THE EXTENDED
MULTI-ATTRIBUTE DECISION
ANALYSIS MODEL (EMACAM)

TECHNICAL REPORT

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SCHOOL OF ENGINEERING
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE, OHIO
THE EXTENDED MULTI-ATTRIBUTE DECISION ANALYSIS MODEL (EMADAM)

Capt. Aaron R. DeWispelare*

Abstract

This research is an on-going effort to produce an interactive, computer-based aid suitable for use in decision situations and long-term planning. The current research involves the development of extensions to the applicability of a decision aid embodied in the computer program MADAM: Multi-Attribute Decision Analysis Model. The theoretical underpinnings of MADAM involve portions of multi-attribute utility theory. This interactive program is designed to aid the decision-maker in all phases of decision analysis from problem formulation to sensitivity analysis. The program is a tool designed to be used by a decision-maker in order to facilitate making rational and consistent trade-offs and subdecisions throughout the entire decision-making process. The stages of the decision analysis covered by the program include formation of an objectives hierarchy, elicitation of an appropriate set of attributes, examining the relationship between the attributes, establishing criterion weights, evaluating candidate solutions, and performing several types of sensitivity analysis.

The significant changes in the model involve the stages of examining the relationship between the attributes and of incorporating probabilistic data and utility concepts. In the previous version of MADAM, the program guides the decision-maker in determining whether or not the condition of mutual preferential independence is met. This determination is important because the previous version of the program is designed to handle the case of deterministic attributes (measurable value analysis) where an additive value function is the appropriate overall value function. The extensions allow MADAM to be utilized for the case of probabilistic attributes (utility analysis). The extended program aids the decision-maker in conducting lottery trade-offs so that independence conditions necessary to use an additive utility function can be ascertained. The utility analysis parallels the former value analysis in structure. MADAM maintains all previous capabilities for sensitivity analysis as well as the new utility analysis capabilities.

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1. Introduction

Decision situations are becoming increasingly complex due to the desire by decision makers to have as much information as possible with which to resolve the situation. This desire for increased quantity and quality information has encouraged analysts to attempt to quantify previously qualitatively addressed concepts and to utilize increasingly robust models to more realistically describe the world. Because of complications in gaining access to the decision maker (DM), in presenting data, and in interpreting the data, a very thorough analysis may never be used or inefficiently used in the resolution of a decision situation (7,6,11). It is hypothesized that it would be beneficial to develop tools to help the DM prioritize salient attributes and quantify preferences in an easily usable format. One technological boom which can help achieve this objective is the availability of inexpensive, computationally capable, and conveniently small computers (15). These computers can manage and display data pertinent to a decision situation, and they can be used in real-time sessions with an individual DM or a group of decision makers.

One tool which has been developed is the software package (MADAM, 16, 17). This computer program is similar to other interactive decision aids which attempt to automate value (deterministic utility) structure elicitation from the DM (4,10,15). The program MADAM approaches a decision situation from a multiple attribute value theory paradigm. It attempts to guide an analyst and/or DM through the steps of structuring the problem in terms of objectives and attributes, quantifying the DM's preferences, evaluating candidate solutions, and performing sensitivity analysis with respect to the preference structure and alternative realizations of candidate solutions. The current capability of this interactive program is conducting a value elicitation (deterministic in nature) with a DM concerning the attributes and candidate solutions for a decision situation, and allowing for several types of sensitivity analyses.
Among applications which are appropriate for utilizing a program like MADAM are evaluation of competing alternatives, ranking of projects, and the testing of the robustness of a solution. As an example, the government could use this program as a decision aid in prioritizing research projects within budgetary constraints. Annually, there are a certain amount of funds left to the discretion of government laboratory managers for dispersement into appropriate research efforts. The universal problem that these DM's face is that there are apparently more deserving projects than resources to adequately fund them. Government DM's could use the decision aid MADAM to evaluate these projects and resolve their dilemma. A major deficiency which is noted in using programs like MADAM is the inability to account (explicitly) for the probability of achieving particular attribute levels among the various projects. The ability to incorporate risk when using decision support software would expand its usefulness because of the need to differentiate among alternatives which are non-deterministic in nature.

This paper describes and motivates the implementation of the modifications to the computer program MADAM. These modifications expand the capability of the computer automated decision aid by allowing for the incorporation of risk and subsequent utility aspects of candidate solutions. The incorporation of the DM's attitude toward risk in a Multiple Attribute Utility Theory (MAUT) model is discussed in Section 2. The actual computer program modifications developed and then implemented in code (FORTRAN) on a mainframe computer are described in Section 3 (See also Appendix A). The modified decision aid program allows interactive operation and contains graphics capability for rapid feedback to the analyst and DM. Section 4 (and Appendix B) delineates a hypothetical application of this decision tool which concerns the prioritization of various types of government research projects by a DM. The primary aim of this effort is to expand the capabilities of MADAM to explicitly address and incorporate elements of risk. The second aim of this effort is to illustrate how this new expanded decision aid may be applied to the government research project prioritization problem.
2. Multiple Attribute Utility Theory

MAUT is widely used in decision situations which involve event outcome uncertainty (2,7,11,12,14). These events have associated with them outcome probabilities formed from either empirical data, or subjective data obtained from expert opinion. The objective of MAUT is to find a scalar scoring function (SSF) which will map each alternative in the decision situation onto the real line, and in the process form a complete ordering (ranking) of all alternatives. For the case which involves uncertainty, the objective is to find the alternative which maximizes the expected utility of the DM. For the discrete cases, this is given by

\[
\text{Maximize } e(u) = E \sum_{j} p_j(a_{ij})u(z_{ij}(a_{ij}))
\]

over each alternative \(a_{ij}\) where \(E\) is the expectation operator, \(p_j\) is the probability of the \(j^{th}\) event outcome, \(z_{ij}\). The SSF, \(u\), is a utility function which incorporates the DM's attitudes toward risk. This function can be formed by combining the salient attributes of the decision situation into a single attribute and then transforming it to a utility function incorporating risk (3), or by use of decomposition techniques which form constituent utility functions for the salient attributes and then aggregating these into a scalar function. Many authors including Keeney and Raiffa (11) describe assessment procedures for this latter method which enable one to discern the mathematical form of \(u\) and to identify scaling parameters based on the relationships among the attributes. This latter method is used to build the models described in Section 3. The alternative policies, events, outcomes and associated probabilities in a MAUT formulation can usually be displayed in a decision tree format such as the simplified single state tree shown in Figure 1. A general algorithm of the MAUT process is shown in the DELTA chart of Figure 2.

2.1 Computerized MAUT

Computers have the potential to significantly enhance the assessment of multiple attribute utility and value functions. This has been demonstrated by recent research
Figure 1. Single Stage Decision Tree Representation Of The Decision Situation
DM decides to use XAUT to resolve the decision situation

DM and analyst
Identify pertinent stakeholders in the decision situation

DM, analyst, and stakeholders
Define the problem and identify the value system through DM, analyst, and stakeholder interaction

DM, analyst and stakeholders
Define an appropriate set of objectives and attributes measures, and elicit preference information to establish relationships between the attributes

DM and analyst
Define alternative policies to resolve the decision situation and develop linkages between the alternatives and event outcomes (this may include encoding of uncertainty over the event outcomes)

DM and analyst
Select a number of alternative policy forms to become the actual decision options

DM
Are the policies implementable?

YES

NO

Analyst
Refine or tune the alternatives as needed using an appropriate optimization technique

DM
Evaluate and rank alternative policies based on the DM's scoring function to identify the optimal policy

Analyst
Conduct a sensitivity analysis to identify modeling errors

DM and analyst
Evaluate the solution obtained

DM and analyst
Prepare an action plan for implementation of the selected policy

Figure 2. DELTA Chart For XAUT Process With Uncertain Outcomes
in the case of a single decision maker (10) and also in the case of group decision-making (15). The development of the previous computerized assessment packages have fallen short in many areas. These deficiencies include: 1) the failure to incorporate the DM's attitude toward risk on an individual attribute basis; 2) the lack of a systematic way to incorporate descriptions of the candidate alternatives in terms of stochastically based raw attribute data; 3) the lack of immediate feedback to the DM of the implications of his preferences; 4) the lack of an efficient procedure to update DM preferences and conduct sensitivity analysis. The computer program MADAM originally did a satisfactory job of assessing value functions and evaluating alternatives with deterministic outcomes. It did not ameliorate the first two previously mentioned deficiencies concentrated around the incorporation of the elements of uncertainty in a decision situation. However the structure of MADAM made it attractive to modify the program by adding several subroutines which allowed all of the aforementioned deficiencies to be appropriately addressed and resolved in the context of risk and utility. Section 3 describes the specific models and accompanying procedures which are implemented in structured subroutines on the digital computer.

3. Utility/Risk Incorporation Into MADAM

3.1 Previous Capabilities of MADAM

MADAM was designed for a complex decision making environment which exhibited characteristics of Type I and Type III problems of Figure 3. The modifications in this effort which incorporated utility concepts into MADAM are intended to allow for solutions to decision problems of Type II and IV. Originally, a DM/analyst was able to use MADAM to conduct interactively a problem formulation phase, the formation of an appropriate value function, and a sensitivity analysis phase. The DELTA chart of Figure 4 shows the program flow for the problem formulation phase of MADAM. In the problem formulation phase, the DM is guided in the construction of an objectives hierarchy which is designed to define issues of concern; limit the
<table>
<thead>
<tr>
<th>Outcome Under:</th>
<th>Single Attribute</th>
<th>Multiple Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certainty</td>
<td>Type I</td>
<td>Type III</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Type II</td>
<td>Type IV</td>
</tr>
</tbody>
</table>

Figure 3. MAUT Formulation Typology
Figure 4. Problem Formulation Phase of MADAM
problem to a tractable size, and identify operational variables or attributes. Additionally, the problem formulation phase establishes an appropriate range of realization levels for each attribute, and characterizes a feasible set of candidate solutions or alternatives in terms of these attributes. There is graphics capability for the appropriate timely feedback of the objectives hierarchy and attribute set to the DM.

The next phase of MADAM explores relationships among the attributes in attempting to establish mutual preferential independence (MPI), and then establishes constituent scoring or value functions for the individual attributes. MADAM uses the weakened sufficiency conditions (12) of pairwise preferential independence (PPI) to explore the existence of MPI. MPI among attributes is both necessary and sufficient for justifying use of the additive form of value function.

\[ V(x) = \sum_{i=1}^{n} W_i \cdot v_i(x_i) \]  \hspace{1cm} (2)

where \( V(x) \) is the scalar value function, \( v_i(x_i) \) is a constituent value function of an individual attribute \( x_i \), and \( W_i \) is a scaling constant reflecting the relative criterion weight of attribute \( x_i \) compared to the other attributes. Currently MADAM only has the capability of utilizing an additive form of \( V(x) \), but caveats are issued automatically if MPI cannot be established warning the DM/analyst of possible error in scoring and ranking the alternatives. The individual value functions are next established using the midvalue splitting technique (11). Once the individual value functions are established, graphical display to the DM of these functions is used to verify their form. Next the scaling constants or criterion weights are elicited using the ratio technique (5,13). Now all parts of the SSF, \( V(x) \), are present for evaluation and ranking of each candidate alternative.

Figure 5 shows a DELTA chart of the value function establishment phase.

Sensitivity analysis is performed in the next and last phase of MADAM. Sensitivity to criterion weight changes for upper level nodes and attributes (data nodes) for all alternatives or any alternative individually, and to attribute levels at a particular node for each alternative explored in this phase.
Assume PPI Among Attributes?

DM/Analyst

Use Regression Analysis To Fit Value Functions For Ease Of Data Handling

DM/Analyst

Graphically Display Value Functions

DM/Analyst

Elicit Criterion Weights For The Nodes Of Objectives Hierarchy

STOP

Score And Rank Alternatives

Go To Sensitivity Analysis Phase

Figure 5. Value Function Phase of MADAM
There is a graphical presentation of the resulting alternative's scores due to the variation of parameters.

In all three phases, only deterministic attribute levels for the alternatives are permissible as input. Also no attempt is made to incorporate the DM's attitude toward the risk involved with each alternative. In the resulting sections, the modifications to MADAM are described which ameliorate these weaknesses.

3.2 Modifications/Current Capabilities of Extended MADAM: EMADAM

The incorporation of stochastic data for alternatives under evaluation and the DM's attitude toward this risk in a utility function was accomplished in three steps: (1) model and implement a protocol for exploring relationships among attributes in terms of utility concepts, 2) model the incorporation of risk into the DM's value function and establishing a protocol for assessing utility functions accompanied by graphical display of these utility functions, 3) model the combination of individual utility functions into a global utility function and then provide a description and subsequent evaluation of candidate alternatives in terms of the risk containing utility development and provide for the inclusion of probabilistic attribute data.

Attribute Relationships

In order to establish a mathematical basis for using a specific utility function with which to score and subsequently rank alternatives, relationships among the attributes must be examined with respect to both the DM's preferences over the attributes and attitude toward risk. A manual approach for checking for Mutual Utility Independence (MUI) among attributes is described by Keeney and Raiffa (11). This approach using PPI and utility independence (UI) for checking for MUI was developed into an algorithm and implemented in a new Subroutine called UPI (Appendix A-3). The flow in UPI is shown in Figure 6.

MUI is both a necessary and sufficient condition for using the multiplicative form of utility function and it is also a necessary condition for using the additive form of utility function as shown in Equation 3 below (11):
DM/Analyst
Assume MUI
Among Attributes

START

DM/Analyst
Test For PPI
Among Attributes, See
Figure

PPI
Established
Among All
Attributes

Yes

No

Caveat
Issued

DM/Analyst
Test For UI Of
Appropriate Attribute

MUI
Established
Among All
Attributes

Yes

No

Caveat
Issued

DM, Analyst
Continue With
Effort Using
Additive Form
Of U

STOP

OR

Go To Utility
Assessment Phase

Figure 6. Flow of Subroutine UPI
where \( u_i(x_i) \) represents a constituent utility function, \( u_i \), which is a function of a single attribute, \( x_i \); and \( k_i \) represents the criterion weight or scaling constant corresponding to \( u_i(x_i) \), and \( U \) is the combined utility function for all attributes. The additive form of \( U \) is used in this effort since it is the form that applications have shown to be very often justified (11). Sufficient conditions for using the additive form of \( U \) are the establishment of Fishburn Marginality but these conditions can become intractable for any practical application where the number of attributes is greater than two (7,11). Caveats are issued if MUI cannot be established and the DM/analyst is given the choice of stopping the analysis or continuing with the knowledge that some error is possible.

Utility Function Assessment

Because MUI is either established or assumed in subroutine UPI, individual utility functions can be established as functions of single attributes. The most common approach for incorporating the DM's attitude toward risk and preference simultaneously is through a simple lottery. Figure 7 shows the construction of a simple lottery where the DM is asked to trade a chance at two outcomes in terms of a single attribute for a minimum amount of the same attribute for certain. This amount is called the certainty equivalent of the lottery (22). The utility of this certainty equivalent can be seen to be equal to the expected utility of the lottery which is calculated using Equation 1. A series of questions in the form of lotteries can define a utility curve for a single attribute. In the assessment process, the probabilities are held constant, and the outcomes are varied. A series of questions in the form of lotteries can define a utility curve for a single attribute. In the assessment process, the probabilities are held constant, and the outcomes are varied. While there may be some drawbacks in using the lottery technique (4), it is by far the most often used technique for assessing a DM's utility (2,11,12). This lottery technique was developed into an algorithm and implemented in Subroutine UTIL.
For Each Attribute, Establish Points On A Utility Curve Using A Lottery Approach

Use Regression Analysis To Fit Utility Functions For Ease Of Data Handling

DM/Analyst

Graphically Display Utility Function

Go To Criterion Weights Determination Phase

DM, Analyst

Regression Acceptable?

Figure 8. Flow of Subroutine UTIL and Adjoining Modules

If A>B>C
then

\[ p = \frac{1}{A} \]

for some \( p \)

Figure 7. Simple Lottery
Appendix A2).

The points of the constituent utility curves just determined are curve fit using a least squares criterion for five forms (exponential, quadratic, linear, logarithm, and square root). The closest fit of the regression attempts is parameterized for ease of data handling for all utility curves. The regression results and error are displayed to DM/analyst. The individual utility functions are graphically presented for the DM/analyst. This visual feedback will corroborate the risk averseness characteristic of each utility curve for each attribute as a consistency check. Subroutines PICTUR and RDATT were modified to accomplish the last two major steps. Figure 8 shows the flow of the utility function assessment.
Probabilistic Data Inclusion/Expected Utility Calculation

The strength of the utility theory approach to decision theory is the ability to take into account the realistic risk associated with levels of the attributes (outcomes occurring in the future) for each alternative. In order to allow for ease of interfacing with the digital computer, the Subroutine RDV (Appendix A-4), asks the analyst to input discretized or spike probability distribution data corresponding to levels of the attributes. A maximum of ten discrete probabilities are allowed for each attribute per alternative. Checks are included to insure that these discrete probabilities are collectively exhaustive. The resulting probability distributions are displayed graphically through Subroutine DRWPRB (Appendix A-6).

The expected utility for each attribute for each alternative is now calculated in Function CONVLT (Appendix A-5) by forming the linear sum shown in Equation 1. Constituent utility values corresponding to the discrete attribute levels just entered are calculated from the previously determined utility curves. These utility values are multiplied by the corresponding probability of occurrence for each attribute. The resulting expecting utilities for each attribute are combined with the previously described scaling constants to produce the linear sum of Equation 3. This results in a combined utility score for a simple alternative. The flow of the data entry and utility calculation phases are shown in Figure 9.

This process is repeated for each alternative. The set of alternatives are ranked and the respective combined utility scores displayed.

The example presented in Section 4 and Appendix B demonstrates the use of the newly enhanced decision aid MADAM for a problem involving probabilistic data and utility concepts.
DM/Analyst
Enter discretized probability distributions for each attribute for each alternative

Calculate the Expected Utility Attribute of Each Alternative by convolving the appropriate formerly determined utility functions with the discrete probability distributions

Score Each Alternative by forming the weighted sum by combining the expected utility with the scaling constants previously determined

Rank the Alternatives in terms of the combined utility score

Go To Sensitivity Analysis Phase

Figure 9. Data Entry/Utility Calculation
4. Prioritizing Research Projects - An Application of EMADAM

4.1 Problem Definition

The Department of Defense (DOD) philosophy on funding initial research and development (R and D) programs (also called "new starts") is to commence efforts in many areas, but only fund the advanced development and eventual procurement of the few efforts that are the most successful, potentially fruitful, or vitally needed (18,19,20,21). Many government laboratories are apportioned a certain amount of funds to start new R and D projects. Unfortunately there is always insufficient funding to cover all the attractive R and D projects. The problems faced annually by the government research executives are how to rapidly and appropriately prioritize the new R and D efforts. A tool like EMADAM allows the DM and analyst or advisor to work through each phase of the prioritization in an informed and timely manner. This allows for not only a ranking of the projects, but also a more thorough understanding of the process by the parties involved.

To serve as an example of a possible use of EMADAM, a hypothetical application concerning R and D project prioritization is now presented. Appendix B gives an interactive listing of this application of the research project prioritization.

4.2 Attributes

An objectives hierarchy was established for this decision situation (Appendices B and D). The measures of attainment of the lowest level objectives are the attributes for this problem. Four attributes were identified as salient in this decision situation. They are (1) technology base, (2) sponsorship potential, (3) cost, and (4) time to project fruition.

The "technology base" attribute addresses the issue of being able to successfully produce a solution for identified needs as opposed to just expanding the technological base in an area. The end objective of each R and D project is evaluated as to the existing technological base as well as estimated difficulty in achieving the end objective. A ten point scale is used to rate each project
(Appendix C) from the extremes of no technology base and extreme difficulty in achieving research objective to simply a new use of existing well developed technology with little difficulty in achieving end objective. Each project is rated based on an extensive literature search of existing technological bases and expert opinion with respect to difficulty in meeting the research objective within five years. In all cases where expert opinion is used to refine attribute levels, a Delphi exercise is used to achieve consensus (13). There is some uncertainty associated with the estimates of the technology base obtained from expert opinion.

The "sponsorship potential" attribute is aimed at ascertaining the number of potential major organizations which will commit funds toward advanced development and pre-production testing. This attribute is used as the primary indicator of the importance of the deficiency or need addressed by a project. Zero through five major organizations is the range of this attribute. Surveys with the potentially interested major organizations are the primary source of data for this attribute for each project. Because some organizations withhold their commitment of funds until some future point in time, there is some uncertainty as to the exact number of sponsoring organizations.

The attribute of cost seems to be the most straightforward attribute but modifications of the yearly costs must be made to establish a common time basis for the research projects. All research budgets are made on a five-year planning cycle as dictated by Congress. Because projects are generally funded for all five years once they are started, this period is used as the absolute maximum time allowed for each project to reach the identified research objective. Therefore, each project is budgeted so that the research objective can be achieved in five years. The highest cost project is used as the basis or standard and all other projects are allotted the same annual amount. This step resolves the arbitrary nature of funding and puts all projects on the same effective-budget schedule. The fact that many projects would be accelerated and produce
Its faster than usual at the basis funding level allows project differentiation in the next attribute to be discussed, which is "time to project fruition." This equalizing of the proposed annual budgets for the projects allows the attribute "cost" to be dropped from analysis so as not to double count its effect. This reduces the number of attributes, and makes the decision situation more tractable in quantitative terms.

The "time to fruition" attribute indicates the actual time (less than or equal to five years) for the R and D project to produce significant results (i.e. achieve the research objective). Because many projects will take less than five years to produce significant results at the equalized effective basis funding level discussed earlier, the combination of this attribute and cost will differentiate among the alternatives. Expert opinion and past research efforts are used to produce the estimates of time to fruition for each project. As with the other attributes, risk is involved in this estimate and therefore a distribution is appropriate for describing the attribute level achieved.

4.3 Alternatives

Five generic R and D projects were ranked in this effort. While these projects were hypothetical, they are very similar in characteristics to actual projects. These projects S, T, X, Y, and Z are described in terms of attribute data in Appendix B. Project S has the characteristics of an expected general project with low to average technology base (TB), a reasonable number of sponsors and an average time to successful results. Project T would be called an average development oriented project with a high TB, a few sponsors, and an average expected time to successful development. Project X is the high risk alternative with a low TB, only one sponsor, and a long expected time to fruition. Project Y has the characteristics of a typical research oriented project with a low to average TB, small number of sponsors and a long lead time to successful results. The final alternative, Project Z, is often called a "sure bet" because it has characteristics that almost always assure success in an average amount of time such as a high TB and many sponsors. The specific
attribute values and accompanying probability distributions are shown in Appendix B.

4.4 Results

A government DM familiar with the R and D funds allocation problem was used in this effort to add realism to this example. The objectives hierarchy, attributes, criterion weights (scaling constants), relationships among the attributes, and individual utility functions were all established by the DM in realistic sessions utilizing EMADAM. Appendix B contains an abbreviated but representative listing of the output for this example.

The DM established the objectives hierarchy (Appendix D) which led to the attributes discussed earlier and listed in Appendix B. The DM was able to establish MUI among the attributes which are necessary conditions justifying use of individual utility functions of individual attributes, and the additive form of SSF (Appendix B). The individual utility functions were elicited from the DM (Appendix B), and as expected all indicate an aversion toward risk with respect to all attributes. The utility functions for "time to fruition" and "number of sponsors" displayed the most risk aversion. The criterion weights established by the DM indicate the "number of sponsors" willing to support development (an indication of need, $W_2 = 50$) is almost twice as important as either "time to fruition" ($W_3 = 30$) and TB ($W_1 = 20$) in prioritizing alternative projects (Appendix B). Of course these weights (scaling constants) may only be valid for the ranges of the attributes considered (11).

The calculated expected utilities for the five projects (Appendix B) are as follows: $U$ (Project S) = 64.20, $U$ (Project T) = 64.68, $U$ (Project X) = 27.15, $U$ (Project Y) = 53.74, $U$ (Project Z) = 65.01. On a 100 point normalized scale, some significant differences are evident. Project Z clearly dominates Projects X and Y, but outdistances Projects S and T by only 1%. The usefulness of a quantitative decision aid such as EMADAM is not only in the absolute ranking of the alternatives, but also in the relative differences between alternative project scores. While not a specific objective of this effort, extensive
sensitivity analysis is available with EMADAM as an aid to the DM, and for this example clearly needed to differentiate projects S, T, and Z.

4.5 Computer Utilization Summary

A listing of the routines developed in this effort (ASKU, UTIL, UPI, DRWPBR, CONVLT, and RDV) is provided in Appendix A. These routines are written in FORTRAN V and all graphics capability is compatible with any common alpha-numeric terminal. In addition to the routines coded, many other subroutines in MADAM were modified to allow compatibility of both deterministic and probabilistic data. The subroutines modified were ATT, ASET, ATTSET, PICTUR, and RDATT. The enhanced version of MADAM (i.e. EMADAM) is now in excess of 5,6000 lines of code. EMADAM is segmented in overlays which at no time take more than 56,6000 bytes of memory. This reasonable memory requirement due to overlaying allows for interactive execution of the program. The CPU execution time is nominal for a reasonable size problem. This example problem took less than six seconds total. This example was performed on a CYBER 175 (CDC) system.

The interactive terminal time totaled approximately three hours for this sample. This time was accomplished with the DM in two sessions. The DM expressed satisfaction with the usability and commented on the ease of understanding the prompts provided by the enhanced MADAM program. The length of time required by the DM/analyst does not seem excessive when one considers the number of steps accomplished in the decision resolution paradigm.

5. Summary, Conclusions, and Recommendations

5.1 Summary

In this effort, several modifications to the decision analysis software tool MADAM (16,17) were accomplished. These modifications enhance this decision making aid by incorporating utility concepts and probabilistic data into the analysis process. The DM/analyst can still accomplish the setting of objectives and determination of attributes (Figure 4), and now has the choice and capability
of using an automated tool for exploring relationships among attributes, assess the DM's value or utility functions, and include attribute data for either the probabilistic or deterministic data case (Figures 5, 6, 8, and 9). Several computer codes were developed to implement the modifications accomplished here. These modifications are summarized in the following tasks:

1. model and code a protocol for examining utility and preference relationships among attributes (Subroutine UPI, Appendix A-3);
2. model and code a protocol for the incorporation of risk into the DM's value function and assess his/her utility functions along with graphical display of these curves (Subroutines ASKU and UTIL, Appendices A-1 and A-2);
3. model and code the inclusion of probabilistic attribute data for the alternatives along with graphical presentation of this data, the combination of individual utility functions into a global utility function employing an expected utility calculation, and the subsequent evaluation of the utility for each alternative (Subroutines RDV and DRWPRB, and Function CONVLT, Appendices A-4, A-6, and A-5).

5.2 Conclusions

Conclusions to be drawn from this effort:
- The enhanced version of MADAM (EMADAM) can effectively incorporate probabilistic data for the attributes of alternative systems under evaluation, and utility concepts (additive form of utility function) into a decision analysis.
- This type of decision aiding software tool is appropriate to project evaluations and selection problems such as the allocation of government research and development funds as demonstrated by the example in Section 4 and Appendix B.
- The usability of EMADAM appears acceptable as demonstrated on a moderately sized problem (Section 4, Appendix B). A DM, with or without an analyst can execute a decision analysis with EMADAM due to the interactive set of prompts presented by the software.
- The enhanced version of EMADAM is efficient in terms of computer memory required (less than 57K bytes due to over-laying), and in terms of CPU execution time (less than six seconds) for a moderately sized problem (Section 4, Appendix B).
The convenience of interactive operation is somewhat offset by the required
terminal time for the DM/analyst (approximately three hours for the example problem
delineated in Section 4, Appendix B).

5.3 Recommendations

Two recommendations are offered in response to this effort. First, expand
EMADAM to accommodate other forms of global utility functions besides the
additive form. The multiplicative form (11) would be a tractible function
which incorporates non-linearities in a decision situation. Second, develop a more
sophisticated procedure to assess the scaling constants (criterion weights).
Such a procedure should allow for more consistency checks without inducing
obfuscation (5,11).
REFERENCES


**Appendix A**

Computer Code Enhancements To MADAM

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**Appendix A-1**

SUBROUTINE ASKU1(X1, X2, XMID)

* THIS ROUTINE ASKS THE QUESTIONS WHICH ELICIT THE
* DATA POINTS FROM WHICH THE ESTIMATED INDIVIDUAL
* UTILITY FUNCTION MAY BE ESTABLISHED.

* CALLED BY: UTIL

* VARIABLES
  * USED: X1, X2, XMID

  MODIFIED: XMID

---

```
SAK
CHARACTER ATT(1)

1
DEF **

* WHAT LEVEL OF ATTRIBUTE *, ATT(1)*
* YOU WOULD TRADE FOR A LOTTERY*
* WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY*
* WITH A 50% CHANCE OF RECEIVING EITHER*
* THE UNIT OF ATTRIBUTE *, ATT(1)*
* OR ITSELF ?
*
READ(*, *(FL, L)) XMP
XM1 = AMAX(XM, XM1)
XM2 = AMAX(XM, XM2)
XM = (XM + XM) / 2
IF((XM > XM1) .OR. (XM < XM2)) THEN
    ** * OUTSIDE THE RANGE OF *XM* TO *XM*
    XM = XMP
    END
```

A-1
** Appendix A-2 **

SUBROUTINE UTIL

THIS ROUTINE GENERATES THE DATA POINTS FROM WHICH THE INDIVIDUAL UTILITY FUNCTIONS ARE ESTIMATED, AND CALLS ROUTINE REGRS TO DO THE ESTIMATION.

CALLED BY: LPI, DPRINT

VARIABLES USED: HATT, XMID

MODIFIED: CHI, VAL, X

COMM/ATR/ATT
COMM/VAL/VAL(3)
SAVE
CHARACTER CH, ATT(1:10)
PRINT * , *
PRINT * , THE UTILITY FUNCTIONS FOR EACH ATTRIBUTE *
PRINT * , WILL NOW BE DETERMINED *
PRINT * , *
PRINT * , DI = (DATT)

1 CALL ASKU(*, ATT(*,2), ATT(*,3), XMID)
VAL(1)=ATT(*,2)
VAL(3)=ATT(*,3)
VAL(3)=XMID
X=X:0
CALL ASKU(*, ATT(*,2), X, XMID)
VAL(3)=XMID
CALL ASKU(*, ATT(*,2), VAL(*,2), XMID)
VAL(*,2)=XMID
CALL REPS( )
PRINT * , *
PRINT * , THE ABOVE YIELDS A UTILITY FUNCTION FOR *, ATT(*,2)
PRINT * , WITH PARAMETER:
PRINT * , H1=*, PARAM(*,3)
PRINT * , L1=*, PARAM(*,3)
PRINT * , THE *
PRINT * , *
PRINT * , UTILITY FUNC.(ATTRIBUTE LEVEL)*
SChi=*, PARAM(*,2), H1=1, THE
PRINT * , U=*, PARAM(*,2), L1=0, THE
PRINT * , *

A-2
ELSE IF (PARAM(1,*).EQ.1.0) THEN
  PRINT*,'(SQUARED FC=4)*
  PRINT*,'(LOGARITHM FC=*')
  PRINT*,'(EXPONENTIAL FC=*')
  PRINT*,'(UTILITY=BC+B1*ATTRIBUTE LEVEL)*
END IF
CALL PICTJR(I)
PRINT*, 'DOES THE ABOVE REPRESENTATION APPEAR REASONABLE? (Y/N)'
READ(*,*)CH
IF((CH.EQ.'Y') .AND. (CH.EQ. 'N')) THEN
  PRINT*,'YOU MUST ENTER 'Y' OR 'N'.
  GD = 2
END IF
IF(CH.EQ. 'N') GO TO 1
CONTINUE
RETURN
END

** Appendix A-3 **
SUBROUTINE UPI

THIS ROUTINE CONDUCTS A TEST OF MUTUAL UTILITY INDEPENDENCE BY
CONDUCTING TESTS OF PAIRWISE PREFERENCE AND INDEPENDENCE FOR
A SELECTED ATTRIBUTE WITH RESPECT TO THE OTHER ATTRIBUTES.

CALLED BY: BOAT

VARIABLES
  ATT: THE

MODIFICATIONS: ATT1,ATT2,BAND,CH,DL,DEL
    MODEL: INC,OUT,MAX,N1,M1,1,M2
    TEMP,TEMP1,TEMP2,TOLE,OTHER

COMMON /ATT/ ATT
COMMON /U1/ U1
DATA ATT /ATT1,ATT2,BAND,CH,DL,DEL/
CHARACTER ATT, ATT1, ATT2, BAND, CH, DL, DEL
REAL BA(3,2),MAX1,MIN1,MAX2,MIN2
INTEGER IA
IF (ATT.LE.0) CALL UTIL
IF (ATT.LE.2) GO TO 10
INUE=0
PRINT*, 'X=??
READ(*,*(I2)*)=X
TOLER=FLOAT(*TOL*)/1000
PRINT*, 'WE ARE WORKING AT PLUS OR MINUS *.TOL.* PERCENT'.
PRINT*, 'WHICH ATTRIBUTE DO YOU WISH TO EXPLORE THE'.
PRINT*, 'UTILITY INDEPENDENCE OF? (IF YOU WISH TO REVIEW'.
PRINT*, 'THE ATTRIBUTES IN THE ORDER THEY WERE INPUT'.
PRINT*, 'ENTER 1000, OTHERWISE ENTER THE ATTRIBUTE NUMBER NOW*)
READ(*,*(I4)*)=IA
IF (NAU.NE.1000) GO TO 11
PRINT*, *
PRINT*, 'ATTRIBUTE NUMBER= *
DO 10 I=1,MAX
PRINT*, *
PRINT*, 'ATT(I)= ***I
CONTINUE
IF (IA.NE.ATT) GO TO 5
ATT1=ATT(AU)
MAX1=MAX1(ATT(AU),2),ATT(AU,3))
MIN1=MN1(ATT(AU),2),ATT(AU,3))
DEL1=(MAX1-MIN1)/10:
DO 20 J=1,ATT
IF (J.EQ.0) GO TO 2;
ATT2=ATT1(J)
MAX2=MAX1(ATT(J),2),ATT(J,3))
MIN2=MN1(ATT(J),2),ATT(J,3))
DEL2=(MAX2-MIN2)/10:
PRINT*, *
PRINT*, 'SUPPOSE THAT THE FOLLOWING'.
PRINT*, 'ATTRIBUTES ARE AT THESE LEVELS:'
DO 30 K=1,ATT
IF (K.EQ.AU) GO TO 30
IFER=ATT(J)
TEMP=((ATT(K,J)-ATT(K,2))=.25ATT(K,2))
PRINT*, TOT-EP = ***E
CONTINUE
PRINT*, 'THIS IS AT THE 5 PERCENT LEVEL'.
PRINT*, *
TEMP1=MAX1-F.E.*DEL1
DEL1=TEMP1-TOT
if  TEMP2=MAX2-F.E.*DEL2
PRINT*, 'NOW SUPPOSE THAT YOU HAVE THE INITIAL CONDITION:'
PRINT*, 'ATT1 GEM *TEMP1* AND *ATT2 GEM *TEMP2
PRINT*, *
TEMP2=TOT-DEL2*.
PRINT*, 'IMAGINE THAT *ATT1* IS CHANGED TO *TEMP2'.
PRINT*, 'WHAT LEVEL IF *ATT 1* WOULD KEEP YOU AS SATISFIED'.
PRINT*, 'DO YOU WISH TO KEEP THE INITIAL CONDITIONS?'
PRINT*, 'ALL THE ATTRIBUTES ARE ATT'.
PRINT*, 'THE 5 PERCENT LEVEL'.
02: 310
02: 320
02: 330
02: 340
02: 350
02: 360
02: 370
02: 390
02: 400
02: 410
02: 420
02: 430
02: 440
02: 450
02: 460
02: 470
02: 480
02: 490
02: 500
02: 510
02: 520
02: 530
02: 540
02: 550
02: 560
02: 570
02: 580
02: 590
02: 600
02: 610
02: 620
02: 630
02: 640
02: 650
02: 660
02: 670
02: 680
02: 690
02: 700
02: 710
02: 720
02: 730
02: 740
02: 750
02: 760
02: 770
02: 780
02: 790
02: 800
02: 810
02: 820
02: 830
02: 840
02: 850
02: 860
02: 870
02: 880
02: 890
02: 900
02: 910
02: 920
02: 930
02: 940
02: 950
02: 960
02: 970
IF(INDEP.EQ.0) THEN
PRINT**,'SINCE ',ATT1(NAU),' IS PAIRWISE PREFERENTIALY *
PRINT**,'INDEPENDENT OF THE OTHER ATTRIBUTES, ATTRIBUTE '
PRINT**,'ATT1(NAU), WILL NOW BE TESTED FOR UTILITY INDEPENDENCE.*
ENDOF
IF(INDEP.EQ.0) THEN
PRINT**,'THERE ARE INDEPENDENCE PROBLEMS'
PRINT**,'AMONG THE ATTRIBUTES (MPI DOES'
PRINT**,'NOT HOLD). DO YOU WISH '0'
PRINT**,'CONTINUE THE ANALYSIS WITH A '
PRINT**,'ADDITIVE UTILITY FUNCTION? (Y/N)
PRINT**,'?'
-EAD(*(*('A1:')CH
IF(C.EQ.2*Y) CALL UTIL
ENDOF
ATT1=ATT1('AU')
MAXI=MAXI(ATT1(AU,2),ATT1(AU,3))
MINI=MINI(ATT1(AU,2),ATT1(AU,3))
DEL1=(MAXI-MINI)/10.
PRINT**,' 'PRINT**,'WITH THE OTHER ATTRIBUTES EXCEPT •,ATT1)
PRINT**,'SET AS THE FOLLOWING LEVELS'
PRINT**,' 'DO 60 K=1,NAU
IF(K.EQ.0) GO TO 60
OTHER=ATT1(K)
TEMP1=(ATT1(K3)-ATT1(K2))*25+ATT1(K2)
PRINT**,'THE 'TEMP1=TEMP1
CONTINUE
TEMP1=(ATT1(K3)-ATT1(K2))*25+ATT1(K2)
TEMP1=MAXI-5*DEL1
D1=TEMP1+0.01
PRINT**,'NOW WHAT VALUE OF ATTRIBUTE •,ATT1, WITH CERTAINTY'
PRINT**,'WOULD YOU TRADE FOR A LOTTERY OF A 50-50 CHANCE OF'
PRINT**,'RECEIVING EITHER •,MAX1, UNITS OR 'MINI, UNITS OF'
PRINT**,'ATTRIBUTE •,ATT1'
PRINT**,'?'
-EAD(*(*('F1',0.1)) TEMPO
IF((TEMP1.LT.0.0).AND.(TEMP1.GT.MAX1)) THEN
PRINT**,'THE INPUT LEVEL IF 'TEMP1'
PRINT**,'OUTSIDE THE RANGE OF •,ATT2(1,2), TO •,ATT3(1,3)
GO TO 60
ENDIF
TEMP1=0.01
D1N(D)=TEMP1+0.1
D1N(D)=TEMP1-0.1
PRINT**,'NOW WHAT VALUE OF ATTRIBUTE •,ATT1, WITH CERTAINTY'
PRINT**,'WOULD YOU TRADE FOR A LOTTERY OF A 50-50 CHANCE OF'
PRINT**,'RECEIVING EITHER •,MAX1, UNITS OR 'MINI, UNITS OF'
PRINT**,'ATTRIBUTE •,ATT1'
PRINT**,'?'
-EAD(*(*('F1',0.1)) TEMPO
IF((TEMP1.LT.0.0).AND.(TEMP1.GT.MAX1)) THEN
PRINT**,'THE INPUT LEVEL IF 'TEMP1'
PRINT**,'OUTSIDE THE RANGE OF •,ATT2(1,2), TO •,ATT3(1,3)
GO TO 52
END IF
TEMP = TEMP3
BAND(2,2) = TEMP1 + D1
BAND(2,3) = TEMP1 - D1
PRINT
PRINT**, "NOW WHAT VALUE OF ATTRIBUTE *ATR1* WITH CERTAINTY"
PRINT**, "WOULD YOU TRADE FOR A LOTTERY OF A 50-50 CHANCE OF"
PRINT**, "RECEIVING EITHER *TEMP2* UNITS OR *MI1* UNITS OF"
PRINT**, "ATTRIBUTE *ATR1"
PRINT**, "?"
READ**(TIC(0))**TEMP4
IF((TEMP4.LT.MI1).GT.(TEMP4.GT.TEMP2)) THEN
PRINT**, "THE INPUT LEVEL OF *TEMP4"
PRINT**, "IS OUTSIDE THE RANGE OF *MI1* TO *TEMP2"
GO TO 53
END IF
TEMP1 = TEMP4
BAND(3,1) = TEMP1 + D1
BAND(3,2) = TEMP1 - D1
PRINT
PRINT**, "SUPPOSE NOW THAT THE FOLLOWING ATTRIBUTES"
PRINT**, "ARE SHIFTED TO THESE LEVELS:"
PRINT**, "?"
GO TO 70
K = 1 + NATT
IF(K.EQ.NAT) GO TO 70
OTHER = ATT1(K)
TEMP = (ATT(K,2) - ATT(K,1)) * 0.75 + ATT(K,2)
PRINT**, OTHER**TEMP
CONTINUE
PRINT**, "THAT IS AT THE 75 PERCENT LEVEL:"
PRINT**, "?"
PRINT**, "NOW FOR THE LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER "
PRINT**, "MAX1** UNITS OR *MI1** UNITS OF ATTRIBUTE *ATR1"
PRINT**, "WOULD YOU TRADE FOR A VALUE OF ATTRIBUTE *ATR1* WITH"
PRINT**, "CERTAINTY BETWEEN *BAND(1,1)** UNITS AND *BAND(1,2)"
PRINT**, "UNITS. (Y/N)?"
READ**(A1)**CH
IF((CH.EQ."Y") .AND. (CH.EQ."*")) THEN
PRINT**, "ONLY "Y** OF "*" IS ALLOWED, *USER"
GO TO 73
END IF
IF((CH.EQ."*") .AND. (CH.EQ."")) THEN
PRINT**, "NOW FOR THE LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER"
PRINT**, "MAX2**UNITS OR *TEMP2** UNITS OF ATTRIBUTE *ATR1"
PRINT**, "WOULD YOU TRADE FOR A VALUE OF ATTRIBUTE *ATR1* WITH"
PRINT**, "CERTAINTY BETWEEN *BAND(2,1)** UNITS AND *BAND(2,2)"
PRINT**, "UNITS. (Y/N)?"
READ**(A1)**CH
IF((CH.EQ."Y") .AND. (CH.EQ."*")) THEN
PRINT**, "ONLY "Y** OF "*" IS ALLOWED, *USER"
GO TO 74
END IF
IF((CH.EQ."*") .AND. (CH.EQ."")) THEN
PRINT**, "NOW FOR THE LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER"
** Appendix A-4 **

---

THIS ROUTINE ELICITS THE ATTRIBUTE LEVELS OF THE ALTERNATIVE SYSTEMS ACROSS ALL THE DATA REGIONS.

CALLED BY: MUL001

VARIABLES:
- USER: INPUT, ATTACH, PROJECT
- MODIFIED ANSWER: I, J, MAX, MIN

---

A-9
COMMON/EX/CC, DATA, FCTCL
COMMON/YC/CC, YC
SAVE
CHARACTER*1' LABEL, OBJECTV(16), SYSLBL,AT1
PRINT*, 'WE ARE AT THE DATA CODE:
CALL OBJECTV(IFIND,OBJCTV)
II=1
DO 5 I=1,NJ
WRITE(*, '(X, A17)) (OBJCTV(K), K=II,II+3)
II = II+4
5 CONTINUE
PRINT*, 'WHICH HAS THE ASSOCIATED ATTRIBUTE * LABEL(IFIND)
DO 10 I=1,NYSYS
DO 30 J=1,NAT
IF(LABEL(IFIND),EQ.,ATTJ1) THEN
PCHECK=ATTJ,1)
GO TO 31
ENDIF
30 CONTINUE
IF(PCHECK, EQ., 0) THEN
PRINT*, 'THE CURRENT LEVEL OF THE ATTRIBUTE * LABEL(IFIND)
PRINT*, 'IS *LEVEL(VRAY(IFIND, I), LABEL(IFIND)),* FOR SYSTEM *
PRINT*, 'SYSLBL(1)
PRINT* *
PRINT*, 'THE RANGE OF THE ATTRIBUTE IS *ATTJ2, To *ATTJ3)
XMIN=ATTJ2 ATTJ3)
XMAX=ATTJ2 ATTJ3)
PRINT* *
PRINT*, 'WHAT IS THE NEW LEVEL (REAL NUMBER) *
READ(*, '(F16.4)').ANSWER
IF ((ANSWER=ATTJ2, XMIN)) OR (ANSWER = XMAX)) THEN
PRINT*, 'THE LEVEL OF *ANSWER* IS OUT OF RANGE *
GO TO 1
ENDIF
ELSE
DELTA=AHS(ATTJ3, ATTJ3)/10.*
Mi = 10*(I-1)+4
11 X=AHS(ATTJ2, ATTJ3)
FUM=1.0
INDEX= Mi +1
DO 30 J=1,K+3
Y=Y+DELTA
INDEX= INDEX+1
PRT* *
PRINT*, 'THE CURRENT SPIKE PATTER (SEE *
PRINT*, 'USC'S MANUAL) FOR *LABEL(IFIND)
PRINT*, 'AT A LEVEL IF *X* IS *ATTJ3,DEX)
30 CONTINUE
PRINT*, 'WHAT IS THE NEW SPIKE PATTER*
READ(*, '(F16.4)').PRT*
IF ((PRT* .LT. 0.) OR (PRT* .GT. 10.)) THEN
PRINT*, 'THE INPUT VALUE IS *PRT*
PRINT*, 'OUTSIDE THE RANGE OF (0,1.0) *
PRINT*, 'SCALE REJECTS THE QUESTION*
A-10
** Appendix A-5 **

```
FUNCTION CONVL(J,M,N,AT,QR)
CHARACTER*1 AT,QR
!,I,J,K
CALL ASIS('AT(J,J) AT(J,J+1) ++')
CONVL=CONVL-J
CONVL=AT(J,J)-AT(J,J+1)/10.
CONVL=CONVL-J
X=AT(J,J) AT(J,J+1)
Y=AT(J,J) AT(J,1)
CONVL=CONVL VALU(Y,AT(J,J) AT(J,J+1))
RETURN
END
```

A-11
** Appendix A-6 **

```plaintext
SUBROUTINE D: PP(J, X: 1, AT: IB)
CHARACTER*1 : AT, FIB, DUMMY(S)
PRINT *, "THE SPIKE PROBABILITIES RESULT IN THE:
PRINT *, "FOLLOWING PLOT:
PRINT *, 0.0, 0.2, 0.4, 0.6, 0.8
PRINT *, DELTA = ABS(AT(J+2) - AT(J+3))/100
X=AM: 1(A(T(J+2), AT(J+3))
INDEX = M: 1
DC 10 I=0, 9
X=X+DELTA
DC 1 K=1, 50
DUMMY(K)= 0
INDEX = INDEX + 1
ISTOP = INT(AT(J+INDEX)/.5)
DC 20 II=1, ISTOP
DUMMY(I)= 0
CONTINUE
WRITE (3, *(1V, FIC, 5, "A1)X, (DUMMY(I), II=2, 50)
CONTINUE
PRINT *, 0.0, 0.2, 0.4, 0.6, 0.8
PRINT *, SPIKE PROBABILITIES FOR ATTRIBUTE: , AT: IB
PRINT *, (Y-AXIS IS AT:IB LEVEL)
RETURN
END
```

A-12
Appendix B
R and D Funds Allocation Example

WHAT IS YOUR NAME, PLEASE? aaron d.
THANK YOU, AARON D. WE WILL NOW BEGIN THE
DECISION ANALYSIS.

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

AARON D. YOUR OPTIONS ARE:
ATT COP DIS DON MOD NEW NUM PRU REV SEL
SEN SPA STA SYS TTL WYC
NOTE: IF YOU NEED AN EXPLANATION, AARON D.
TYPE "HELP"

WHAT IS YOUR CHOICE? AARON D? new

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

THE CURRENT TREE IS NUMBER 1
WITH WHICH TREE WOULD YOU LIKE TO WORK, AARON D? 1

OPENING FILE NUMBER 1
IS THIS DATA NEW (N) OR STORED (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 DELETE NEW EXIT

B-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.

ADDD DELETEN NEW EXIT

ENTER A TITLE FOR THIS DATA STRUCTURE...

? research and development
? funds allocation
? project selection

B-2
SPANNING NODES: "A"=ALL "S"=SELECT

DO YOU WISH TO BUILD A NEW TREE? AARON D. ? (Y/N)

DO YOU WISH TO BY-PASS THE BETWEEN NODE CHECK?n

ADDING DOWMLINKS TO NODE:

AARON D. , WHAT IS THE NEXT SUBOBJECTIVE?

USE NO MORE THAN TWO 80 CHARACTER LINES)

? TO PROVIDE FOR SUCCESSFUL

PLEASE CONTINUE

? R AND D EFFORTS

THE LAST SUBOBJECTIVE ENTERED IS:

R AND D EFFORTS

CURRENT NUMBER OF NODES: 2(MAX 500)
CURRENT NUMBER OF LEVELS: 2(MAX 20)
CURRENT NUMBER OF SYSTEMS: 5(MAX 59)

ADDING DOWMLINKS TO NODE:

1

TO PROVIDE FOR SUCCESSFUL

R AND D EFFORTS

AARON D. , WHAT IS THE NEXT SUBOBJECTIVE?

USE NO MORE THAN TWO 80 CHARACTER LINES)

? TO PRODUCE SIGNIFICANT RESULTS

PLEASE CONTINUE

? FROM R AND D EFFORTS

THE LAST SUBOBJECTIVE ENTERED IS:

TO PRODUCE SIGNIFICANT RESULTS

FROM R AND D EFFORTS
WHICH IS SUBOBJECTIVE NUMBER 1
FOR THE OBJECTIVE:
TO PROVIDE FOR SUCCESSFUL
R AND D EFFORTS

CURRENT NUMBER OF NODES: 3 (MAX 500)
CURRENT NUMBER OF LEVELS: 2 (MAX 20)
CURRENT NUMBER OF SYSTEMS: 5 (MAX 59)
ADDING DOWNLINKS TO NODE:
1 1
TO PRODUCE SIGNIFICANT RESULTS
FROM R AND D EFFORTS

AARON D., WHAT IS THE NEXT SUBOBJECTIVE?
(USE NO MORE THAN TWO 80 CHARACTER LINES)
? to expand technology base, but not at
PLEASE CONTINUE
? expense of focused R and D efforts
THE LAST SUBOBJECTIVE ENTERED IS:
TO EXPAND TECHNOLOGY BASE, BUT NOT AT
EXPENSE OF FOCUSED R AND D EFFORTS

WHICH IS SUBOBJECTIVE NUMBER 1
FOR THE OBJECTIVE:
TO PRODUCE SIGNIFICANT RESULTS
FROM R AND D EFFORTS

AARON D., WHAT IS THE NEXT SUBOBJECTIVE?
(USE NO MORE THAN TWO 80 CHARACTER LINES)
? to gain sponsorship for funding the
PLEASE CONTINUE
? advanced development of R and D projects
THE LAST SUBOBJECTIVE ENTERED IS:
TO GAIN SPONSORSHIP FOR FUNDING THE
ADVANCED DEVELOPMENT OF R AND D PROJECTS

WHICH IS SUBOBJECTIVE NUMBER 2
FOR THE OBJECTIVE:
TO PRODUCE SIGNIFICANT RESULTS
FROM R AND D EFFORTS
AARON D., WHAT IS THE NEXT SUBOBJECTIVE?
(USE NO MORE THAN TWO 80 CHARACTER LINES)

? TO REALIZE SIGNIFICANT
PLEASE CONTINUE
? RESULTS IN MINIMUM TIME
THE LAST SUBOBJECTIVE ENTERED IS:
TO REALIZE SIGNIFICANT
RESULTS IN MINIMUM TIME

WHICH IS SUBOBJECTIVE NUMBER 3
FOR THE OBJECTIVE:
TO PRODUCE SIGNIFICANT RESULTS
FROM R AND D EFFORTS

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

TO PRODUCE SIGNIFICANT RESULTS
FROM R AND D EFFORTS
TO EXPAND TECHNOLOGY BASE, BUT NOT AT EXPENSE OF FOCUSED R AND D EFFORTS
TO GAIN SPONSORSHIP FOR FUNDING THE ADVANCED DEVELOPMENT OF R AND D PROJECT
TO REALIZE SIGNIFICANT RESULTS IN MINIMUM TIME
AARON D., DO THE SUBOBJECTIVES ADDRESS ALL FACETS OF THE PARENT OBJECTIVE? (Y/N)

? Y

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

? N

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

? Y

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

? N

CURRENT NUMBER OF NODES: 6 (MAX 500)
CURRENT NUMBER OF LEVELS: 3 (MAX 20)
CURRENT NUMBER OF SYSTEMS: 5 (MAX 59)

ADDING DOWNLINKS TO NODE:
1 1 1
TO EXPAND TECHNOLOGY BASE, BUT NOT AT EXPENSE OF FOCUSED R AND D EFFORTS

AARON D., WHAT IS THE NEXT SUBOBJECTIVE? (USE NO MORE THAN TWO 80 CHARACTER LINES)
? TO START PROJECTS WITH HIGH PROBABILITY
PLEASE CONTINUE
? OF SUCCESS IN MEETING IDENTIFIED NEEDS
THE LAST SUBOBJECTIVE ENTERED IS:
TO START PROJECTS WITH HIGH PROBABILITY
OF SUCCESS IN MEETING IDENTIFIED NEEDS

WHICH IS SUBOBJECTIVE NUMBER 1
FOR THE OBJECTIVE:
TO EXPAND TECHNOLOGY BASE, BUT NOT AT EXPENSE OF FOCUSED R AND D EFFORTS
AARON D., WHAT IS THE NEXT SUBOBJECTIVE?
(USE NO MORE THAN TWO 80 CHARACTER LINES)
\[\text{PLEASE CONTINUE}\]
\[\text{THE LAST SUBOBJECTIVE ENTERED IS:}\]
\[\text{TO START PROJECTS WITH THE SPONSORSHIP OF MAJOR ORGANIZATIONS WILLING TO COMMIT DEVELOPMENT FUNDS TO SUCCESSFUL R AND D PROJECTS (NUMBER OF SPONSORS)}\]

\[\text{WHICH IS SUBOBJECTIVE NUMBER 1 FOR THE OBJECTIVE:}\]
\[\text{TO GAIN SPONSORSHIP FOR FUNDING THE ADVANCED DEVELOPMENT OF R AND D PROJECT}\]

\[\text{AARON D., WHAT IS THE NEXT SUBOBJECTIVE?}\]
(USE NO MORE THAN TWO 80 CHARACTER LINES)

\[\text{CURRENT NUMBER OF NODES: 9 (MAX 500)}\]
\[\text{CURRENT NUMBER OF LEVELS: 4 (MAX 20)}\]
\[\text{CURRENT NUMBER OF SYSTEMS: 5 (MAX 59)}\]
\[\text{ADDING DOWNLINKS TO NODE:}\]
\[1 1 2 1\]
\[\text{TO START PROJECTS WITH THE SPONSORSHIP OF MAJOR ORGANIZATIONS WILLING TO COMMIT DEVELOPMENT FUNDS TO SUCCESSFUL R AND D PROJECTS (NUMBER OF SPONSORS)}\]
ADDING DOWNLINKS TO NODE:
1 1 3
TO REALIZE SIGNIFICANT RESULTS IN MINIMUM TIME

AARON D. > WHAT IS THE NEXT SUBOBJECTIVE?
(USE NO MORE THAN TWO 80 CHARACTER LINES)
? to start r and d projects with

PLEASE CONTINUE

? minimum time to fruition
THE LAST SUBOBJECTIVE ENTERED IS:
TO START R AND D PROJECTS WITH

MINIMUM TIME TO FRUITION

WHICH IS SUBOBJECTIVE NUMBER 1
FOR THE OBJECTIVE:
TO REALIZE SIGNIFICANT

RESULTS IN MINIMUM TIME

AARON D. > PLEASE INPUT AN ATTRIBUTE FOR THE DATA MODE WITH THE OBJECTIVE:
TO START R AND D PROJECTS WITH AN ESTABLISHED TECHNOLOGY BASE WITH WHICH TO MEET IDENTIFIED NEEDS
(TECHNOLOGY BASE UNITS - TB UNITS)
(10 LETTERS OR LESS)
? tb units

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

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

WILL THIS ATTRIBUTE BE PROBABILISTIC? (Y/N)
?y

B-8
WHAT IS THE WORST ACCEPTABLE LEVEL (REAL NUMBER) OF TB UNITS?

0

THE LEVEL STORED WAS 0.

WHAT IS THE BEST (REALISTICALLY) LEVEL (REAL NUMBER) OF TB UNITS, AARON D.?

10

THE LEVEL STORED WAS 10.

AARON D., PLEASE INPUT AN ATTRIBUTE FOR THE DATA NODE WITH THE OBJECTIVE:

TO START PROJECTS WITH THE SPONSORSHIP OF MAJOR ORGANIZATIONS WILLING TO

COMMIT DEVELOPMENT FUNDS TO SUCCESSFUL R AND D PROJECTS (NUMBER OF SPONSORS)

(10 LETTERS OR LESS)

?sp:

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

?y

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

?n

WILL THIS ATTRIBUTE BE PROBABILISTIC? (Y/N)

?y

WHAT IS THE WORST ACCEPTABLE LEVEL (REAL NUMBER) OF SPONSORS?

0

THE LEVEL STORED WAS 0.

WHAT IS THE BEST (REALISTICALLY) LEVEL (REAL NUMBER) OF SPONSORS, AARON D.?

10

THE LEVEL STORED WAS 10.

AARON D., PLEASE INPUT AN ATTRIBUTE FOR THE DATA NODE WITH THE OBJECTIVE:

TO START R AND D PROJECTS WITH

MINIMUM TIME TO FRUITION

(10 LETTERS OR LESS)

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

?Y

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

?N

WILL THIS ATTRIBUTE BE PROBABILISTIC? (Y/N)

?Y

WHAT IS THE WORST ACCEPTABLE
LEVEL (REAL NUMBER) OF TIME_YEARS
?5

THE LEVEL STORED WAS 5.

WHAT IS THE BEST (REALISTICALLY)
LEVEL (REAL NUMBER) OF TIME_YEARS? AARON D. ?

?0

THE LEVEL STORED WAS 0.

TB UNITS SPONSORS TIME_YEARS

THE ABOVE IS THE CURRENT SET OF ATTRIBUTES, AARON D.

IF YOU SEE ANY WHICH ARE REDUNDANT, 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, AARON D.? (Y/N)

?N

DO YOU WISH TO BYPASS INDEPENDENCE TESTING?n

AT WHAT TOLERANCE DO YOU WANT TO CHECK YOUR
RESPONSE AARON D. (PLUS OR MINUS X PERCENT)?

X=10

WE ARE WORKING AT PLUS OR MINUS 10 PERCENT
AARON D. WHICH ATTRIBUTE DO YOU WISH TO EXPLORE THE
UTILITY INDEPENDENCE OF

UTILITY INDEPENDENCE OF? (IF YOU WISH TO REVIEW
THE ATTRIBUTES IN THE ORDER THEY WERE INPUT,
ENTER 1000, OTHERWISE ENTER THE ATTRIBUTE NUMBER NOW.)

1000

ATTRIBUTE NUMBER

TB UNITS 1

B-10
Suppose that you wish to explore the utility independence of? (If you wish to review the attributes in the order they were input, enter 1000, otherwise enter the attribute number now.)

Suppose that the following attributes are at these levels:
TIME YEARS = 1.25
That is at the 25 percent level

Now suppose that you have the initial conditions:
TB UNITS = 5, and SPONSORS = 5.

Imagine that SPONSORS is changed to 2. What level of TB UNITS would keep you as satisfied as you were under the initial conditions? (Remember that all other attributes are at the 25 percent level)

Suppose that you are starting at:
TB UNITS = 5, and SPONSORS = 5.

Imagine that 8. in SPONSORS is achieved. To what level would you change?
To what level would you change TB UNITS in order to remain as satisfied as you were initially?

(Remember that all other attributes are at the 25 percent level)

Suppose now that the following attributes are shifted:

Are shifted to these levels:
TIME YEARS = 3.75
That is at the 75 percent level

Suppose that you have
TB UNITS = 5, and SPONSORS = 5.
IMAGINE THAT THE LEVEL OF SPONSORS IS CHANGED TO 2.
WOULD THE LEVEL OF TB UNITS NEEDED TO REMAIN AS SATISFIED AS AT THE INITIAL CONDITIONS LIE BETWEEN 8.5 AND 7.5?
(Y/N) ?

SUPPOSE THAT YOU HAVE THE INITIAL CONDITIONS:
TB UNITS = 5, AND SPONSORS = 5.

IMAGINE THAT YOU MUST ACCEPT A LEVEL OF 8. IN SPONSORS
WOULD THE LEVEL OF TB UNITS THAT YOU WOULD HAVE TO MOVE TO (IN ORDER TO BE AS SATISFIED AS UNDER THE INITIAL CONDITIONS) LIE BETWEEN 3.5 AND 2.5?
(Y/N) ?

THERE ARE NO INDEPENDENCE PROBLESMS WITH THE ATTRIBUTES TESTED SO FAR, DO YOU WISH TO ASSUME MPI FOR THE REMAINING ATTRIBUTES? (Y/N)

EVEN IF YOU DO NOT WISH TO ASSUME MPI AMONG THE ATTRIBUTES, DO YOU WANT TO STOP MUI TESTING? (Y/N).

SUPPOSE THAT THE FOLLOWING ATTRIBUTES ARE AT THESE LEVELS:
SPONSORS = 2.5
THAT IS AT THE 25 PERCENT LEVEL

NOW SUPPOSE THAT YOU HAVE THE INITIAL CONDITIONS:
TB UNITS = 5, AND TIME, YEARS = 2.5

IMAGINE THAT TIME, YEARS IS CHANGED TO 1.
WHAT LEVEL OF TB UNITS WOULD KEEP YOU AS SATISFIED AS YOU WERE UNDER THE INITIAL CONDITIONS?
(REMEMBER THAT ALL OTHER ATTRIBUTES ARE AT THE 25 PERCENT LEVEL)
?

SUPPOSE THAT YOU ARE STARTING AT
TB UNITS = 5, AND TIME, YEARS = 2.5

IMAGINE THAT 4. IN TIME, YEARS IS ACHIEVED.
TO WHAT LEVEL WOULD YOU CHANGE TB UNITS IN ORDER TO REMAIN AS SATISFIED AS YOU WERE INITIALLY?
(REMEMBER THAT ALL OTHER ATTRIBUTES ARE AT THE 25 PERCENT LEVEL)
?
Raspberry.  Suppose now that the following attributes are shifted to these levels:
SPONSORS = 7.5
That is at the 75 percent level

Suppose that you have
TB UNITS = 5, and TIME_YEARS = 2.5

Imagine that the level of TIME_YEARS is changed to 1.
Would the level of TB UNITS needed to remain as satisfied as at the initial conditions lie between 2.5 and 1.5
(Y/N) ?

Suppose that you have the initial conditions:
TB UNITS = 5, and TIME_YEARS = 2.5

Imagine that you must accept a level of 4. in TIME_YEARS
Would the level of TB UNITS that you would have to move to (in order to be as satisfied as under the initial conditions) lie between 8.5 and 7.5
(Y/N) ?

There are no independence problems with the attributes tested so far. Do you wish to assume MPI for the remaining attributes? (Y/N)

Even if you do not wish to assume MPI among the attributes, do you want to stop MUI testing?

Do you want to stop MUI testing? (Y/N).

Since TB UNITS is pairwise preferentially independent of the other attributes, attribute TB UNITS will now be tested for utility independence.

With the other attributes except TB UNITS set as the following levels:
SPONSORS = 2.5
TIME_YEARS = 1.25

Now what value of attribute TB UNITS with certainty would you trade for a lottery of a 50-50 chance?

Would you trade for a lottery of a 50-50 chance of receiving either 10 UNITS or 0 UNITS of attribute TB UNITS?
NOW WHAT VALUE OF ATTRIBUTE TB UNITS WOULD YOU TRADE FOR A LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER 10. UNITS OR 3. UNITS OF ATTRIBUTE TB UNITS?

NOW WHAT VALUE OF ATTRIBUTE TB UNITS WOULD YOU TRADE FOR A LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER 3. UNITS OR 0. UNITS OF ATTRIBUTE TB UNITS?

AARON D., SUPPOSE NOW THAT THE FOLLOWING ATTRIBUTES ARE SHIFTED TO THESE LEVELS:

SPONSORS = 7.5
TIME, YEARS = 3.75
THAT IS AT THE 75 PERCENT LEVEL

NOW FOR THE LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER 10. UNITS OR 0. UNITS OF ATTRIBUTE TB UNITS
WOULD YOU TRADE FOR A VALUE OF ATTRIBUTE TB UNITS WITH CERTAINTY BETWEEN 3.5 UNITS AND 2.5 UNITS. (Y/N)?

NOW FOR THE LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER 10. UNITS OR 3. UNITS OF ATTRIBUTE TB UNITS
WOULD YOU TRADE FOR A VALUE OF ATTRIBUTE TB UNITS WITH CERTAINTY BETWEEN 6.5 UNITS AND 5.5 UNITS. (Y/N)?

NOW FOR THE LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER 3. UNITS OR 0. UNITS OF ATTRIBUTE TB UNITS
WITH CERTAINTY BETWEEN 1.5 UNITS AND .5 UNITS. (Y/N)?
ONLY "Y" OR "N" IS ALLOWED, AARON D.

NOW FOR THE LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER 3. UNITS OR 0. UNITS OF ATTRIBUTE TB UNITS
WITH CERTAINTY BETWEEN 1.5 UNITS AND .5 UNITS. (Y/N)?
ONLY "Y" OR "N" IS ALLOWED, AARON D.

NOW FOR THE LOTTERY OF A 50-50 CHANCE OF RECEIVING EITHER 3. UNITS OR 0. UNITS OF ATTRIBUTE TB UNITS
WITH CERTAINTY BETWEEN 1.5 UNITS AND .5 UNITS. (Y/N)?

THE ATTRIBUTES AREUTILITY INDEPENDENT

THE UTILITY FUNCTIONS FOR EACH ATTRIBUTE WILL NOW BE DETERMINED
THE UTILITY FUNCTIONS FOR EACH ATTRIBUTE WILL NOW BE DETERMINED

NOW WHAT LEVEL OF ATTRIBUTE TB UNITS WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY WITH A 50-50 CHANCE OF RECEIVING EITHER 10. UNITS OR 0. UNITS OF ATTRIBUTE TB UNITS?

NOW WHAT LEVEL OF ATTRIBUTE TB UNITS WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY WITH A 50-50 CHANCE OF RECEIVING EITHER 3. UNITS OR 0. UNITS OF ATTRIBUTE TB UNITS?

NOW WHAT LEVEL OF ATTRIBUTE TB UNITS WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY WITH A 50-50 CHANCE OF RECEIVING EITHER 3. UNITS OR 0. UNITS OF ATTRIBUTE TB UNITS?

THE ABOVE YIELDS A UTILITY FUNCTION FOR TB UNITS WITH PARAMETERS:

\[ B_0 = .0360853789916 \quad B_1 = .4143262372915 \]

SUM OF SQUARED ERROR = 0.00439475958282

LOGARITHMIC FORM

\[ \text{UTILITY} = B_0 + B_1 + \ln(\text{ATTRIBUTE LEVEL}) \]

\[
\begin{array}{c|c}
\text{ATTRIBUTE LEVEL} & \text{UTILITY} \\
\hline
10.00 & + \\
8.00 & + \\
5.50 & + \\
3.00 & + \\
.50 & + \\
\end{array}
\]

\[
\begin{array}{c}
0.0 \quad 0.25 \quad 0.5 \quad 0.75 \quad 1 \\
\hline
\end{array}
\]

UTILITY FUNCTION FOR TB UNITS

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

Y
NOW WHAT LEVEL OF ATTRIBUTE SPONSORS WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY WITH A 50-50 CHANCE OF RECEIVING EITHER 10. UNITS OR 0. UNITS OF ATTRIBUTE SPONSORS ?

NOW WHAT LEVEL OF ATTRIBUTE SPONSORS WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY WITH A 50-50 CHANCE OF RECEIVING EITHER 2. UNITS OR 0. UNITS OF ATTRIBUTE SPONSORS ?

NOW WHAT LEVEL OF ATTRIBUTE SPONSORS WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY WITH A 50-50 CHANCE OF RECEIVING EITHER 2. UNITS OR 10. UNITS OF ATTRIBUTE SPONSORS ?

THE ABOVE YIELDS A UTILITY FUNCTION FOR SPONSORS WITH PARAMETERS:

B0 = .01501703492854  B1 = .3317918697555
SUM OF SQUARED ERROR = .0396686467344

(SQUARE-ROOT FORM)

UTILITY = B0 + B1*(ATTRIBUTE LEVEL)**0.5

10.00  +

2.00  +

5.50  +

3.00  +

.50  +

0.0  +

0.25  +

0.5  +

0.75  +

1  +

UTILITY FUNCTION FOR SPONSORS

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

B-16
NOW WHAT LEVEL OF ATTRIBUTE TIME, YEARS
WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY
WITH A 50-50 CHANCE OF RECEIVING EITHER
0. UNITS OR 5. UNITS OF ATTRIBUTE TIME, YEARS
?

NOW WHAT LEVEL OF ATTRIBUTE TIME, YEARS
WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY
WITH A 50-50 CHANCE OF RECEIVING EITHER
4. UNITS OR 5. UNITS OF ATTRIBUTE TIME, YEARS
?

NOW WHAT LEVEL OF ATTRIBUTE TIME, YEARS
WITH CERTAINTY WOULD YOU TRADE FOR A LOTTERY
WITH A 50-50 CHANCE OF RECEIVING EITHER
4. UNITS OR 0. UNITS OF ATTRIBUTE TIME, YEARS
?

THE ABOVE YIELDS A UTILITY FUNCTION FOR TIME, YEARS
WITH PARAMETERS:
B0=1.059734255292  B1=-.0397675626542
SUM OF SQUARED ERROR=.01605919685755
(SQUARED FORM)
UTILITY=BO+B1*(ATTRIBUTE LEVEL)**2.0

UTILITY FUNCTION FOR TIME, YEARS

DOES THE ABOVE REPRESENTATION APPEAR REASONABLE? (Y/N)
YOU MAY NOW ENTER WEIGHTS, VALUES, OR (RE)CALCULATE THE TREE. CHOOSE YOUR OPTION:
W<IGHT  V<VALUES  C<ALCULATE  E<EXIT

VALUES : A<LL  S<ELECT

WE ARE AT THE DATA NODE:
TO START R AND D PROJECTS WITH AN ESTABLISHED TECHNOLOGY BASE WITH WHICH TO MEET IDENTIFIED NEEDS (TECHNOLOGY BASE UNITS - TB UNITS) WHICH HAS THE ASSOCIATED ATTRIBUTE TB UNITS

THE CURRENT SPIKE PROBABILITY (SEE USER'S MANUAL) FOR TB UNITS AT A LEVEL OF 1. IS 0.

WHAT IS THE NEW SPIKE PROBABILITY ?

THE CURRENT SPIKE PROBABILITY (SEE USER'S MANUAL) FOR TB UNITS AT A LEVEL OF 2. IS 0.

WHAT IS THE NEW SPIKE PROBABILITY ?

THE CURRENT SPIKE PROBABILITY (SEE USER'S MANUAL) FOR TB UNITS AT A LEVEL OF 3. IS 0.

WHAT IS THE NEW SPIKE PROBABILITY ?.25

THE CURRENT SPIKE PROBABILITY (SEE USER'S MANUAL) FOR TB UNITS AT A LEVEL OF 4. IS 0.

WHAT IS THE NEW SPIKE PROBABILITY ?.5

THE CURRENT SPIKE PROBABILITY (SEE USER'S MANUAL) FOR TB UNITS AT A LEVEL OF 5. IS 0.

WHAT IS THE NEW SPIKE PROBABILITY ?.25
The current spike probability (see user's manual) for TB units at a level of 6. is 0.

What is the new spike probability?

The current spike probability (see user's manual) for TB units at a level of 7. is 0.

What is the new spike probability?

The current spike probability (see user's manual) for TB units at a level of 8. is 0.

What is the new spike probability?

The current spike probability (see user's manual) for TB units at a level of 9. is 0.

What is the new spike probability?

The current spike probability (see user's manual) for TB units at a level of 10. is 0.

What is the new spike probability?

The spike probabilities result in the following plot:

<table>
<thead>
<tr>
<th>0.0</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0000</td>
<td>3.0000</td>
<td>3.0000</td>
<td></td>
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</tr>
<tr>
<td>4.0000</td>
<td>4.0000</td>
<td>4.0000</td>
<td></td>
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</tr>
<tr>
<td>5.0000</td>
<td>5.0000</td>
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<td></td>
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<tr>
<td>6.0000</td>
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<tr>
<td>7.0000</td>
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</tr>
<tr>
<td>8.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Spike probabilities for attribute TB units (Y-axis is attribute level)
SPIKE PROBABILITIES FOR ATTRIBUTE TB UNITS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT T

SPIKE PROBABILITIES FOR ATTRIBUTE TB UNITS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT X

SPIKE PROBABILITIES FOR ATTRIBUTE TB UNITS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT Y

B-20
SPIKE PROBABILITIES FOR ATTRIBUTE TB UNITS
(Y-AXIS IS ATTRIBUTE LEVEL)

SPIKE PROBABILITIES FOR ATTRIBUTE SPONSORS
(Y-AXIS IS ATTRIBUTE LEVEL)

SPIKE PROBABILITIES FOR ATTRIBUTE SPONSORS
(Y-AXIS IS ATTRIBUTE LEVEL)

B-21
SPIKE PROBABILITIES FOR ATTRIBUTE SPONSORS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT X

SPIKE PROBABILITIES FOR ATTRIBUTE SPONSORS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT Y

SPIKE PROBABILITIES FOR ATTRIBUTE SPONSORS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT Z

B-22
SPIKE PROBABILITIES FOR ATTRIBUTE TIME, YEARS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT S

SPIKE PROBABILITIES FOR ATTRIBUTE TIME, YEARS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT T

SPIKE PROBABILITIES FOR ATTRIBUTE TIME, YEARS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT X

B-23
SPIKE PROBABILITIES FOR ATTRIBUTE TIME, YEARS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT Y

SPIKE PROBABILITIES FOR ATTRIBUTE TIME, YEARS
(Y-AXIS IS ATTRIBUTE LEVEL)

PROJECT Z

PROJECT DATA ENTERED

YOU MAY NOW ENTER WEIGHTS, VALUES, OR (RE)CALCULATE
THE TREE. CHOOSE YOUR OPTION:
- WEIGHT
- VALUES
- CALCULATE
- EXIT
WE ARE WEIGHTING THE NODE SET:
TO EXPAND TECHNOLOGY BASE, BUT NOT AT
EXPENSE OF FOCUSED R AND D EFFORTS

THE ABOVE OBJECTIVE IS FACTOR 1
TO GAIN SPONSORSHIP FOR FUNDING THE
ADVANCED DEVELOPMENT OF R AND D PROJECT
3
THE ABOVE OBJECTIVE IS FACTOR 2
TO REALIZE SIGNIFICANT
RESULTS IN MINIMUM TIME
THE ABOVE OBJECTIVE IS FACTOR 3

DO YOU WISH TO ENTER THE RELATIVE WEIGHTS DIRECTLY, (Y/N) ?Y
ENTER THE (UNNORMALIZED) WEIGHTS.
WHAT IS THE WEIGHT FOR FACTOR 1 ?2
WHAT IS THE WEIGHT FOR FACTOR 2 ?5
WHAT IS THE WEIGHT FOR FACTOR 3 ?3
NORMALIZED: 20 50 30

ARE YOU HAPPY WITH THESE RELATIVE WEIGHTS? (Y/N) ?Y
ENTER COMMENTS ON THESE WEIGHTS
?OK

YOU MAY NOW ENTER WEIGHTS, VALUES, OR (RE)CALCULATE
THE TREE. CHOOSE YOUR OPTION:
W<IGHT  V<ALES  C<ALCULATE  X<IT

?C
INTERIOR TREE VALUES ARE BEING CALCULATED...
HOW MUCH DO YOU WANT TO REVIEW...
A<LL    S<ELECT
?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)
?r

REVIEW
RESEARCH AND DEVELOPMENT
FUNDS ALLOCATION - PROJECT SELECTION

NODE REFERENCE NUMBER (AND OBJECTIVE):
1
TO PROVIDE FOR SUCCESSFUL R AND D EFFORTS

RELATIVE WEIGHT: 1.
CUMULATIVE WEIGHT: 1.

SYSTEM VALUES:
PROJECT S  PROJECT T  PROJECT X  PROJECT Y
  64.20  64.68   27.15   53.74
PROJECT Z
  65.01

OK
(PRESS ANY LETTER TO CONTINUE (EXCEPT "E"))
(PRESS "E" TO EXIT)
?r
Appendix C
Technology Base Units

The following scale was used to rate projects on the attribute reflecting technical foundation of a research area.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Technology Base (TB) Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Base Fully Developed Adequate Data To Go Into Production</td>
<td>9</td>
</tr>
<tr>
<td>Research Base Developing With Foundation For Further Development, Growing Data Base For Specific Technology</td>
<td>7</td>
</tr>
<tr>
<td>Research Base Partially Developed, Some Data Available On Specific Technology</td>
<td>5</td>
</tr>
<tr>
<td>Research Base Undeveloped, Data Available But Only From Related Areas</td>
<td>3</td>
</tr>
<tr>
<td>Research Base Undeveloped, Technology Area New, No Data</td>
<td>1</td>
</tr>
</tbody>
</table>
Appendix D - Objectives Hierarchy - R and D Funds Allocation

1.
To Provide For A Successful R and D Effort

1.1
To Provide Significant Results From R and D Effort

1.1.1
To Expand Technology Base, But Not At Expense Of Focused R and D Efforts

1.1.1.1
To Start Projects With High Probability Of Success In Meeting Identified Needs

1.1.1.1.1
To Start R and D Projects With An Established Technology With Which To Meet Identified Needs (Technology Base Units-TBU's)

1.1.2
To Gain Sponsorship For Funding Advanced Development of R and D Projects

1.1.2.1
To Start Projects With The Sponsorship of Major Organizations Willing To Commit Development Funds To Successful R and D Projects (Number of Sponsors)

1.1.3
To Realize Significant Results In Minimum Time

1.1.3.1
To Start R And D Projects With Minimum Time To Fruition (Years)
**Title:** The Extended Multi-Attribute Decision Analysis Model

**Authors:** Aaron R. DeWispelare

**Type of Report:** Technical Report

**Date of Report:** August 1983

**Page Count:** 67

**Abstract:** This research is an on-going effort to produce an interactive, computer-based aid suitable for use in decision situations and long-term planning. The current research involves the development of extensions to the applicability of a decision aid embodied in the computer program MADAM: Multi-Attribute Decision Analysis Model. The theoretical underpinnings of MADAM involve portions of multi-attribute utility theory. This interactive program is designed to aid the decision-maker in all phases of decision analysis from problem formulation to sensitivity analysis. The program is a tool designed to be used by a decision-maker in order to facilitate making rational and consistent trade-offs and sub-decisions throughout the entire decision-making process. The stages of the decision analysis covered by the program include formation of an objectives hierarchy, elicitation of an appropriate set of attributes, examining the relationship between the attributes, establishing criterion weights, evaluating candidate solutions, and performing several types of sensitivity analysis.

**Subject Terms:** Decision Making, Statistical Analysis, Decision Theory, Computer Application, Project Assessment.
Item 19. (Cont'd)

The significant changes in the model involve the stages of examining the relationship between the attributes and of incorporating probabilistic data and utility concepts. In the previous version of MADAM, the program guides the decision-maker in determining whether or not the condition of mutual preferential independence is met. This determination is important because the previous version of the program is designed to handle the case of deterministics attributes (measurable value analysis) where an additive value function is the appropriate overall value function. The extension allow MADAM to be utilized for the case of probabilistic attributes (utility analysis). The extended program aids the decision-maker in conducting lottery trade-offs so that independence conditions necessary to use an additive utility function can be ascertained. The utility analysis parallels the former value analysis in structure. MADAM maintains all previous capabilities for sensitivity analysis as well as the new utility analysis capabilities.
END

FILMED

4-84

DTIC