZE LOW-ALTITUDE

AERODYNAMIC PERFORMANCE

WHICH HAS THE ASSOCIATED ATTRIBUTE LOW-AERO

THE CURRENT LEVEL OF THE ATTRIBUTE LOW-AERO  
IS 1.028044533414 FOR SYSTEM  
F-4

THE RANGE OF THE ATTRIBUTE IS 0. TO 10.

WHAT IS THE NEW LEVEL (REAL NUMBER)?1.0  
THE INPUT ATTRIBUTE LEVEL CAUSES  
THE VALUE GENERATED (BASED ON THE  
ESTIMATED INDIVIDUAL VALUE FUNCTION)  
TO BE OUTSIDE THE RANGE (0.0-1.0).  
IN ORDER TO REMAIN IN THE PROPER RANGE,  
YOUR INPUT VALUE IS BEING CHANGED TO  
1.028044533414  
IF THIS IS UNACCEPTABLE, USE \*\*\*ATT\*\*\*  
TO ADJUST THE VALUE FUNCTION, AFTER  
EXITTING THIS OPTION.

THE CURRENT LEVEL OF THE ATTRIBUTE LOW-AERO  
IS 1.028044533414 FOR SYSTEM  
F-15

THE RANGE OF THE ATTRIBUTE IS 0. TO 10.

WHAT IS THE NEW LEVEL (REAL NUMBER)?1.5  
THE INPUT ATTRIBUTE LEVEL CAUSES  
THE VALUE GENERATED (BASED ON THE  
ESTIMATED INDIVIDUAL VALUE FUNCTION)  
TO BE OUTSIDE THE RANGE (0.0-1.0).  
IN ORDER TO REMAIN IN THE PROPER RANGE,  
YOUR INPUT VALUE IS BEING CHANGED TO  
1.028044533414  
IF THIS IS UNACCEPTABLE, USE \*\*\*ATT\*\*\*  
TO ADJUST THE VALUE FUNCTION, AFTER  
EXITTING THIS OPTION.

THE CURRENT LEVEL OF THE ATTRIBUTE LOW-AERO  
IS 1.028044533414 FOR SYSTEM  
F-111

THE RANGE OF THE ATTRIBUTE IS 0. TO 10.

WHAT IS THE NEW LEVEL (REAL NUMBER)?3.0

ENTER COMMENTS ON THESE ENTRIES.  
?the low-aero ratings reflect engineering data  
?combined with real combat data  
?

WE ARE AT THE DATA NODE:  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

WHICH HAS THE ASSOCIATED ATTRIBUTE VULNER

THE CURRENT LEVEL OF THE ATTRIBUTE VULNER  
IS .9740972043714 FOR SYSTEM  
F-4

THE RANGE OF THE ATTRIBUTE IS 1. TO 0.

WHAT IS THE NEW LEVEL (REAL NUMBER)?2

THE CURRENT LEVEL OF THE ATTRIBUTE VULNER  
IS .9740972043714 FOR SYSTEM  
F-15

THE RANGE OF THE ATTRIBUTE IS 1. TO 0.

WHAT IS THE NEW LEVEL (REAL NUMBER)?1

THE CURRENT LEVEL OF THE ATTRIBUTE VULNER  
IS .9740972043714 FOR SYSTEM  
F-111

THE RANGE OF THE ATTRIBUTE IS 1. TO 0.

WHAT IS THE NEW LEVEL (REAL NUMBER)?25

ENTER COMMENTS ON THESE ENTRIES.

?the vulnerability estimates are based on the assumption of a  
?model sortie under expected value conditions  
?

WE ARE AT THE DATA NODE:  
TO MAXIMIZE AIR-TO-AIR COMBAT

EFFECTIVENESS

WHICH HAS THE ASSOCIATED ATTRIBUTE AIR-AIR

THE CURRENT LEVEL OF THE ATTRIBUTE AIR-AIR  
IS 1.219566222946 FOR SYSTEM  
F-4

THE RANGE OF THE ATTRIBUTE IS 1. TO 5.

WHAT IS THE NEW LEVEL (REAL NUMBER)?4.0

THE CURRENT LEVEL OF THE ATTRIBUTE AIR-AIR  
IS 1.219566222946 FOR SYSTEM  
F-15

THE RANGE OF THE ATTRIBUTE IS 1. TO 5.

WHAT IS THE NEW LEVEL (REAL NUMBER)?4.5

THE CURRENT LEVEL OF THE ATTRIBUTE AIR-AIR  
IS 1.219566222946 FOR SYSTEM  
F-111

THE RANGE OF THE ATTRIBUTE IS 1. TO 5.

WHAT IS THE NEW LEVEL (REAL NUMBER)?2.0

ENTER COMMENTS ON THESE ENTRIES.

?air-air entries involve direct pilot assessment  
?

WE ARE AT THE DATA NODE:  
TO MAXIMIZE AIR-TO-GROUND COMBAT

EFFECTIVENESS

WHICH HAS THE ASSOCIATED ATTRIBUTE AIR-GROUND

THE CURRENT LEVEL OF THE ATTRIBUTE AIR-GROUND  
IS .9499290258972 FOR SYSTEM  
F-4

THE RANGE OF THE ATTRIBUTE IS 1. TO 5.

WHAT IS THE NEW LEVEL (REAL NUMBER)?2.0

THE CURRENT LEVEL OF THE ATTRIBUTE AIR-GROUND  
IS .9499290258972 FOR SYSTEM  
F-15

THE RANGE OF THE ATTRIBUTE IS 1. TO 5.

WHAT IS THE NEW LEVEL (REAL NUMBER)?1.5

THE CURRENT LEVEL OF THE ATTRIBUTE AIR-GROUND  
IS .9499290258972 FOR SYSTEM  
F-111

THE RANGE OF THE ATTRIBUTE IS 1. TO 5.

WHAT IS THE NEW LEVEL (REAL NUMBER)?1.75

ENTER COMMENTS ON THESE ENTRIES.

?air-ground entries are based on combat data  
?and simulation  
?

WE ARE AT THE DATA NODE:  
TO MAXIMIZE RECCE CAPABILITY

WHICH HAS THE ASSOCIATED ATTRIBUTE RECCE

THE CURRENT LEVEL OF THE ATTRIBUTE RECCE  
IS 1.052201680755 FOR SYSTEM  
F-4

THE RANGE OF THE ATTRIBUTE IS 1. TO 5.

WHAT IS THE NEW LEVEL (REAL NUMBER)?3.0

THE CURRENT LEVEL OF THE ATTRIBUTE RECCE  
IS 1.052201680755 FOR SYSTEM  
F-11

THE RANGE OF THE ATTRIBUTE IS 1. TO 5.

WHAT IS THE NEW LEVEL (REAL NUMBER)?1.25

THE CURRENT LEVEL OF THE ATTRIBUTE RECCE  
IS 1.052201680755 FOR SYSTEM  
F-111

THE RANGE OF THE ATTRIBUTE IS 1. TO 5.

WHAT IS THE NEW LEVEL (REAL NUMBER)?3.5

ENTER COMMENTS ON THESE ENTRIES.  
?tree entries reflect command and staff evaluations  
?of user organizations  
?

YOU MAY NOW ENTER WEIGHTS, VALUES, OR (RE)CALCULATE  
THE TREE. CHOOSE YOUR OPTION:

W(EGHT) V(ALUE) C(ALCULATE) E(XIT)

?c

INTERIOR TREE VALUES ARE BEING CALCULATED...

W.STIMPSON, YOUR OPTIONS ARE:

ATT COP DIS DON MOU NEW NUM PRU REV SEL  
SEN SPA STA SYS TTL WVC

\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?num

HOW MUCH DO YOU WANT TO REVIEW...

A(ALL) S(FLECT

?a

IF ANY MODIFICATIONS HAVE BEEN MADE TO THE TREE  
SINCE IT HAS BEEN CALCULATED NUMERICAL VALUES  
WILL BE INCORRECT.

(PRESS ANY LETTER TO CONTINUE)

?d

#### REVIEW

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

NODE REFERENCE NUMBER(AND OBJECTIVE):

1

TO OBTAIN THE BEST AVAILABLE PLANE

FOR FORWARD DEPLOYMENT

RELATIVE WEIGHT: 1.

CUMULATIVE WEIGHT: 1.

SYSTEM VALUES:

F-4

49.09

F-15

50.28

F-111

38.25

THE WEIGHTS ON NODES 1.1, 1.2, AND 1.3 REFLECT THE  
EXPECTED SCENARIOS DURING ALERT CONDITIONS

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))

(PRESS "E" TO EXIT)

?d

#### REVIEW

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

NODE REFERENCE NUMBER(AND OBJECTIVE):

1 1

TO MAXIMIZE AIRCRAFT SURVIVABILITY

RELATIVE WEIGHT: .1428571428571  
CUMULATIVE WEIGHT: .1428571428571

SYSTEM VALUES:

|       |       |       |
|-------|-------|-------|
| F-4   | F-15  | F-111 |
| 13.45 | 24.31 | 42.47 |

THE WEIGHTS ON NODES 1.1.1 AND 1.1.2 REFLECT INCREASED  
CONCERN WITH CAS/DAI CONSIDERATIONS  
(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

Td

REVIEW

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

NODE REFERENCE NUMBER(AND OBJECTIVE):

1 1 1  
TO MAXIMIZE HIGH-ALTITUDE

AERODYNAMIC PERFORMANCE

RELATIVE WEIGHT: .3  
CUMULATIVE WEIGHT: .04285714285714

SYSTEM VALUES:

|       |       |       |
|-------|-------|-------|
| F-4   | F-15  | F-111 |
| 44.83 | 81.03 | 29.31 |

HIGH-AERO RATINGS REFLECT DATA FROM FIELD-  
EXERCISES CONDUCTED OVER THE PAST THREE YEARS  
(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

Td

# REVIEW

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

NODE REFERENCE NUMBER(AND OBJECTIVE):

1 1 2  
TO MAXIMIZE LOW-ALTITUDE  
AERODYNAMIC PERFORMANCE

RELATIVE WEIGHT: .7  
CUMULATIVE WEIGHT: .1

SYSTEM VALUES:

|      |      |       |
|------|------|-------|
| F-4  | F-15 | F-111 |
| 0.00 | 0.00 | 48.11 |

THE LOW-ALTITUDE RATINGS REFLECT ENGINEERING DATA  
COMBINED WITH REAL COMBAT DATA  
(PRESS ANY LETTER TO CONTINUE (EXCEPT "F"))  
(PRESS "E" TO EXIT)  
?d

# REVIEW

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

NODE REFERENCE NUMBER(AND OBJECTIVE):

1 2  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

RELATIVE WEIGHT: .2857142857143  
CUMULATIVE WEIGHT: .2857142857143

SYSTEM VALUES:

|       |       |       |
|-------|-------|-------|
| F-4   | F-15  | F-111 |
| 55.96 | 69.54 | 50.48 |

THE VULNERABILITY ESTIMATES ARE BASED ON THE ASSUMPTION OF A  
MODEL SORTIE UNDER EXPECTED VALUE CONDITIONS  
(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "L" TO EXIT)  
?d

REVIEW

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

NODE REFERENCE NUMBER(AND OBJECTIVE):

1 3

TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

RELATIVE WEIGHT: .5714285714286

CUMULATIVE WEIGHT: .5714285714286

SYSTEM VALUES:

F-4

54.57

F-15

47.14

F-111

31.08

THE WEIGHTS ON NODES 1.3.1, 1.3.2, AND 1.3.3 REFLECT  
THE EXPECTATIONS OF A SHORT, FAST-MOVING ENGAGEMENT  
(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

?d

REVIEW

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 19 NOV 1981

NODE REFERENCE NUMBER(AND OBJECTIVE):

1 3 1

TO MAXIMIZE AIR-TO-AIR COMBAT

EFFECTIVENESS

RELATIVE WEIGHT: .4285714285714

CUMULATIVE WEIGHT: .3448979591837

SYSTEM VALUES:

F-4

60.41

F-15

78.10

F-111

10.46

AIR-AIR ENTRIES INVOLVE DIRECT PILOT ASSESSMENT  
(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))  
(PRESS "E" TO EXIT)

?d

#### REVIEW

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 17 NOV 1981

NOTE REFERENCE NUMBER(AND OBJECTIVE):

1 3 2

TO MAXIMIZE AIR-TO-GROUND COMBAT

EFFECTIVENESS

RELATIVE WEIGHT: .4285714285714

CUMULATIVE WEIGHT: .2448979591837

SYSTEM VALUES:

F-4

F-15

F-111

47.96

29.43

39.36

AIR-GROUND ENTRIES ARE BASED ON COMBAT DATA  
AND SIMULATION

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))

(PRESS "E" TO EXIT)

?d

#### REVIEW

THIS EXAMPLE IS INTENDED TO ILLUSTRATE THE CAPABILITIES OF  
MADAM, AND IN NO WAY REFLECTS REAL DATA (CLASSIFIED OR  
UNCLASSIFIED). ALL PREFERENCES AND VALUES ARE HYPOTHETICAL.  
WAYNE A. STIMPSON 17 NOV 1981

NOTE REFERENCE NUMBER(AND OBJECTIVE):

1 3 3

TO MAXIMIZE RECCE CAPABILITY

RELATIVE WEIGHT: .1428571428571  
CUMULATIVE WEIGHT: .00163265306122

SYSTEM VALUES:

|       |      |       |
|-------|------|-------|
| F-4   | F-15 | F-111 |
| 56.91 | 7.43 | 68.09 |

RECCE ENTRIES REFLECT COMMAND AND STAFF EVALUATIONS  
OF USER ORGANIZATIONS

(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))

(PRESS "E" TO EXIT)

?e

W.STIMPSON, YOUR OPTIONS ARE:

ATT COP DIS DON MOD NEW NUM PRU REV SEL

SEN SPA STA SYS TTL WUC

\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?d

ENTER NODE TO BE DISPLAYED...

ENTER...NRN?1

0

IF ANY MODIFICATIONS HAVE BEEN MADE TO THE TREE  
SINCE IT HAS BEEN CALCULATED, NUMERICAL VALUES  
WILL BE INCORRECT.

(PRESS ANY LETTER TO CONTINUE)

?d

THE PARENT OBJECTIVE IS:

TO OBTAIN THE BEST AVAILABLE PLANE

FOR FORWARD DEPLOYMENT

IT HAS 3 SUBOBJECTIVES (FACTORS).

FACTOR 1:

TO MAXIMIZE AERODYNAMIC PERFORMANCE

FACTOR 2:  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

FACTOR 3:  
TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

|                         |                        |       |  |
|-------------------------|------------------------|-------|--|
| 1 FACTOR 1              | CUM WT: .1428571428571 |       |  |
| F-4                     | F-15                   | F-111 |  |
| 13.45                   | 24.31                  | 42.47 |  |
| 1 FACTOR 2 DATA NODE    | CUM WT: .2857142857143 |       |  |
| F-4                     | F-15                   | F-111 |  |
| 55.96                   | 69.54                  | 50.48 |  |
| 1 FACTOR 3              | CUM WT: .5714285714286 |       |  |
| F-4                     | F-15                   | F-111 |  |
| 54.57                   | 47.14                  | 31.08 |  |
| SUMMARY OF PARENT NODE: |                        |       |  |
| F-4                     | F-15                   | F-111 |  |
| 49.09                   | 50.28                  | 38.25 |  |

|          |   |    |    |    |    |     |
|----------|---|----|----|----|----|-----|
| BRANCH   | 0 | 20 | 40 | 60 | 80 | 100 |
| FACTOR 1 | + | A  | +  | B  | +  | C   |
| FACTOR 2 | + |    | +  |    | C  | A   |
| FACTOR 3 | + |    | +  |    | B  | A   |
| BRANCH   | 0 | 20 | 40 | 60 | 80 | 100 |

LEGEND:

SYMBOL:A IS SYSTEM: F-4

SYMBOL:B SYSTEM:F-15

SYMBOL:C SYSTEM:F-111

W.STIMPSON, YOUR OPTIONS ARE:

ATT COP DIS DON MOD NEW NUM PRU REV SEL

SEN SPA STA SYS TTL WVC

\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE 'HELP' \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?dis

ENTER NODE TO BE DISPLAYED...

ENTER...NRN?1

1  
0

IF ANY MODIFICATIONS HAVE BEEN MADE TO THE TREE  
SINCE IT HAS BEEN CALCULATED, NUMERICAL VALUES  
WILL BE INCORRECT.

(PRESS ANY LETTER TO CONTINUE)

7d

THE PARENT OBJECTIVE IS:  
TO MAXIMIZE AERODYNAMIC PERFORMANCE

IT HAS 2 SUBOBJECTIVES (FACTORS).

FACTOR 1:

TO MAXIMIZE HIGH ALTITUDE

AERODYNAMIC PERFORMANCE

FACTOR 2:

TO MAXIMIZE LOW ALTITUDE

AERODYNAMIC PERFORMANCE

1 FACTOR 1 DATA NODE CUM WT: .04285714285714

|       |       |       |
|-------|-------|-------|
| F-4   | F-15  | F-111 |
| 44.02 | 31.03 | 29.31 |

1 FACTOR 2 DATA NODE CUM WT: .1

|      |      |       |
|------|------|-------|
| F-4  | F-15 | F-111 |
| 0.00 | 0.00 | 48.11 |

SUMMARY OF PARENT NODE:

|       |       |       |
|-------|-------|-------|
| F-4   | F-15  | F-111 |
| 13.45 | 24.31 | 42.47 |

|            |   |    |    |    |    |     |
|------------|---|----|----|----|----|-----|
| BRANCH     | 0 | 20 | 40 | 60 | 80 | 100 |
| FACTOR 1*A |   | +  | C  | +  | A  | +   |
| FACTOR 2*B |   | +  |    | +  | C  | +   |
| BRANCH     | 0 | 20 | 40 | 60 | 80 | 100 |

LEGEND:

SYMBOL:A IS SYSTEM:F-4

SYMBOL:B SYSTEM:F-15

SYMBOL:C SYSTEM:F-111

W.STIMPSON, YOUR OPTIONS ARE:  
ATT COP DIS DON NOD NEW NUM PRU REV SEL  
SEN SPA STA SYS TTL WVC  
\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE 'HELP' \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?dis

ENTER NODE TO BE DISPLAYED...

ENTER...NRN?1

2

0

NODE IS A DATA NODE, AND CANNOT BE DISPLAYED  
(PRESS ANY LETTER TO CONTINUE)

?d

ENTER NODE TO BE DISPLAYED...

ENTER...NRN?1

3

0

IF ANY MODIFICATIONS HAVE BEEN MADE TO THE TREE  
SINCE IT HAS BEEN CALCULATED, NUMERICAL VALUES  
WILL BE INCORRECT.

(PRESS ANY LETTER TO CONTINUE)

?d

THE PARENT OBJECTIVE IS:  
TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

IT HAS 3 SUBOBJECTIVES (FACTORS).

FACTOR 1:

TO MAXIMIZE AIR-TO-AIR COMBAT

EFFECTIVENESS

FACTOR 2:  
TO MAXIMIZE AIR-TO-GROUND COMBAT

EFFECTIVENESS

FACTOR 3:  
TO MAXIMIZE RECCE CAPABILITY

3 FACTOR 1 DATA NODE CUM WT: .2448979591837

|       |       |       |
|-------|-------|-------|
| F-4   | F-15  | F-111 |
| 60.41 | 78.10 | 10.46 |

3 FACTOR 2 DATA NODE CUM WT: .2448979591837

|       |       |       |
|-------|-------|-------|
| F-4   | F-15  | F-111 |
| 47.96 | 29.43 | 39.36 |

3 FACTOR 3 DATA NODE CUM WT: .08163265306122

|       |      |       |
|-------|------|-------|
| F-4   | F-15 | F-111 |
| 56.91 | 7.43 | 68.09 |

SUMMARY OF PARENT NODE:

|       |       |       |
|-------|-------|-------|
| F-4   | F-15  | F-111 |
| 54.57 | 47.14 | 31.08 |

|           |   |    |    |    |    |     |
|-----------|---|----|----|----|----|-----|
| BRANCH    | 0 | 20 | 40 | 60 | 80 | 100 |
| FACTOR 1* | C | +  | +  | +A | B+ | +   |
| FACTOR 2* |   | +  | B  | C  | A  | +   |
| FACTOR 3* | B | +  | +  | +  | C  | +   |
| BRANCH    | 0 | 20 | 40 | 60 | 80 | 100 |

LEGEND:

SYMBOL:A IS SYSTEM: F-4

SYMBOL:B SYSTEM:F-15

SYMBOL:C SYSTEM:F-111

W.STIMPSON, YOUR OPTIONS ARE:

ATT COP DIS DON MOD NEW NUM PRU REV SEL

SEN SPA STA SYS TTL WVC

\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?sen

SENSITIVITY ANALYSIS

CHOOSE YOUR OPTION:

C)UMWT

R)ELWT

L)EVEL

S)YSTEM

E)XIT

?c

SENSITIVITY ANALYSIS FOLLOWS...  
ENTER NRN FOR WHICH CUMWT IS  
TO BE PERTURBED...

ENTER...NRN?1

1

0

TO MAXIMIZE AERODYNAMIC PERFORMANCE

CURRENT CUMWT IS .1428571428571

MINIMUM CUMWT (0.-1.) IS?.1

MAXIMUM CUMWT (.1-1.) IS?.3

CUMWT ANALYSIS: T)ABULAR G)GRAPHICAL E)XIT

?L

FOR NODE:  
TO MAXIMIZE AERODYNAMIC PERFORMANCE

| CUMWT | F-4     | F-15     | F-111   |
|-------|---------|----------|---------|
| .1000 | 50.8744 | 51.5774* | 38.0378 |
| .1100 | 50.4586 | 51.2744* | 38.0870 |
| .1200 | 50.0427 | 50.9714* | 38.1363 |
| .1300 | 49.6269 | 50.6685* | 38.1855 |
| .1400 | 49.2110 | 50.3655* | 38.2347 |
| .1500 | 48.7952 | 50.0625* | 38.2839 |
| .1600 | 48.3793 | 49.7596* | 38.3331 |
| .1700 | 47.9635 | 49.4566* | 38.3824 |
| .1800 | 47.5476 | 49.1536* | 38.4316 |
| .1900 | 47.1318 | 48.8507* | 38.4808 |
| .2000 | 46.7159 | 48.5477* | 38.5300 |
| .2100 | 46.3001 | 48.2447* | 38.5793 |
| .2200 | 45.8842 | 47.9418* | 38.6285 |
| .2300 | 45.4684 | 47.6388* | 38.6777 |
| .2400 | 45.0526 | 47.3359* | 38.7269 |
| .2500 | 44.6367 | 47.0329* | 38.7762 |
| .2600 | 44.2209 | 46.7299* | 38.8254 |
| .2700 | 43.8050 | 46.4269* | 38.8746 |
| .2800 | 43.3892 | 46.1240* | 38.9238 |
| .2900 | 42.9733 | 45.8210* | 38.9731 |
| .3000 | 42.5575 | 45.5180* | 39.0223 |

CUMWT ANALYSIS: T)ABULAR G)GRAPHICAL E)XIT  
 ?g

GRAPHICAL ANALYSIS: N)ORMAL E)XPANDED  
 ?h

LEGEND:

SYMBOL=A IS SYSTEM:F-4

SYMBOL=B IS SYSTEM:F-15

SYMBOL=C IS SYSTEM:F-111

SENSITIVITY ANALYSIS ON CUMWT

| OVERALL VALUE        |    |    |    |    |     |
|----------------------|----|----|----|----|-----|
| 0                    | 20 | 40 | 60 | 80 | 100 |
| .11+++++C++++AB+++++ |    |    |    |    |     |
| +                    | +  | C+ | B  | +  | +   |
| +                    | +  | C+ | B  | +  | +   |
| +                    | +  | C+ | B  | +  | +   |
| .15+++++C++++AB+++++ |    |    |    |    |     |
| +                    | +  | C+ | AB | +  | +   |
| +                    | +  | C+ | AB | +  | +   |
| +                    | +  | C+ | AB | +  | +   |
| +                    | +  | C+ | B  | +  | +   |
| .20+++++C++++AB+++++ |    |    |    |    |     |
| +                    | +  | C+ | AB | +  | +   |
| +                    | +  | C+ | AB | +  | +   |
| +                    | +  | C+ | AB | +  | +   |
| +                    | +  | C+ | AB | +  | +   |
| .25+++++C++++AB+++++ |    |    |    |    |     |
| +                    | +  | C+ | AB | +  | +   |
| +                    | +  | C+ | AB | +  | +   |
| +                    | +  | C+ | AB | +  | +   |
| +                    | +  | C+ | AB | +  | +   |
| .30+++++C++++AB+++++ |    |    |    |    |     |
| 0                    | 20 | 40 | 60 | 80 | 100 |
| OVERALL VALUE        |    |    |    |    |     |

(PRESS ANY LETTER TO CONTINUE)

?d

CUMWT ANALYSIS: T)ABULAR G)GRAPHICAL E)XIT  
?sen  
ENTER "T", "G", OR "E"

CUMWT ANALYSIS: T)ABULAR G)GRAPHICAL E)XIT  
?e

W.STIMPSON, YOUR OPTIONS ARE:  
ATT CDP DIS DON MOD NEW NUM PRU REV SCL  
SEN SPA STA SYS TTL WVC  
\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?sen

### SENSITIVITY ANALYSIS

CHOOSE YOUR OPTION:  
C)UMWT R)ELWT L)EVEL S)YSTEM E)XIT  
?r

SENSITIVITY ANALYSIS FOLLOWS...  
ENTER NRN FOR WHICH RELWT IS  
TO BE PERTURBED...

ENTER...NRN?1  
2  
0

TO MAXIMIZE AIRCRAFT SURVIVABILITY

CURRENT RELWT IS .2857142857143

MINIMUM RELWT (0.-1.) IS 7.1

MAXIMUM RELWT (.1-1.) IS 7.5

RELWT ANALYSIS: TABULAR GRAPHICAL EXIT  
7t

FOR NODE:  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

| RELWT | F-4      | F-15     | F-111   |
|-------|----------|----------|---------|
| .1000 | 47.3076* | 45.2722  | 35.0677 |
| .1200 | 47.4998* | 45.8114  | 35.4102 |
| .1400 | 47.6919* | 46.3506  | 35.7528 |
| .1600 | 47.8841* | 46.8898  | 36.0954 |
| .1800 | 48.0763* | 47.4289  | 36.4380 |
| .2000 | 48.2685* | 47.9681  | 36.7806 |
| .2200 | 48.4607  | 48.5073* | 37.1231 |
| .2400 | 48.6529  | 49.0465* | 37.4657 |
| .2600 | 48.8451  | 49.5857* | 37.8083 |
| .2800 | 49.0373  | 50.1249* | 38.1509 |
| .3000 | 49.2295  | 50.6641* | 38.4935 |
| .3200 | 49.4217  | 51.2032* | 38.8360 |
| .3400 | 49.6139  | 51.7424* | 39.1786 |
| .3600 | 49.8061  | 52.2816* | 39.5212 |
| .3800 | 49.9983  | 52.8208* | 39.8638 |
| .4000 | 50.1904  | 53.3600* | 40.2064 |
| .4200 | 50.3826  | 53.8992* | 40.5490 |
| .4400 | 50.5748  | 54.4384* | 40.8915 |
| .4600 | 50.7670  | 54.9776* | 41.2341 |
| .4800 | 50.9592  | 55.5167* | 41.5767 |
| .5000 | 51.1514  | 56.0559* | 41.9193 |

RELWT ANALYSIS: T)TABULAR G)GRAPHICAL E)EXIT  
?e

W.STIMPSON, YOUR OPTIONS ARE:  
ATT COP DIS DON MOD NEW NUM PRU REV SEL  
SEN SPA STA SYS TTL WVC  
\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?1  
L IS NOT AN ALLOWED ENTRY, W.STIMPSON.

W.STIMPSON, YOUR OPTIONS ARE:  
ATT COP DIS DON MOD NEW NUM PRU REV SEL  
SEN SPA STA SYS TTL WVC  
\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?son

#### SENSITIVITY ANALYSIS

CHOOSE YOUR OPTION:  
C)UMWT R)RELWT L)LEVEL S)SYSTEM E)EXIT  
?1

SENSITIVITY ANALYSIS FOLLOWS...  
ENTER NRN FOR WHICH LEVEL IS  
TO BE PERTURBED...

ENTER...NRN?1  
2  
0

TO MAXIMIZE AIRCRAFT SURVIVABILITY

SYSTEMS AVAILABLE:

F-4

F-15

F-111

ENTER SYSTEM OF WHICH VULNER IS TO BE  
PERTURBED...

TP-4

CURRENT NODE LEVEL IS .2

WE ARE WORKING WITH ATTRIBUTE: VULNER

MINIMUM LEVEL (0.-1.) IS .1

MAXIMUM LEVEL (.1-1.) IS .5

LEVEL ANALYSIS: T)ABULAR G)GRAPHICAL E)XIT

TL

LEVEL:LEVEL: VULNER

FOR NODE:

TO MAXIMIZE AIRCRAFT SURVIVABILITY

| LEVEL | F-4      | F-15     | F-111   |
|-------|----------|----------|---------|
| .1000 | 52.9720% | 50.2789  | 38.2488 |
| .1200 | 52.0780% | 50.2789  | 38.2488 |
| .1400 | 51.2559% | 50.2789  | 38.2488 |
| .1600 | 50.4907% | 50.2789  | 38.2488 |
| .1800 | 49.7720  | 50.2789% | 38.2488 |
| .2000 | 49.0922  | 50.2789% | 38.2488 |
| .2200 | 48.4457  | 50.2789% | 38.2488 |
| .2400 | 47.8279  | 50.2789% | 38.2488 |
| .2600 | 47.2354  | 50.2789% | 38.2488 |
| .2800 | 46.6652  | 50.2789% | 38.2488 |
| .3000 | 46.1151  | 50.2789% | 38.2488 |
| .3200 | 45.5830  | 50.2789% | 38.2488 |
| .3400 | 45.0674  | 50.2789% | 38.2488 |
| .3600 | 44.5666  | 50.2789% | 38.2488 |
| .3800 | 44.0796  | 50.2789% | 38.2488 |
| .4000 | 43.6053  | 50.2789% | 38.2488 |
| .4200 | 43.1427  | 50.2789% | 38.2488 |
| .4400 | 42.6909  | 50.2789% | 38.2488 |
| .4600 | 42.2494  | 50.2789% | 38.2488 |
| .4800 | 41.8173  | 50.2789% | 38.2488 |
| .5000 | 41.3941  | 50.2789% | 38.2488 |

LEVEL ANALYSIS: TABULAR GRAPHICAL EXIT  
 ?a

GRAPHICAL ANALYSIS: NORMAL EXPANDED  
 ?n

LEGEND:

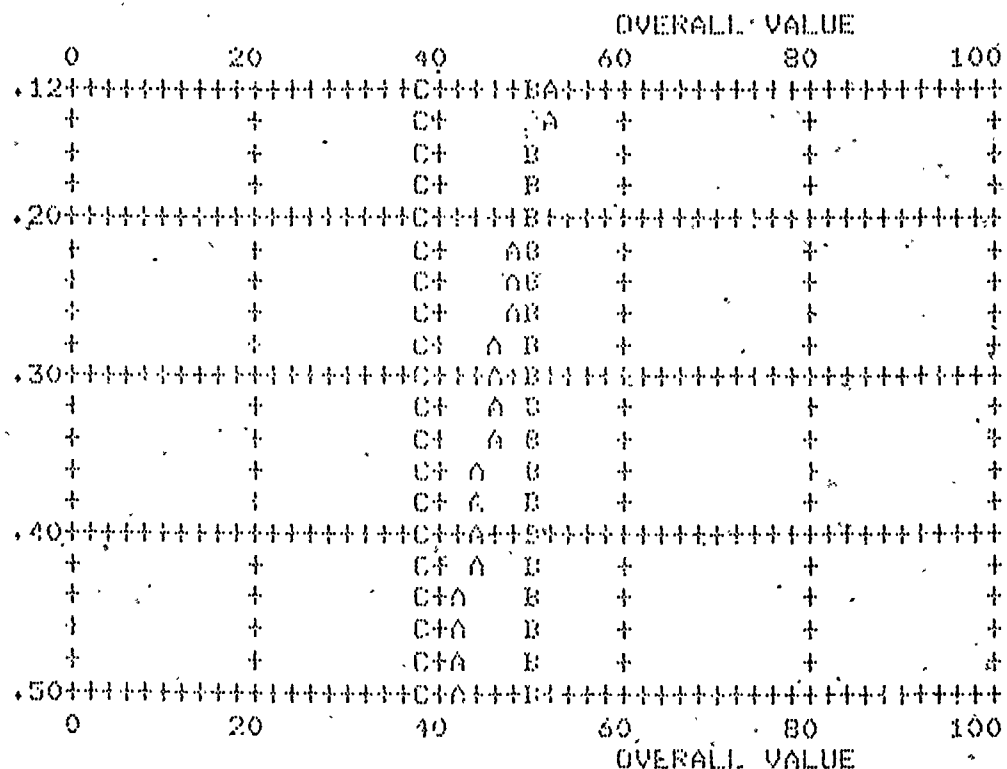
SYMBOL=A IS SYSTEM:F-4

SYMBOL=B IS SYSTEM:F-15

SYMBOL=C IS SYSTEM:F-111

LEVEL ANALYSIS ON SYSTEM F-4

FOR ATTRIBUTE VULNER



(PRESS ANY LETTER TO CONTINUE)  
 ?d

LEVEL ANALYSIS: T)TABULAR G)GRAPHICAL E)EXIT

?e

W.STIMPSON, YOUR OPTIONS ARE:

ATT COP DIS DON MOD NEW NUM PRU REV SEL

SEN SPA STA SYS TTL WVC

\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP".\*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON? sen

#### SENSITIVITY ANALYSIS

CHOOSE YOUR OPTION:

C)UMWT

R)ELWT

L)LEVEL

S)SYSTEM

E)EXIT

?e

SYSTEMS AVAILABLE:

F-4

F-15

F-111

WHAT SYSTEM IS TO BE ANALYZED?

?f-4

WHAT TYPE OF ANALYSIS WOULD YOU LIKE TO DO...

C)UMWT

R)ELWT

V)ALUE

?c

HOW MANY NOTES WOULD YOU LIKE TO EXAMINE? (1-50)

?03

ENTER NRN FOR WHICH CUMWT IS  
TO BE PERTURBED...

ENTER...NRN?1

1

0

THE OBJECTIVE IS:  
TO MAXIMIZE AERODYNAMIC PERFORMANCE

ENTER NRN FOR WHICH CUMWT IS  
TO BE PERTURBED...

ENTER...NRN?1

2

0

THE OBJECTIVE IS:  
TO MAXIMIZE AIRCRAFT SURVIVABILITY

ENTER NRN FOR WHICH CUMWT IS  
TO BE PERTURBED...

ENTER...NRN?1

3

0

THE OBJECTIVE IS:  
TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

MINIMUM CUMWT(0.-1.) IS?2

MAXIMUM CUMWT(.2-1.) IS?7

U  
 SYSTM ANALYSIS: T)ABULAR G)RAPHICAL E)XIT  
 ?

FOR SYSTEM F-4  
 CUMWT

|       | NODE    | NODE     | NODE    |
|-------|---------|----------|---------|
| .2000 | 46.7159 | 48.2685% | 44.3438 |
| .2250 | 45.6763 | 48.5088% | 44.6634 |
| .2500 | 44.6367 | 48.7490% | 44.9830 |
| .2750 | 43.5971 | 48.9892% | 45.3026 |
| .3000 | 42.5575 | 49.2295% | 45.6222 |
| .3250 | 41.5179 | 49.4697% | 45.9418 |
| .3500 | 40.4783 | 49.7100% | 46.2614 |
| .3750 | 39.4386 | 49.9502% | 46.5810 |
| .4000 | 38.3990 | 50.1904% | 46.9006 |
| .4250 | 37.3594 | 50.4307% | 47.2202 |
| .4500 | 36.3198 | 50.6709% | 47.5398 |
| .4750 | 35.2802 | 50.9112% | 47.8594 |
| .5000 | 34.2406 | 51.1514% | 48.1790 |
| .5250 | 33.2010 | 51.3916% | 48.4986 |
| .5500 | 32.1613 | 51.6319% | 48.8183 |
| .5750 | 31.1217 | 51.8721% | 49.1379 |
| .6000 | 30.0821 | 52.1124% | 49.4575 |
| .6250 | 29.0425 | 52.3526% | 49.7771 |
| .6500 | 28.0029 | 52.5927% | 50.0967 |
| .6750 | 26.9633 | 52.8331% | 50.4163 |
| .7000 | 25.9237 | 53.0733% | 50.7359 |

SYSTM ANALYSIS: T)ABULAR G)RAPHICAL E)XIT  
 ?

GRAPHICAL ANALYSIS:      NORMAL      EXPANDED

?n

LEGEND:

SYMBOL=A IS NODE:

TO MAXIMIZE AERODYNAMIC PERFORMANCE

SYMBOL=B IS NODE:

TO MAXIMIZE AIRCRAFT SURVIVABILITY

SYMBOL=C IS NODE:

TO OPTIMIZE MULTI-ROLE COMBAT

CAPABILITY

SENSITIVITY ANALYSIS ON SYSTEM  
FOR SYSTEM F-4

| OVERALL VALUE |       |         |       |       |       |
|---------------|-------|---------|-------|-------|-------|
| 0             | 20    | 40      | 60    | 80    | 100   |
| .23           | +++++ | +++++   | +++++ | +++++ | +++++ |
| +             | +     | + C B   | +     | +     | +     |
| +             | +     | + A C B | +     | +     | +     |
| +             | +     | + A C B | +     | +     | +     |
| .33           | +++++ | +++++   | +++++ | +++++ | +++++ |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| .45           | +++++ | +++++   | +++++ | +++++ | +++++ |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| .58           | +++++ | +++++   | +++++ | +++++ | +++++ |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| .70           | +++++ | +++++   | +++++ | +++++ | +++++ |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| +             | +     | A C B   | +     | +     | +     |
| 0             | 20    | 40      | 60    | 80    | 100   |
| OVERALL VALUE |       |         |       |       |       |

(PRESS ANY LETTER TO CONTINUE)

?d

SYSTM ANALYSIS: T)ABULAR G)GRAPHICAL E)XIT  
Te

W.STIMPSON,YOUR OPTIONS ARE:  
ATT COP DIS DON MOD NEW NUN PRU REV SEL  
SEN SPA STA SYS TTL WVC  
\*\*\*NOTE: IF YOU NEED AN EXPLANATION, W.STIMPSON  
TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, W.STIMPSON?don  
STOP  
51000 MAXIMUM EXECUTION FL.  
6.370 CP SECONDS EXECUTION TIME.

## VI. Conclusions and Recommendations

This research project has generated several observations pertaining to this project and to potential work on similar projects. These observations may be most clearly considered by examining those which apply directly to this research first and then considering those which apply to future research. In order to most concisely present those observations which apply to this research, it is useful to artificially decompose the decision-making process into subprocesses. These subprocesses are: formation of the alternative system set to be considered, construction of the objective hierarchy, generation of an attribute set, super position of a preference structure onto the alternative system set, and observation of choice sensitivity to perturbed parameters. It should be noted that the above decomposition is indeed artificial in that all of these "separate" activities impact one another, and there is no clear cut distinction where the boundary of one activity relative to another may be set.

With respect to the formation of the set of alternative systems, MADAM does not offer much to the enhancement of an unaided DM. Since the program is designed to handle a relatively general class of problems, it is virtually impossible to predispose MADAM toward offering or selecting alternative systems as a solution to the problem at hand. There may be some consideration given to designing decision-aids to fit more specific types of problems (a decision template) so that certain alternatives may be automatically generated. This may prevent the waste of effort in having to redo the problem analysis for the omitted systems, not to mention the embarrassment of a DM who was too pressured for time to carefully consider alternative options.

With respect to the construction of an objective hierarchy, MADAM does offer several advantages. Although, as stated above, the program considers a set of problems too general to offer predisposed suggestions, it does provide a thorough consideration of the hierarchy formation at each step (if the between-node check is being used). At the very least the program provides a convenient mechanism for storing and modifying the hierarchy. At best, it may alert the DM to potential hazards during construction of the hierarchy that would impede further analysis and result in much wasted effort and frustration. As before, if one were willing to trade general applicability for specificity, it would be possible to design an aid which is predisposed toward a suggested hierarchy or set of hierarchies.

With respect to the generation of an attribute set, MADAM offers several advantages over the unaided DM. This program not only conveniently stores and works with the attribute set, but it also aids the DM in quickly identifying problems with the attribute set which will cause complications. Not only does MADAM assist in the generation of the attribute set, but once the attribute set is established, MADAM provides a convenient mechanism for measuring and storing the individual value functions defined over each attribute. This step exploits the virtually instantaneous computational capability of the computer to provide early insights into the DM's preference structure.

The stage of superimposing the DM's preference structure onto the alternative system set is critical. The crux of a MAUT analysis is to provide the mechanism for such a task. MADAM allows the use of an additive overall value function for finding the final ranking of the alternatives with respect to preference. The program provides the mechanism to

test the independence condition among the attributes which justified use of the additive form. If this testing is undesired or unnecessary, the program allows this testing to be skipped. It may be noted that although MADAM exploits the equivalence of PPI and MPI to reduce the testing to a polynomial rather than exponential function of the number of attributes, it is possible that the still lengthy process of PPI testing may incline the DM to ignore or avoid this process.

It is with respect to the sensitivity to parameters that MADAM offers the most outstanding advantages over the unaided DM. By utilizing rapid computational capability, MADAM offers the advantage of performing a dynamic as well as a static decision analysis. The program allows the testing of sensitivity of the alternative system values to all of the critical parameters of the type of problem appropriate for analysis with MADAM: relative weights, cumulative weights, and attribute levels. The program allows comparison of systems at a single node, or comparison of a single system response over a set of nodes.

To see more clearly where MADAM rests relative to the concerns of other researchers, it is useful to see what, if any, of their concerns are incorporated into MADAM. The suggestions of Morlan (1979) offer a useful example. He suggests that a decision aid should allow a sensitivity analysis over the attribute levels. Clearly this is met by MADAM. Morlan also suggests that sensitivities over simultaneous changes in several nodes is useful. MADAM does allow the comparison of nodes based on individual changes, but due to concerns with introducing confusion into the sensitivity analysis, and the problem of interpreting rates of change, a simultaneous sensitivity analysis does not appear to offer much to the DM in terms of information. Other suggestions of Morlan's include

measuring actual value functions and considering independence testing between the attributes. MADAM has addressed both considerations. Lee (1981) also suggests the use of actual value functions so that the DM may work with real attribute levels.

As noted in the background of this project, Kelley (Fischer et al, 1978) noted that important functions of decision aids are to facilitate communication and storage of rationales behind the model parameters, and to offer special help in problem structuring. MADAM provides a useful vehicle for both of these functions. It must be noted, however, that although MADAM is designed to be as machine independent as possible, use of the program does involve access to a reasonably larger computer (work space of about 60,000 words). Also, use of the program requires a FORTRAN V compiler. The present segmentation of the program into overlays suitable for the CYBER 175 system is easily convertible into a segmentation appropriate to a new host system.

Utilizing the above observations of MADAM in its present form, several observations may be made concerning future research projects of a similar nature. In the short-term, there are two developments that would be fruitful. First, by modifying the algorithm which generates the individual value functions, and that which elicits the attribute levels of the alternatives, MADAM could be converted into a program which allows a utility function analysis (that is, it could directly incorporate risk into the analysis). Independence testing among the attributes would have to be modified so as to use the independence conditions required in utility theory rather than those of value theory. A second short-term benefit may be gained by constructing a library of objective tree templates which could be accessed by MADAM to aid in the rapid analysis of certain types

of problems. The template objective hierarchies could be tailored through the \*\*\*SPA\*\*\*, \*\*\*MOD\*\*\*, and \*\*\*PRU\*\*\* options to fit the actual problem. The library could also contain appropriate alternative sets so as to generate some of the advantages mentioned earlier.

Reaching further into the future for mid-term benefits, it would be advantageous to expand the independence testing and computational abilities to include other decompositions besides the additive case. This could be combined with the earlier work of providing a utility analysis. Finally, in the long term, it would be beneficial to pursue the implementation of the current work by Farquhar (1979) which would involve using a set of the attributes to "span" the consequence space, thus allowing for use only of individual utility functions rather than complicated decomposition approaches.

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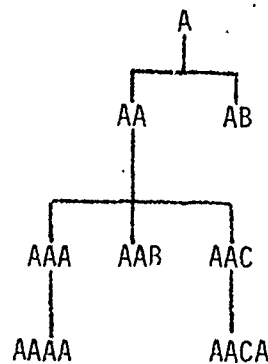
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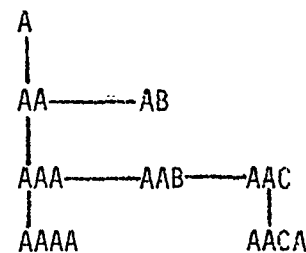
## Appendix A

### Glossary

Note - the following tree hierarchies will be used to demonstrate several defined concepts:



(tree structure)



(data structure)

backlink - this is a construct of the data structure. It represents the node preceding a backlinked node (AA is the backlink of AB, A is the backlink of AA).

branching node - a node with at least one descendent.

children - a hierarchical construct. The children of a node are those nodes down one level from a node, and descendants of that node. (A has children AA, AB; AA has children AAA, AAB, AAC).

completeness - a set of attributes is complete if it is adequate in indicating the degree to which the overall objective is met.

## Glossary (contd)

comprehensive - a quality of an attribute if, by knowing the level of an attribute, the DM has a clear understanding of the extent to which the associated objective is achieved.

crosslink - a data structure concept. The first sibling node is the crosslink to a node. (AB is a crosslink to AA, AAC is a crosslink to AAB).

cumulative weight - the weight of a node relative to the root node. This represents its contribution to the overall hierarchical structure.

data node - a node with no descendants. Its objective has an associated attribute.

decomposable - the attribute set is decomposable if the tasks of quantifying the DM's preferences for consequences can be broken down into parts of smaller dimensionality.

descendant - a node which occurs lower than a given node on the hierarchy.

depth-first search - a synthesis of data and logic structure concepts. This technique adds new levels first (if possible) then goes to the crosslink nodes. A depth-first traversal of the example is the ordering:  
A, AA, AAA, AAAA, AAB, AAC, AACA, AB

direct preference measure - the DM must directly assign the conditional expected utilities for achieving the objective.

goal - a specific level of an attribute which is achieved or not.

level - represents the number of nodes separating a given node from the root node. (A is level 1, AAAA is level 4).

measurable - an attribute is measurable if  
(1) it is possible to obtain a probability distribution over the possible levels of the attribute and  
(2) it is possible to assess the DM's preferences for different levels of the attribute

## Glossary (contd)

mutual preferential independence - a condition where all subsets of the attributes set are preferentially independent of their complements.

node - an element of the objective hierarchy.

node digit - the number stating the position of a node on its span.  
(AAB has node digit 2, AA has node digit 1, AACA has node digit 1).

node reference number (NRN) - the vector which draws a path from the root node to a given node. Each node has a unique NRN. Each element of a NRN is a node digit. (AAAA has NRN = 1.1.1.1, AACA has NRN = 1.1.3.1, AB has NRN = 1.2).

non redundancy - the attributes should be defined to avoid double counting of consequences.

objective - an entity which indicates the "direction" in which to strive.

operational - the attributes must be meaningful to the DM. They should also facilitate explanation to others.

pairwise preferential independence - that condition each pair of attributes is preferentially independent of its complement.

parent node - the node directly in line, one level above a given node.  
(A is the parent of AA and AB; AA is the parent of AAA, AAB and AAC).

preferential independence - a condition where the preferences over a subset of the attributes are independent of the level of the remaining attributes.

proxy attribute - one that reflects the degree to which an associated objective is met, but does not directly measure the objective.

## Glossary (contd)

relative weight - the importance of a node relative to its siblings.  
They are positive and normalized to sum to unity.

root (root node) - the topmost node in a hierarchy, representing the overall objective of the hierarchical structure.

sibling - those nodes which have the same parent node. (AA and AB are siblings; AAA and AAB and AAC are siblings).

span - a set of siblings. (AA and AB comprise a span).

specification - subdividing an objective into lower level objectives of more detail.

strategic equivalence - the value functions  $v_1$  and  $v_2$  are strategically equivalent ( $v_1 \sim v_2$ ) if  $v_1$  and  $v_2$  have the same indifference curves and induced preferential ordering.

value - the worth of a level of a particular attribute for a given alternative under conditions of certainty.

APPENDIX B

USER'S MANUAL

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## OVERVIEW

MADAM is a computer based decision support aid. It is designed to test the conditions necessary and sufficient to utilize a MAUT analysis with an additive decomposition for the value function. If these conditions are satisfied then a decision analysis under certainty is completed with a sensitivity analysis. MADAM is written in FORTRAN V and is currently implemented on the CYBER 175 system. It is run interactively and memory requirements are a function of the size of the problem. The user should refer to Chapter V: An Illustrative Example (of the main text) to see how these options appear for a sample output. Note that the following description only show those outputs which require an input (prompts). By comparing the descriptions of this appendix with the sample output of Chapter V of Volume I, it is possible to see the other, informative output which the program provides.

## I. CAPABILITIES AND LIMITATIONS

MADAM is capable of handling a full decision analysis for a hierarchical problem which satisfies the conditions for an additive decomposition (MAUT) under certainty. The analysis is freely structured in that it allows the user to interactively input the objective hierarchy, the attribute set, the alternative set, relative weights, and attribute levels via the program options. The interactive program uses line printer style intermediate graphics to aid the user in input, and a separate program converts the data structure into a separate plot file which is device independent and can be used to generate hard copy graphics (or reviewed at a graphics terminal). MADAM automatically calculates the overall value of each of the alternative systems at the root node as well as intermediate values at all other nodes in the objective hierarchy. Data is both graphical and tabular in format, and the user's option. An emphasis has been made in keeping MADAM as machine independent as possible so that it may be used on any computer with a minimum of changes.

One of the most significant advantages of MADAM (or any real-time decision aid) is the powerful capabilities of the sensitivity analysis.

Although MADAM may be applied to a wide variety of problems, there are limitations which must be considered. One of the most basic limitations is that MADAM may be used only for problems which can be represented as a hierarchical objective structure. There are situations where it would be meaningless to take such an approach. For those problems which are suitable for a MAUT approach, only those cases which involve the additive decomposition may be fully explored by using MADAM. Although the necessary and sufficient conditions for using the attribute

decomposition are ascertained, MADAM is not currently designed to handle other forms of the value function for those situations where the conditions do not hold. Finally, there are operational limitations on the size of the problem based on arbitrary choice of parameters (see Table B.1). Most of these limitations may be removed by modifying the program code. Further details are provided in the Programmer's Manual.

Maximum:

|                               |     |
|-------------------------------|-----|
| Number of Nodes               | 500 |
| Number of Levels              | 20  |
| Number of Alternative Systems | 59  |
| Number of Nodes on a Span     | 9   |
| Data Sets (single session)    | 3   |

Table B.1 Operational Limitations

## II. INPUT

In this context, input refers to all data used in running the program. This data is obtained either from interactive user responses to questions or from previously generated and stored data files. Anytime that a user response is required to generate data, a prompting question is displayed. A question mark appears either at the end of the question or at the beginning of the line following the prompt. No other type of output required (or accepts) a response from the user.

### Program Control

The flow of the program is controlled by user responses to prompts or by user selection of a main option. Selections are made in one of three ways: (1) using a three character code concluded by a RETURN, (2) using a single letter followed by RETURN, or (3) entering "Y" or "N" followed by a RETURN. The type of response required is self evident from the prompt, which usually displays the alternative entries. Most of the routines have fail-safe mechanisms to allow graceful recovery from a mistaken entry. The user should note, however, that the data file is stored only if the program is exited normally (option \*\*\*DON\*\*\*).

### Conventions

For clarity, all computer input and output is capitalized, except for output variable values, alternative listings, and node reference numbers which are delineated by <.>.

### Terminology

The program and manuals use terminology specific to tree structures and data structures. Appendix A should provide a concise reference for unfamiliar or unique words and phrases.

### III. PROGRAM FLOW

At the initiation of the program, a very brief introductory routine is invoked which will prompt the user to enter his/her name. The purpose of this is two fold. First, the user's name is an element of several questions in order to emphasize the personal nature of the preference data. Second, for those situations where more than one DM may wish to compare analyses, it provides readily available information as to what data is attributable to each DM. MADAM is designed to facilitate partial analysis of the problem while storing data. That is, it is possible to use MADAM to construct the objective hierarchy, attribute set, and alternative set, and then to store this data while the DM acquires the required information concerning attribute levels. The user may call up the stored information and continue the decision analysis from that point.

If a new data file is to be constructed, the next option to be used is option **\*\*\*NEW\*\*\***. The option automatically takes the user through options **\*\*\*SYS\*\*\***, **\*\*\*TTL\*\*\***, **\*\*\*SPA\*\*\***, and **\*\*\*ATT\*\*\*** in order to enter the alternative systems, the objective hierarchy and the attribute set respectively. If a previously stored data file is to be used, option **\*\*\*SEL\*\*\*** instead of **\*\*\*NEW\*\*\*** should be called. This allows the user to pick the stored data file, but then returns to the main options, where the user may choose the entry option.

Under the **\*\*\*SYS\*\*\*** the user is allowed to enter the alternative systems to be compared. At least one system must be entered at this point. If any changes to this alternative set must be made after leaving this option, these changes may be implemented by invoking **\*\*\*SYS\*\*\*** from the main option selection.

Option **\*\*\*TTL\*\*\***, which is automatically entered when using option **\*\*\*NEW\*\*\***, allows the user to enter a descriptive title for the data structure. This title appears as a header for the output when using the **\*\*\*REV\*\*\*** or **\*\*\*NUM\*\*\*** options. The title should contain information such as name, date, subject, requesting source, and any other data useful in identifying the data structure.

The **\*\*\*SPA\*\*\*** option allows the user to construct the objective hierarchy. The tree is entered on a node by node basis using a depth-first approach. If changes are necessary during the construction, the user is automatically sent to the appropriate routine (MODIFY, PRUNE) and then brought back to the **\*\*\*SPA\*\*\*** option. Later changes to the tree structure (after leaving **\*\*\*SPA\*\*\***) are possible through the use of **\*\*\*MOD\*\*\*** or **\*\*\*PRIJ\*\*\***. At the conclusion of **\*\*\*SPA\*\*\*** the data file is closed and then reopened. This ensures that the data generated up to this point is not lost in the event that the program exits abnormally (crashes).

The **\*\*\*ATT\*\*\*** option involves construction of the attribute set. As each data node is encountered in a depth-first search, the user is solicited for information about an attribute to be associated with that objective. The program checks the attributes for PPI. If PPI holds, the individual value functions will be stored for each attribute.

At this point, the user is returned to the main option selection. The option **\*\*\*WVC\*\*\*** should be invoked in order to enter the node weights, the attribute levels, and to calculate the tree. The input weights are either directly entered as ratios (they will be normalized automatically) or by a pairwise-comparison technique. After entering the weights and attribute levels, the tree values are calculated. Calculations is mandatory before any output is used or any sensitivity analysis conducted.

If at any time changes are made in the data structure, the tree must be recalculated.

At this point the program is able to provide the user with the desired output. The two basic options for review are **\*\*\*NUM\*\*\*** and **\*\*\*DIS\*\*\***. Option **\*\*\*NUM\*\*\*** is a numerical review of selected nodes in the data structure. Along with relative and cumulative weights of each node, the values of the alternative systems at that node are presented. The **\*\*\*DIS\*\*\*** option reviews only a single node and its descendants. This option allows for a graphical display as well as a numerical one.

The sensitivity analysis is provided by the main option **\*\*\*SEN\*\*\***. Current options for the sensitivity analysis allow for a sensitivity analysis on cumulative weight, relative weight, or attribute level. Also a system option may be invoked which will allow the analysis to cover several chosen nodes. When a cumulative weight, relative weight or attribute level analysis is invoked directly, only one node is examined and all of the system value changes are relative for that node. When using the system suboption and then using a cumulative weight, relative weight, or value analysis, only one system is considered, but system values are given relative to a set of nodes. These options are more explicitly described in the sensitivity analysis section (Chapter IV) of the main text.

#### IV. MAIN OPTIONS

This section gives a detailed description of each of the main options. The options are presented in alphabetical, rather than logical order to facilitate referencing. The general format used to present each option is given in Figure B.1.

OPTION: (option mnemonic)(option name)

USE: A general discussion of the use of the option

\*\*\*\*\* CAUTION \*\*\*\*\*

CAUTION ASSOCIATED WITH THE USE OF THIS OPTION

\*\*\*\*\* CAUTION \*\*\*\*\*

PROMPT or MESSAGE output of the computer which will require a response

SITUATION describes the meaning of the prompt and the implications of some responses

RESPONSE acceptable responses to the prompt

This PROMPT-SITUATION-RESPONSE is repeated as often as necessary

Figure B.1 Option Discussion Format

Each of these responses must be followed by a carriage return.

## MAIN OPTION SELECTION

PROMPT: <user name>, YOUR OPTIONS ARE:

ATT, DIS, DON, MOD, NEW, NUM, PRU, REV, SEL

SEN, SPA, STA, SYS, TTL, WVC

\*\*\*NOTE: IF YOU NEED AN EXPLANTION, <user name>

TYPE "HELP" \*\*\*

WHAT IS YOUR CHOICE, <user name>

SITUATION: After the introduction or the conclusion of a main option, the user is transferred to this selection routine. From here, the user may enter any of the main options. Use of HEL or HELP will elicit a brief description of each of the main options. Entering an illegitimate entry will cause an error message and this prompt to be repeated.

RESPONSE: HELP or a three letter main option.

OPTION: ATT (ATTRibute)

USE: This option is used to enter the attributes which will be associated with the tree structure. It is automatically invoked when using option \*\*\*NEW\*\*\*. It may be used directly to alter the existing data structure

\*\*\*\*\* CAUTIONS \*\*\*\*\*

1. ALL EXISTING ATTRIBUTE INFORMATION WILL BE OVERWRITTEN IF THIS OPTION IS USED (FOR THE CURRENT TREE FILE).
2. BY-PASSING THE INDEPENDENT TESTING IS NOT ALLOWED IF NUMERICAL INFORMATION IS TO BE GENERATED (THE VALUE FUNCTIONS WILL BE ILL DEFINED).

\*\*\*\*\* CAUTIONS \*\*\*\*\*

PROMPT-1: <user name>, PLEASE INPUT AN ATTRIBUTE FOR THE DATA NODE WITH THE OBJECTIVE:  
<objective>  
(10 LETTERS OR LESS)

SITUATION: MADAM is prepared to accept an attribute to be associated with the given data node.

RESPONSE-1: Enter a 10 (or less) letter mnemonic for the desired attribute

PROMPT-2: IS THE ATTRIBUTE <attribute>  
SUCH THAT BY KNOWING ITS LEVEL,  
THE ATTAINMENT OF THE OBJECTIVE  
IS TOTALLY DETERMINED? (Y/N)  
?

SITUATION: Desirability of the attribute is being tested. If no, prompt-1 will be repeated.

RESPONSE-2: Y or N

PROMPT-3: COULD THE ATTRIBUTE <attribute>  
BE CHANGED SO AS TO IMPROVE  
COMMUNICATING WHAT IS IMPLIED  
BY THE OBJECTIVE? (Y/N)  
?

SITUATION: The attribute is being tested for desirability  
A negative response will generate a repeat of  
prompt-1.

RESPONSE-3: Y or N

PROMPT-4: WHAT IS THE WORST ACCEPTABLE  
LEVEL (REAL NUMBER) OF <attribute>

SITUATION: A lower bound on this attribute is sought.

RESPONSE-4. Enter a real number

PROMPT-5: WHAT IS THE BEST (REALISTICALLY) LEVEL  
(REAL NUMBER) OF <attributes>, <user name>?  
SITUATION: An upper bound on this attribute is sought.

RESPONSE-5: Enter a real number

[The process is repeated from prompt-1 until all data nodes  
have been associated with an attribute.]

PROMPT-6: DO YOU WISH TO REFORM THE ATTRIBUTE SET, <user name>?  
(Y/N) ?

SITUATION: The overall attribute set is being established as  
appropriate for the analysis. A negative response  
reinitializes \*\*\*ATT\*\*\*.

RESPONSE-6: Y or N

PROMPT-7: DO YOU WISH TO BYPASS INDEPENDENCE TESTING?  
SITUATION: MADAM is determining if the user wishes to skip  
PPI testing. Any response besides Y will be  
interpreted as a negative answer.

RESPONSE-7: Y or any letter

[If response-7 is a Y, control goes directly to the routine  
which input value-functions (see prompt-13). Otherwise,  
the following analysis is generated.]

PROMPT-8: AT WHAT TOLERANCE DO YOU WANT TO CHECK YOUR  
RESPONSES, <user name> (PLUS OR MINUS X PERCENT)?  
X = ?

SITUATION: The tolerance window for PPI testing will be set at  
+ X% based on the mid-range of the attribute levels.  
Two digits must be entered (e.g. 05 means 5%).

RESPONSE-8: A right-justified two digit number

PROMPT-9: WHAT LEVEL OF <attribute> WOULD KEEP YOU AS SATISFIED  
AS YOU WERE UNDER THE INITIAL CONDITIONS?  
(REMEMBER THAT ALL OTHER ATTRIBUTES ARE AT THE 25  
PERCENT LEVEL)  
?

SITUATION: An indifference curve is being established.

RESPONSE-9: Any real number

PROMPT-10: TO WHAT LEVEL WOULD YOU CHANGE <attribute>, IN ORDER  
TO REMAIN AS SATISFIED AS YOU WERE INITIALLY?  
(REMEMBER THAT ALL OTHER ATTRIBUTES ARE AT THE 25  
PERCENT LEVEL)  
?

SITUATION: An indifference curve is being established.

RESPONSE-10: Any real number

PROMPT-11: WOULD THE LEVEL OF <attribute> NEEDED TO REMAIN AS SATISFIED AS AT THE INITIAL CONDITIONS LIE BETWEEN <number> AND <number> (Y/N) ?

SITUATION: MADAM is testing for shifts in the indifference curve based on changing the background attributes.

RESPONSE-11: Any real number

PROMPT-12: WOULD THE LEVEL OF <attribute> THAT YOU WOULD HAVE TO MOVE TO (IN ORDER TO BE AS SATISFIED AS UNDER THE INITIAL CONDITIONS) LIE BETWEEN <number> AND <number> (Y/N) ?

SITUATION: MADAM is testing for shifts in the indifference curve based on changing the background attributes.

RESPONSE-12: Any real number

[Prompts 9-12 are repeated for all pairs of attributes. These pairs are generated based on the order in which the attributes were entered. The pairs tested are ATT1-ATT-2, ATT1-ATT3, ..., ATT1, ATTn, ATT2-ATT3, etc.]

PROMPT-13: DO YOU WISH TO ASSUME PPI FOR THE REMAINING ATTRIBUTES? (Y/N)

SITUATION: Independence testing between a particular pair of attributes has been completed. There have been no independence problems so far, and the user may now by-pass the remaining independence testing.

RESPONSE-13: Y or N

PROMPT-14: EVEN IF YOU DO NOT WISH TO ASSUME PPI AMONG THE REMAINING ATTRIBUTES, DO YOU WANT TO STOP PPI TESTING? (Y/N)

SITUATION: The answer to prompt-14 was N.

RESPONSE-14: Y or N

PROMPT-15: THERE ARE INDEPENDENCE PROBLEMS AMONG THE ATTRIBUTES ALREADY TESTED. DO YOU WANT TO STOP PPI TESTING? (Y/N)

SITUATION: Analogous to prompt -14 except that independence problems have been established.

RESPONSE-15: Y or N

PROMPT-16: THERE EXIST INDEPENDENCE PROBLEMS AMONG THE ATTRIBUTES (PPI DOES NOT HOLD). DO YOU WISH TO CONTINUE THE ANALYSIS WITH AN ADDITIVE VALUE FUNCTION? (Y/N)

?

SITUATION: Significant shifts in the indifference curves were found when the background attributes were shifted. The user may desire to reformulate the problem rather than continue with the analysis with the incorrect additive form of the value function.

RESPONSE-16: Y or N

PROMPT-17: WHAT LEVEL OF <attribute> WOULD BE SUCH THAT YOU WOULD FEEL THE SAME AMOUNT OF CHANGE IN SATISFACTION IN MOVING FROM <number> TO IT, AS FROM THAT LEVEL TO <number>?

?

SITUATION: MADAM is establishing the form of the value function. This prompt is repeated three times.

RESPONSE-17: Any real number

PROMPT-18: DOES THE ABOVE REPRESENTATION APPEAR REASONABLE? (Y/N)

?

SITUATION: The user is asked to validate the generated value function based on curvature and levels.

RESPONSE-18: Y or N

[Prompts 17-18 are repeated for all attributes.]

OPTION: COP (COPY)

USE: This option is used to copy the descendant structure of one node onto a second node. Copying includes all information contained in the children of the time of copying.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

1. THE NODE BEING COPIED TO MUST NOT BE A DESCENDANT OF THE NODE BEING COPIED.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

PROMPT-1: ENTER NODE TO BE COPIED TO.  
ENTER...NRN?

SITUATION: The user is asked to enter the node reference number of the node which will gain the descendants. Entering an invalid node reference number will abort the option.

RESPONSE-1: Enter a NRN followed by 0, each digit followed by <cr>

PROMPT-2: ENTER NODE TO BE COPIED.  
ENTER...NRN?

SITUATION: The user is asked to enter the parent of the descendants which are to be copied. All descendants of the parent node will be copied. An invalid node will abort cop.

RESPONSE-2: Enter a NRN followed by 0, each digit followed by <cr>

OPTION: DIS

USE: The routine allows display of a desired node and its children. This option has no cautions associated with it.

PROMPT-1: ENTER NODE TO BE DISPLAYED...  
ENTER...NRN?

SITUATION: MADAM is ready to display the node associated with the input NRN.

RESPONSE-1: Enter the desired NRN one digit at a time with each digit followed by a <cr>. End the input by entering a 0 followed by <cr>.

PROMPT-1a: NODE IS A DATA NODE AND CANNOT BE DISPLAYED  
(PRESS ANY LETTER TO CONTINUE)  
?

SITUATION: The input NRN was associated with a data node (a node with no descendants). This type of node cannot be displayed. Prompt-1 will be repeated.

RESPONSE-1a: Enter any letter

PROMPT-2: IF ANY MODIFICATIONS HAVE BEEN MADE TO THE TREE  
SINCE IT HAS BEEN CALCULATED, NUMERICAL VALUES  
WILL BE INCORRECT.  
(PRESS ANY LETTER TO CONTINUE)  
?

SITUATION: MADAM is presenting a warning in case the user neglected to recalculate the tree after modifying it.

RESPONSE-2: Enter any letter

OPTION: DON (DONE)

USE: This is the last option used. This signals the program to end and to save the data. The data files will be stored as local files. There are no cautions or prompts associated with this option. Tape files must be converted to permanent files before logging-out. For the CYBER 175 system, the procedure is as follows:

COMMAND - REQUEST, A, \*PE  
COMMAND - REWIND, TAPE 1, A  
COMMAND - COPY, TAPE 1, A  
COMMAND - CATALOG, TAPE 1, <pfname>, RP=999

This will store a local file TAPE 1 on to a permanent file <pfname>. Each tree file number (m) will produce a local file TAPE n.

This stored file may be retrieved by using:

COMMAND - ATTACH, TAPE 1, <pfname>

NOTE: Use the same tape number as tree file number.

A preferred alternative to the above (due to file size) is to use the indirect file library system. To use this, the following commands are invoked:

COMMAND - ATTACH, ZZZZLB, IFSLIB, PW-TKIFS, CY=999,  
ID=A810171, SN = ASD  
COMMAND - LIBRARY, ZZZZLB.

The very first time this library is used, the command entered is BUILD. For all subsequent uses, this is not done. Files are saved by using SAVE, TAPEn or REPLACE, TAPEn (in the case of a previously stored file). The files are accessed by the command GET, TAPEn. Just before logging out, the REORG command should be invoked.

OPTION: HELP (HELp)

USE: This option is designed to aid the user in choosing a main option. It lists a brief description of each of the main options. There are no cautions associated with this option.

PROMPT-1: (PRESS ANY LETTER TO CONTINUE)  
?

SITUATION: Approximately a screenful of information has been displayed, and the program is pausing to allow the user to assimilate the information before continuing the listing.

RESPONSE-1: Press any letter and then a carriage return

OPTION: MOD (MOD'fy)

USE: This option is used to modify the existing tree structure one node at a time. Each node input is either created with necessary predecessor or the existing objective is changed if the node already exists.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

1. ALL NRN'S ENTERED MUST HAVE A FIRST DIGIT OF 1. USE OF ANY OTHER PRIMARY DIGIT WILL CAUSE A LOSS OF TREE STRUCTURE.
2. EXCEEDING THE LIMIT OF 9 DESCENDANTS ON EACH NODE WILL HAVE UNPREDICATABLE RESULTS.
3. A DIGIT OF 1 SHOULD BE USED IN THE NRN OF THE PLACE CORRESPONDS TO A NON-EXISTING SPAN.
4. OVERALL TREE SIZE LIMITATIONS MAY NOT BE EXCEEDED.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

PROMPT-1: ENTER...NRN?

SITUATION: The user is asked to enter the node reference number of the node to be added or the objective to be changed. Entering a 0 <cr> will return control to the calling routine.

RESPONSE-1: Enter the desired NRN subject to the above cautions.

PROMPT-2: ENTER YOUR NEW OBJECTIVE  
?

SITUATION: The user is asked to associate an objective with the modified or added node. Entering a null string will abort the option. Control will be returned to the calling routine. If response-2 is not a null-string, prompt-1 will be repeated.

RESPONSE-2: Enter an objective of less than two 80 character lines in length (use a carriage return between lines or a null string).

OPTION: NEW (NEW data file)

USE: This option is used to generate a new tree structure either in a newly created file or by over writing an existing file.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

1. CHOOSING A TREE FILE NUMBER WHICH HAS PREVIOUSLY STORED DATA WILL CAUSE THE STORED DATA TO BE LOST.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

PROMPT-1: WITH WHICH TREE WOULD YOU LIKE TO WORK, <user name>?  
SITUATION: MADAM is allowing the user to specify which of the three tree files is to be the current work file.

RESPONSE-1: 1, 2, or 3

PROMPT-2: OPENING FILE NUMBER <number>  
IS THIS DATA NEW (N) OR STORED (S)?  
SITUATION: MADAM is ascertaining whether or not this file contains previously stored data. A response of "N" causes the file to be blanked out (initialized). A response of "S" allows the user to continue with option \*\*\*NEW\*\*\* only if the number of nodes is zero. This latter situation occurs if the user has previously answered this question with a "N" for this file number.

RESPONSE-2: "N" or "S"

See option \*\*\*SYS\*\*\*  
See option \*\*\*TTL\*\*\*  
See option \*\*\*SPA\*\*\*  
See option \*\*\*ATT\*\*\*

(Control is returned to main option selection. The next main option selected should be \*\*\*WVC\*\*\*).

OPTION: NUM (NUMerical review)

USE: This option is used to review the objective hierarchy one node at a time. This option is similar to \*\*\*REV\*\*\* but it includes numerical values at the node.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

1. THIS ROUTINE MUST BE EXITED AFTER THE LAST NODE (DEPTH-FIRST ORDERING) IS REVIEWED.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

PROMPT-1: HOW MUCH DO YOU WANT TO REVIEW...

A)LL S)ELECT

?

SITUATION: MADAM is preset at this point to review the entire hierarchy starting at the root node. A response of "A" begins this review. A response of "S" results in prompt-1a.

RESPONSE-1: "A" or "S"

PROMPT-1a: ENTER NRN...?

SITUATION: MADAM is prepared to begin the review at any node which is desired. Input of a null string or invalid NRN causes the full review to be initiated.

RESPONSE-1a: NRN followed by 0 each digit followed by <cr> or null string.

PROMPT-2: IF ANY MODIFICATIONS HAVE BEEN MADE TO THE TREE SINCE IT HAS BEEN CALCULATED, NUMERICAL VALUES WILL BE INCORRECT.

(PRESS ANY LETTER TO CONTINUE)

?

SITUATION: MADAM is presenting a standard warning in case the user failed to recalculate the tree. The option still continues even if values are incorrect.

RESPONSE-a: Any letter

PROMPT-3: (PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))

(PRESS "E" TO EXIT)

?

SITUATION: MADAM has finished reviewing the current node and is prepared to either review the next (depth-first order) node or to return control to the main option selection.

RESPONSE-3: Any letter of "E"

OPTION: PRU (PRUne nodes)

USE: This option is used to eliminate an undesired node from the tree. It is entered automatically, if needed, from \*\*\*SPA\*\*\* or \*\*\*NEW\*\*\*. It can be invoked directly.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

1. MODIFICATION TO DATA STRUCTURE ARE PERMANENT. TEMPORARY "PRUNING" MAY BE DONE BY ENTERING A RELATIVE WEIGHT OF ZERO IN THE \*\*\*WVC\*\*\* OPTION

\*\*\*\*\* CAUTIONS \*\*\*\*\*

PROMPT-1: ENTER NODE TO BE REMOVED.  
ENTER NRN...?

SITUATION: MADAM is preparing to prune the hierarchy. If the user does not wish to continue with this option, enter an invalid NRN (see prompt-1a).

RESPONSE-1: Enter NRN followed by "0" each digit followed by <cr>

PROMPT-1a: NODE NOT FOUND, DO YOU WISH TO TRY AGAIN? (Y/N)

SITUATION: NRN entered was invalid. A negative response returns control to the calling routine. A positive response results in a repeat of prompt-1.

RESPONSE-1a: "Y" or "N"

PROMPT-2: SELECT PRUNING OPTION:  
N)ODE+DOWN D)OWN ONLY S)ELECT DOWN E)XIT

SITUATION: MADAM is prepared to remove a node(s).  
A response of "N" results in that node and all of its descendants being omitted.  
A response of "D" eliminates only the descendants.  
A response of "S" results in prompt-3.  
A response of "E" returns control to the calling routine.

RESPONSE-a: "N", "D", "S", or "E"

PROMPT-3: <objective>  
WHICH IS CURRENT DESCENDANT NUMBER <NRN digit>  
DO YOU WISH TO ELIMINATE THIS DESCENDANT? (y/N)  
?

SITUATION: MADAM is selecting a descendant to either eliminate or skip over.

RESPONSE-3: "Y" or "N"

OPTION: REV (REview hierarchy)

USE: This option is used to review the objective hierarchy one node at a time (depth-first order). No numerical information (except NRN) is provided. This option has the same cautions and prompts as option \*\*\*NUM\*\*\*.

OPTION: SEL

USE: This option allows the selection of a different tree number. The prompts and cautions are like those of option \*\*\*NEW\*\*\*. If the data file chosen is not empty, control is returned to the main option selection rather than proceeding with option \*\*\*NEW\*\*\*.

OPTION: SEN (SENSitivity analysis)

USE: This option provides a sensitivity analysis of the model parameters. There are no cautions associated with this option.

PROMPT-1: CHOOSE YOUR OPTION:

C)UMWT R)ELWT L)EVEL S)YSTEM E)XIT

SITUATION: MADAM is prepared to do the sensitivity analysis of the user's choice. A response of "C" results in a direct cumulative weight analysis. A response of "R" results in a direct relative weight analysis. "L" results in an attribute level analysis. "S" results in a system analysis. "E" will return control to the main option selection. Those prompts resulting from "C", "R", or "L" are given a postscript 'a'. Those prompts resulting from "S" are given a postscript 'b'.

RESPONSE-1: C, R, L, S, and E.

PROMPT-2a: ENTER NRN FOR WHICH <option> IS TO BE  
PERTURBED...  
ENTER NRN...?

SITUATION: MADAM is prepared to run a direct cumulative weight, relative weight, or attribute level analysis at the node which you select. An attribute level analysis may only be performed at a data node.

RESPONSE-2a: Enter NRN followed by "0" each digit followed by <cr>

PROMPT-3a: <options> ANALYSIS: T)ABULAR G)GRAPHICAL E)XIT

SITUATION: MADAM is establishing the desired output format. "G" results in prompt-7b, 8b. "E" returns control to main option selection. "T" repeats this prompt after table is generated.

RESPONSE-3a: "T", "G" or "E"

PROMPT-2b: WHAT SYSTEM IS TO BE ANALYZED?  
?

SITUATION: After displaying the alternative systems, the user is asked which system will be the one of interest.

RESPONSE-2b: System name

PROMPT-3b: WHAT TYPE OF ANALYSIS WOULD YOU LIKE TO DO...  
C)UMWT R)ELWT V)ALUE  
?

SITUATION: MADAM is prepared to do a sensitivity analysis on the system entered over a set of nodes. A response of "C" results in a cumulative weight analysis. "R" results in a relative weight analysis. "V" results in an analysis over the individual attribute level value.

RESPONSE-3b: "C", "R", or "V"

PROMPT-4b: HOW MANY NODES WOULD YOU LIKE TO EXAMINE? (1-50)  
?

SITUATION: MADAM is preparing to store the node set over which to do the system analysis.

RESPONSE-4b: An integer between 1 and 50 followed by  
(use two digit format e.g. 2 --> 02)

PROMPT-5b: ENTER NRN FOR WHICH <option> IS TO BE  
PERTURBED...  
ENTER NRN...?

SITUATION: MADAM is storing the NRN's associated with the nodes of interest. This prompt will be repeated until as many nodes as were specified in prompt-4b are stored.

RESPONSE-5b: Enter NRN followed by 0 each digit

PROMPT-6b: SYSTEM ANALYSIS: T)ABULAR G)GRAPHICAL E)XIT  
?

SITUATION: The user is being asked for the desired format. "G" will result in prompt-7b, 8b. "E" returns control to main option selection. "T" repeats this prompt after table is generated.

RESPONSE-6b: "T", "G", or "E"

PROMPT-7b: GRAPHICAL ANALYSIS N)ORMAL E)XPANDED  
?

SITUATION: MADAM is asking whether the overall value axis should go from 0-100 (normal) or from lowest to highest computed value (expanded).

RESPONSE-7b: "N", or "E"

PROMPT-8b: (PRESS ANY LETTER TO CONTINUE)  
?

SITUATION: MADAM is done with graph. Control is returned to prompt-6a, or 6b.

RESPONSE-8b: Any letter

OPTION: SPA (SPAN hierarchy)

USE: This option is used to construct an objective hierarchy. It is called automatically by option \*\*\*NEW\*\*\*. It may be invoked directly.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

1. ANY PREVIOUS DESCENDANTS OF A NODE ARE LOST IF A DESCENDANT IS ADDED TO THE NODE OF PREVIOUSLY STORED DATA FILE. TO ADD NODES TO A PREVIOUSLY STORED DATA FILE. TO ADD NODES TO A PREVIOUSLY STORED NODE, WITH OTHER DESCENDANTS, USE OPTION \*\*\*ADD\*\*\*.
2. A MAX OF 9 DESCENDANTS FROM ANY NODE IS ALLOWED.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

PROMPT-1: SPANNING NODES: A)LL S)ELECT  
?

SITUATION: MADAM is ready to start building the objective hierarchy. "A" results in starting to build at a hidden master node (first node entered becomes the root node). "S" results in prompt 1-a.

RESPONSE-1: "A" or "S"

PROMPT-1a: ENTER NRN...?

SITUATION: MADAM is allowing you to enter the node which will be the start of the building process.

RESPONSE-1a: Enter NRN followed by "0" each digit followed <cr>

PROMPT-2: DO YOU WISH TO BUILD A NEW TREE, <user name>? (Y/N)  
?

SITUATION: MADAM is giving the user one last chance to exit this option without changing the currently stored data file. A negative response will return control of the program to the main option selection.

RESPONSE-2: "Y" or "N"

PROMPT-3: DO YOU WISH TO BYPASS THE BETWEEN NODE CHECK?

SITUATION: MADAM allows the user to examine the set of sub-objectives entered before proceeding to the next parent node. If the user has a previously constructed tree or time constraints, it may be desirable to bypass the review. Only a response of "Y" will result in a bypass.

RESPONSE-3: "Y" or any letter

PROMPT-4: <user name>, WHAT IS THE NEXT SUBOBJECTIVE?  
(USE NO MORE THAN TWO 80 CHARACTER LINES)  
?

SITUATION: MADAM is prepared to add a new code. If an entry is desired, any non-blank character must appear within the first 10 characters. Entering a null string will cause a repeat of this prompt with a new parent objective if the response to prompt-3 was "Y", otherwise the following prompts result. Entering a valid string causes this node to be generated. This prompt is repeated with the same parent node.

RESPONSE-4: Any character string or null string

PROMPT-5: <user name>, DO THE SUBOBJECTIVES ADDRESS ALL FACETS OF THE PARENT OBJECTIVE? (Y/N)  
?

SITUATION: The response to prompt-3 was something other than "Y" so the between node check is in progress. The same situation and "Y" or "N" response is for prompts 5-8, so they will not be repeated. A response indicating a problem with the subobjective results in the automatic invocation of PRUNE or ADD as appropriate. Control is returned to prompt-5 if this occurs.

RESPONSE-5: "Y" or "N"

PROMPT-6: IS THERE ANY OVERLAP BETWEEN THE COVERAGES OF THE SUBOBJECTIVES, <user name>? (Y/N)

PROMPT-7: <user name>, ARE ALL THE SUBOBJECTIVES OPERATIONALLY MEANINGFUL TO YOU? (Y/N)  
?

PROMPT-8: COULD ANY OF THE SUBOBJECTIVES BE IGNORED WITHOUT SIGNIFICANTLY IMPACTING YOUR PREFERENCES, user name ?  
?

(At this point control is returned to prompt-4 with a new parent objective. This is repeated until no new parents exist. Then control is returned to the main option selection if \*\*\*SPA\*\*\* was called directly, otherwise control is shifted to option \*\*\*ATT\*\*\*.

OPTION: STA (STatus of hierarchy)

USE: This option is used to check how many nodes are being used, how many levels are in the hierarchy, and how many alternative systems are in memory. Note that the number of nodes shown by this option will not agree one-for-one with size of the problem at hand, but will reflect internal mechanisms of MADAM. Thus it is this number of nodes rather than the problem size which must be kept under 500. There are no cautions or prompts associated with this option. Control is returned to the main option selection if \*\*\*STA\*\*\* is called directly. It is called automatically by \*\*\*SPA\*\*\* if the between node check is being used.

OPTION: SYS (SYSem entry)

USE: This option is used to enter or modify the list of alternatives under consideration. It may be called directly. It is called automatically when using \*\*\*NEW\*\*\*.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

1. AT LEAST ONE SYSTEM MUST BE ENTERED BEFORE MANY OTHER OPTIONS MAY BE USED.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

PROMPT-1: YOU ARE AT THE POINT WHERE YOU WILL BE ENTERING THE ALTERNATIVE SYSTEMS WHICH WILL BE RANKED IN TERMS OF PREFERENCE. PLEASE CHOOSE THE APPROPRIATE OPTION  
A)DD D)ELETE N)EW E)XIT

SITUATION: MADAM is ready to deal with the set of alternatives. Response "N" must be used at least once before the other responses are used. Use of "E" returns control to the calling routine. If called as a part of \*\*\*NEW\*\*\* use response "N".

RESPONSE-1: "A", "D", "N", or "E"

PROMPT-2a: ENTER SYSTEM <nsys> LABEL...  
?

SITUATION: Response-1 was "A". MADAM is ready to add a new alternative to the list. Entering a null string returns control to prompt-1. Any other response repeats prompt-2a with the new system added.

RESPONSE-2a: Any character string (truncated to 10 characters) or null string

PROMPT-2b: WHAT SYSTEM IS TO BE DELETED...  
?

SITUATION: Response-1c was "D". MADAM is prepared to delete an alternative. Entry of a valid system causes deletion and return of control to prompt-1. A null string or invalid entry returns control to prompt-1.

RESPONSE-2c: System name or null string

PROMPT-2c: ENTER...SYSTEM <nsys> LABEL  
(10 LETTERS OR LESS)  
?

SITUATION: Response-1 was "N". MADAM is ready to add a new system to the alternative set. This prompt is repeated until a null string is entered. At that time return of control is at prompt-1.

RESPONSE-2c: Any character string or null string

OPTION: TTL (Title)

USE: This option is used to enter a title for the data structure. It may be called directly. It is invoked automatically by \*\*\*NEW\*\*\*. There are no cautions associated with this option.

PROMPT-1: ENTER A TITLE FOR THIS DATA STRUCTURE...  
?

SITUATION: MADAM is ready to store a descriptive title to be used by the \*\*\*REV\*\*\* and \*\*\*NUM\*\*\* options. Entering anything but a null string for the first 10 characters will result in storage and the question mark to be repeated. This does not overwrite what was just input. This allows entry of more than one one-line of information. Enter a null string to exit this option.

RESPONSE-1: Any character string or null string

OPTION: WVC (Weights, Values, and Calculate)

USE: This option is used to enter the relative weights of the objectives, or the attribute levels of the alternatives, or to calculate the tree. It should be used after any modification to the data structure.

\*\*\*\*\* CAUTIONS \*\*\*\*\*

1. DO NOT USE "C" BEFORE USING OTHER OPTIONS

\*\*\*\*\* CAUTIONS \*\*\*\*\*

PROMPT-1: YOU MAY NOW ENTER WEIGHTS, VALUES, OR (RE) CALCULATE THE TREE. CHOOSE YOUR OPTION.  
W(EIGHT V(ALUES C(ALCULATE E(XIT  
?

SITUATION: MADAM is prepared to deal with the numerical aspects of the problem. "E" returns control to the main option selection. Prompts associated with "w" have a postscript of "a". Prompts associated with "v" have a postscript of "b". There are no prompts associated with "c". Control automatically returns to the main option selection after using "c".

PROMPT-2a: WEIGHTS: A(LL S(ELECT  
?

SITUATION: The user is asked whether or not the whole hierarchy is to be weighted. "S" results in prompt-2a.

RESPONSE-2a: "A" or "S"

PROMPT-2aa: ENTER NRN...?

SITUATION: MADAM is asking for the node which will be the parent of the first span to be weighted.

RESPONSE-2aa: Enter NRN followed by 0 each digit followed by <cr>

PROMPT-3a: DO YOU WISH TO ENTER THE RELATIVE WEIGHTS DIRECTLY, (Y/N) ?

SITUATION: The user is being asked to enter the relative weights of a specified node set. Prompts associated with "Y" have the postscript "a1", prompts associated with "N" have the postscript "a2".

RESPONSE-3a: "Y" or "N"

PROMPT-2a1: WHAT IS THE WEIGHT FOR FACTOR <n>  
?

SITUATION: The user is entering the relative weights directly. The numbers entered should be such that their ratios of relative importances of the factors. The inputs will be normalized by MADAM to sum to 100 across the span. This prompt is repeated for all factors in the span.

RESPONSE-2a1: A real number followed by

PROMPT-2a2: ENTER THE NUMERATOR OF THE RATIO...  
?

SITUATION: The user is inputting weights through a pairwise comparison matrix between factors on the span. MADAM computes the weights as the normalized geometric mean vector across the rows of the pairwise-comparison matrix. One of the following numbers should be entered as the numerator or the denominator (prompt not shown) of the ratio. The other element of the fraction should be 1.

| <u>Number</u> | <u>Meaning</u>                |
|---------------|-------------------------------|
| 1             | equally important             |
| 3             | more important                |
| 5             | much more important           |
| 7             | very much more important      |
| 9             | overwhelmingly more important |

2,4,6,8 provide intermediate values  
See Saaty (1980) for a more detailed discussion.

RESPONSE-2a2: 1 or digit between 1 and 9

PROMPT-4a: ARE YOU HAPPY WITH THESE RELATIVE WEIGHTS? (Y/N)  
?

SITUATION: MADAM is verifying the normalized relative weights. A negative response returns control to prompt-3a with the same node set.

RESPONSE-4a: "Y" or "N"

PROMPT-5a: ENTER COMMENTS ON THESE WEIGHTS...  
?

SITUATION: The user is invited to enter rationale about the relative weights. This is similar to the \*\*\*TTL\*\*\* option and these comments will appear in \*\*\*NUM\*\*\* output. Control is returned to 3a with a new span.

RESPONSE-5a: Any character string or null string

PROMPT-2b: VALUES: A(LL S(ELECT  
?

SITUATION: MADAM is asking whether system attribute levels will be entered for all data nodes. "S" results in prompt-2bb.

RESPONSE-2b: "A" or "S"

PROMPT-2bb: ENTER NRN...?

SITUATION: MADAM is asking for that node where attribute levels will be input. This node should be a data node.

U  
RESPONSE-2bb: Enter NRN followed by 0 each digit followed by

PROMPT-3b: WHAT IS THE NEW LEVEL (REAL NUMBER)?

SITUATION: MADAM is asking for the attribute level of the current system for the given attribute. This prompt is repeated for each system at one node.

RESPONSE-3b: Real number

PROMPT-4b: ENTER COMMENTS ON THESE ENTRIES...

?

SITUATION: Similar to prompt-5a but it applies to the input attribute levels. Control returns to prompt-3a with a new node.

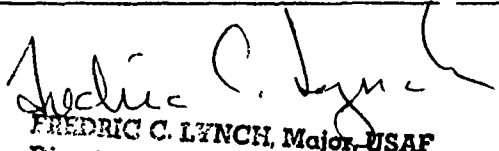
RESPONSE-4b: Any character string or null string

### VITA

Wayne Alan Stimpson was born on 22 September 1957 in Laconia, New Hampshire. He graduated from St. Paul's Preparatory School in Concord, New Hampshire in 1975 with honors in science. He attended the University of Vermont, from which he received the degree of Bachelor of Arts in 1981 after completing a double-major program in psychology and mathematics. For his undergraduate work, he was elected into Who's Who among Students in American Universities and Colleges. Mr. Stimpson entered the Air Force through the AFROTC program as a distinguished graduate. His first assignment was to complete a Master of Science (Operations Research) at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio. For his work as a graduate student, Mr. Stimpson was elected into honor societies for engineering (Tau Beta Pi) and the decision sciences (Alpha Iota Delta). After completing the degree program at AFIT in December, 1981, he began an assignment at Foreign Technology Division, also at Wright-Patterson Air Force Base.

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| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                             | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM                    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|----------------------------------------------------------------|
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| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>Multiple-Attribute<br>Decision Analysis<br>Computer Aid<br>Preference<br>Value<br><br>APPROVED FOR PUBLIC RELEASE AFR 190-17.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                             |                                                                |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>The complex multifaceted decision situations present today suggest the need for a timely, automated tool. A decision-maker is forced into comparing alternative actions or systems over an entire set of different measures of merit. This effort is an on-line, real-time, computer-based decision aid designed to assist the decision-maker in clarifying preferences in a complex decision environment. It is applicable to problems which may be represented by a hierarchy of objectives to be satisfied. The program is MADAM: Multiple-Attribute Decision Analysis Model, and it is written in FORTRAN V and is implemented on the CYBER 175 |                                             |                                                                |

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system. MADAM is designed to aid the decision-maker as he or she progresses through problem formulation, parameterization, sensitivity analyses, and a decision, including storage of all data and rationales. Deterministic problems are analyzed through Multi-Attribute Utility Theory concepts and an additive value function is utilized for sensitivity analysis. Pairwise preferential independence is tested between attributes. The sensitivity analyses include a cumulative weight analysis, a relative weight analysis, and an attribute level analysis. The analyses may be conducted by fixing an objective to be considered and conducting the analysis across the alternative systems or actions, or conversely by fixing the alternative to be considered and conducting the analysis across a desired set of objectives.

The work is divided into two volumes. Volume I is a theoretical presentation and includes a user's manual. It requires no programming expertise and may be used independently of Volume II. Volume II is a programming manual including the source code. It may not be used independently of Volume I.

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