Antonio Leal

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Contract MDA903-77-C-0184
ARPA Order No. 3344
February, 1978

AN INTERACTIVE COMPUTER AIDING SYSTEM FOR GROUP DECISION MAKING

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NOTES

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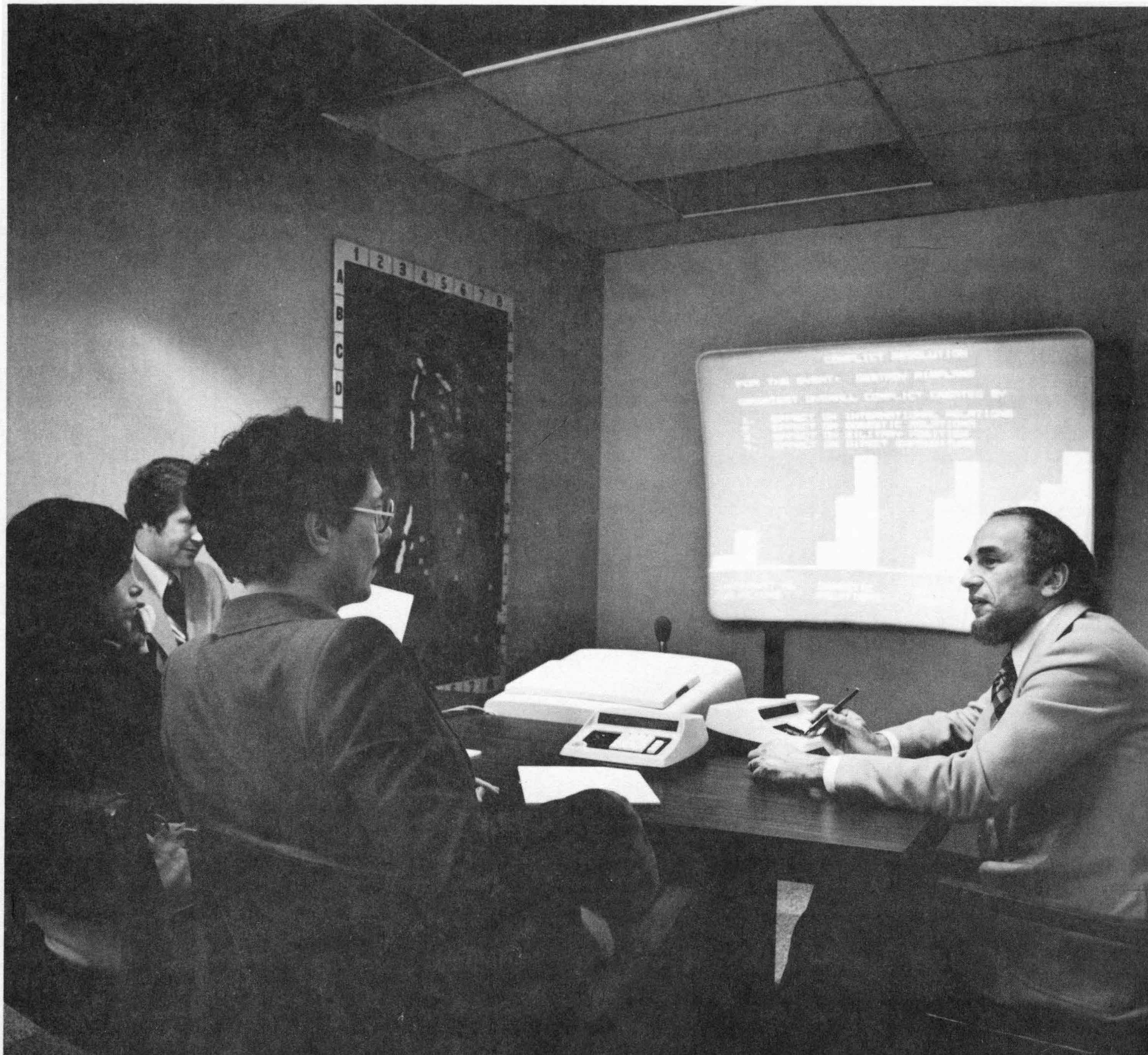

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1. INTRODUCTION

1.1 Summary

This report presents a new system for interactive computer aiding of group decision making, developed under the sponsorship of ARPA's Cybernetics Technology office. The group decision aid is supported by a PDP 11/45 minicomputer using the UNIX operating system. It features simple individual data entry terminals and a large-screen color video display for feedback of computer-generated information. Its purpose is to guide the group decision making process by selective elicitation of a decision tree which incorporates value and probability inputs from all group members. A specially-trained system operator, called an intermediator, facilitates group interaction with the aiding program, so that group members need have no prior familiarity with computers or decision analysis. Initial trials with the aiding system were conducted using a crisis scenario formulated under subcontract by CACI, Washington, D.C. These trials were highly successful. Experimental groups were immediately able to use the system to generate decision trees of more than 40 nodes during three to four-hour discussion periods. Group members reported that the aid significantly enhanced the decision making process. The present report describes the current aiding system, and discusses its future development and application.

1.2 Decision Analytical Approach

Constant advancements in technology and communications, as well as the growing complexity of world affairs, have increased the importance of the decision making function. In today's military environment most upper-level decisions are made by committees and staff groups. In non-military environments as well, including those of government, business, medicine, and the law, group decisions often have a wide and substantial impact on future events and relationships. Decision making groups typically contain experts from several specialty areas, who bring to the decision environment disparate sets of values.

Decision time is usually limited, the decision making procedure is relatively unstructured, and intra-group conflicts arise on a broad variety of issues. The group usually cannot consider the maximum set of alternatives, conflicts tend to be resolved in an arbitrary manner, if at all, and as a consequence the resultant decision is rarely up to the aggregate potential of the group membership.

Decision analysis offers a promising approach to solving these problems. The analytical procedure of building a decision tree formalizes the decision process, and permits incorporation of individual values (utilities) into the selection of alternative courses of action (Hays, O'Connor, Peterson, 1975). However, decision analysis as it is usually practiced is a highly personal and time-consuming process. Trained decision analysts are generally used to assist in the solution of problems ranging over a large variety of domains. In most cases the decision analysts know far less about the problem-domain than do their clients. Joint education of the analysts and the clients takes up a disproportionate amount of decision making time.

Accordingly, it appears highly worthwhile to automate the analytical process, using a domain-independent system to interrogate decision makers directly, and to construct a decision tree based on their responses. Leal and Pearl (1976) have shown that automated tree elicitation from individuals is feasible, and that on-line sensitivity analysis can be used to concentrate tree development on the branches with highest pay-off, thus streamlining the entire decision analysis process. Likewise, Gardiner and Edwards (1975) and Sheridan (1975) have shown that direct, real-time feedback of responses in group decision making focuses the effort on areas of real difference, while maintaining the advantages of full group participation. Finally, Decision and Designs, Inc. has shown the usefulness of automated decision aiding with a portable computerized system for choosing an optimum alternative given a wide range of expected event outcomes (Kelly and Stewart, 1977).

The Perceptronics Group Decision Aid puts this aggregate decision technology at the command of a group of expert decision makers who must arrive at a decision solution in a relatively short amount of time. Focus is on problem structuring, on quick resolution of group conflicts, and on constant guidance on the most critical issues.

One of the objectives of decision analysis is to provide simple formal procedures and structures for coding intuitive judgments about a particular problem situation. The types of problems most often treated by decision analytical methods are those in which the goal is to select one specific course of action from among a number of contending alternative courses of action. This type of selection is defined as a "decision". The role of decision analysis is to provide a procedure for the elicitation of relevant problem information so that a "best" decision can be reached within reasonable amount of time.

The approach taken by decision analysis assumes that people are able reliably to detect, to store, and to retrieve fragments of knowledge and information, but cannot as reliably aggregate these fragments into a global judgment. By forcing decision makers to decompose their decision problems into relevant components, judgmental values assigned to these components can be aggregated mathematically into a global recommendation. If the value estimates on each problem component can be individually justified, and if the aggregation method is sound, then the resultant global inference is both rational and acceptable.

Decision Tree. One of the most common structures used in decision analysis is the decision tree. The decision tree permits the logical enumeration of possible decision actions and relevant event outcomes in the future. Potential future situations that could result as a consequence of the currently available action alternatives are analyzed and evaluated separately. Then, a formal algorithm can integrate these evaluations and exhibit their impact on the overall decision problem.

A simplified decision tree is shown in Figure 1-1. It begins with a listing of the major available alternatives, from which one must be selected. The square box is called a "decision node", and indicates that the branches emanating from it are to be considered as possible actions. The decision maker is free to choose one and only one of these actions. It is thus a necessary requirement of decision trees that all action lists must be mutually exclusive. Actions can precipitate other actions, and also events over which the decision maker has no control. Event nodes, shown as circles, have as branches all the outcomes that may occur at that point in the tree.

As the decision tree is expanded, more and more possible events and opportunities for actions arise. Thus, the tree looks forward into time. If one path from the beginning of the tree is followed to the end, it describes a possible future "scenario". At every decision node, the decision maker is free to choose one of the available alternatives; at every event node, an outcome will happen which is not under the decision maker's control. It is up to the group to identify all important and relevant actions and events in the particular problem domain. There are no restrictions on the number of decision or event nodes, nor is there any assumed standard length of time from one node to the next.

Judgmental Values and Probabilities. The generation of a decision tree requires not only problem structuring, but also value assignment. A "value" is a judgmental estimate in numerical form as to the worth of a particular action or event outcome. This estimate can be made on a relative scale from 0 to 100, where 0 represents the "worst" possible situation and 100 represents the "best" possible situation. Such an estimate is called a "utility" judgment. Each time additional action alternatives or event outcomes are added to the decision tree, a utility judgment is necessary for each of them. In addition, all event outcomes require an estimate of their likelihood of occurrence. This likelihood is given in the form of a probability estimate from 0% to 100%, where estimates near 0% mean that the event is highly unlikely to occur, and estimates near 100% mean that the event is very likely to occur.

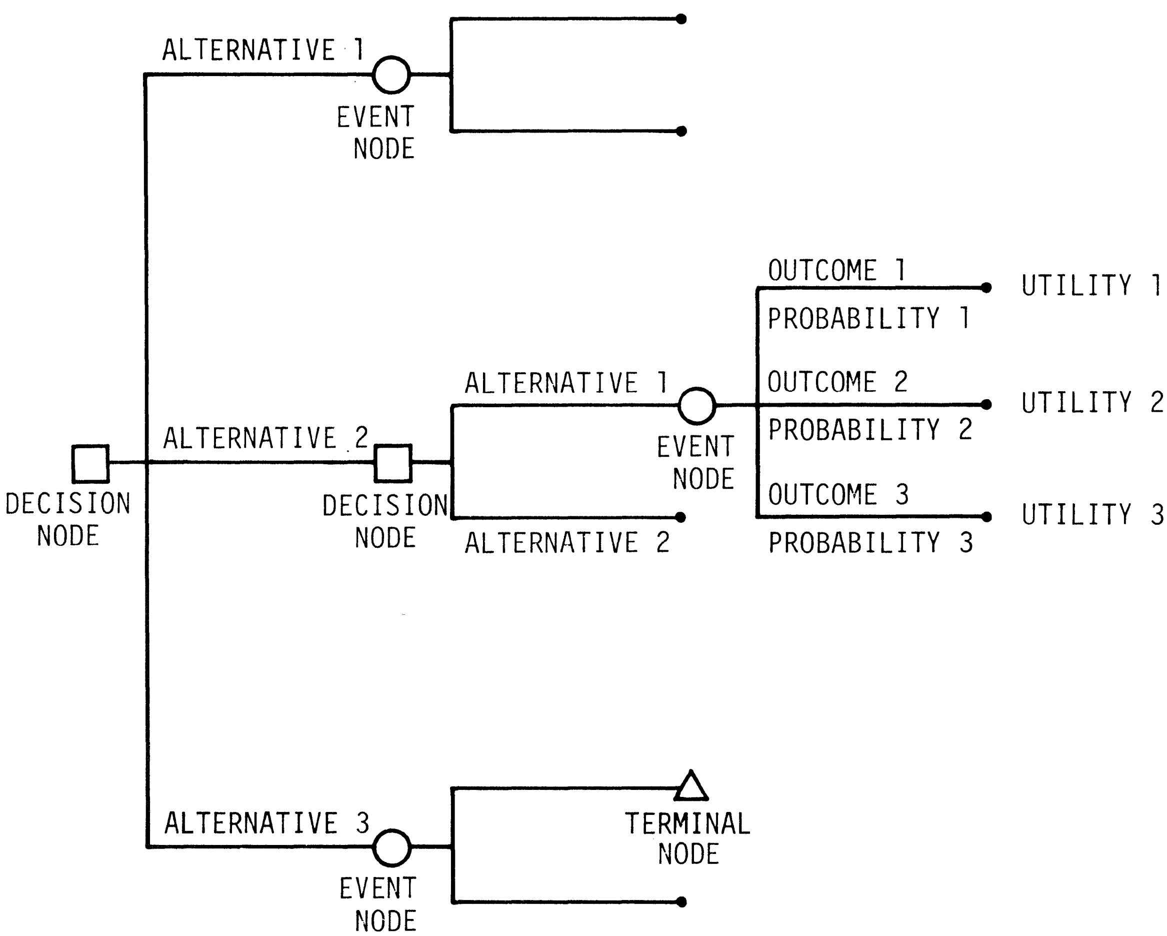


FIGURE 1-1. SAMPLE DECISION TREE

Decision Rule. With the utility and probability information in hand, it is a simple mechanical procedure to determine which of the decision options at the root of the tree is the "best". Starting from the tip nodes and working backwards, every internal tree node can be assigned a value based on the values at the end of its branches. The value of each decision node is simply the maximum of the values on its branches. This rule reflects the notion that, given a choice, a rational decision maker will choose that option with the highest utility. The value of each event node, on the other hand, is the expected value of its branches. That is, on each branch, the probability estimate is multiplied by the corresponding utility and then summed with the values on the other branches. This rule reflects the fact that events are not under the direct control of the decision maker.

When the nodal values are "rolled-back" to the root node, the initial branch with the highest value (expected utility) is recommended for adoption. Further, the final decision tree acts as a contingency plan for future decisions. Since the tree is time-oriented, the proper path can be traced as actual events occur. Every time a decision node is encountered, the branch with the highest expected utility should be followed.

1.3 System Description

The Perceptronics group decision aiding system is an integrated, computer-supported aid. Its purpose is to improve group decision making by permitting continuous participant interaction with the computer during the decision making process. The aiding methodology combines guided elicitation of a group decision tree with direct and immediate feedback of key elements in the tree-building process. The decision system aids the group process in five main ways:

(1) Decision Tree Problem Structuring

(2) Full Group Participation

(3) Identification of Critical Issues

(4) Conflict Resolution

(5) Decision Recommendations

Each of these are discussed separately below.

Decision Tree Structuring. Basically, the aiding system guides the group in the construction of the decision tree -- a structure that permits the formal representation of major decision alternatives as well as possible future consequences. Through use of the decision tree structure, the group members are able to focus their discussion on the issues that are most consequential in reaching a final problem solution. This structuring does not inhibit the formation of creative or innovative problem solutions to the decision problem. However, it prevents loss of valuable time in arguments about irrelevant issues.

Full Group Participation. Each group member enjoys full and equal participation in the decision process through individual computer-entry of required probability and utility values. These inputs are aggregated with those of the other members to form a group value which is displayed to the group, and is open for discussion. By giving each participant an assured voice in the decision process, domination by one or two individuals is avoided.

Identification of Critical Issues. As the decision situation is dissected, a more and more detailed analysis is required. Normally the group would be required to treat all aspects of the analysis equally, regardless of whether a particular area was worth the effort required to develop it. Through a technique called "sensitivity analysis", the aiding system automatically identifies those parts of the decision tree most critical to the final decision, and recommends these for discussion by the decision group.

In this way, the group is constantly led toward consideration of the most crucial issues, and toward a more efficient decision making process.

Conflict Resolution. During the course of utility entry by individual group members, excessively large differences in value may occur on particular issues. The group decision system recognizes these value conflicts, and helps to resolve them. When a value conflict occurs, the area of conflict is identified, and a decomposition procedure based on the Multi-Attribute Utility Model (MAUM) is initiated. This procedure breaks the area of conflict into its constituent attributes. The group then enters separate values for each of the attributes, with the objective of isolating the conflict to one or two. By finally resolving conflicts on a few detailed points, the group is generally able to come to an agreement on the overall area.

Decision Recommendation. The Group Decision Aid recommends a course of action based, by decision analytical calculations, on the inputs contributed by all group members. Each alternative is given an expected utility value. The recommended alternative is the one with the highest utility. Values and recommendations are available at every stage of the tree-building process. If a recommended alternative is clearly ahead of its neighbors, the group may elect to accept it at any time. If, on the other hand, expected utilities are tightly clustered, the group may elect to continue analysis until a clearly superior alternative appears, or until a decision is forced by a time deadline.

A major advantage of the group decision aiding system is that there is no minimum time necessary to obtain a final decision. The decision aiding process is structured into repetitive decision "cycles". Each cycle expands one aspect of the problem in greater detail, and a system recommendation on the best group decision is available after each cycle. Of course, the quality of the final decision will depend upon how much time is spent using the aid.

However, preliminary experiments have shown that a typical group can complete 40 to 50 decision cycles in about 4 hours. This level of detail is sufficient to provide all group members with a high level of confidence in the value of the final decision.

An innovative design element in the group aiding system is the use of a skilled technician called the "intermediator". The primary function of the intermediator is to facilitate communication between the group and the computer. The intermediator both directs operation of the aiding program, and translates spoken requests from the group into computer language. This leaves the participants with only the simple task of entering numerical values at designated program points. As a result, virtually no participant training is needed to operate the system, and a group can begin work on its decision problem almost immediately after it is convened.

1.4 Empirical Evaluation

Empirical evaluation and testing of the group decision aid has played a major role in its development. Several experimental decision making sessions were included in the first-year effort. These experiments were performed by representative decision groups using a previously synthesized scenario.[1] The scenario, which involves the choice of reactions to an international terrorist event, was chosen to fulfill a number of important criteria. These include:

(1) Credibility and interest to the military as well as to the test groups

(2) Inclusion of options already familiar to the selected group participants

(3) Reasonable complexity to allow a rich set of alternatives and events

(4) Existence of significant judgmental issues which may form the basis for conflict in values

[1] Formulated by CACI Federal Systems Group, Washington, D.C.

Initial tests have shown a clear acceptance of the aid by the participants. It was found that a very small amount of time is necessary to become familiar with the system procedures even by people with no formal training in decision analysis or value estimation. Group members felt that they were helped significantly by the automatic guidance features of the computer program. At the same time, the participants felt that the intermediator's role was crucial. Presence of the intermediator provided the necessary level of confidence required to follow the prescribed procedures and use the aid efficiently. Thus the Group Decision Aid represents a unique and useful example of man-machine synergism.

2. SYSTEM DESCRIPTION

2.1 Decision Environment

2.1.1 Conference Facilities. The Perceptronics Group Decision Aiding System occupies two adjacent rooms, with the computer support equipment separated from the decision room. The group decision room, shown in Figure 2-1, is presently designed for three participants and an intermediator, all seated at a conference table. The conference table is equipped with specialized data entry terminals for the participants as well as a keyboard-display terminal for the intermediator. Facilities also exist for both audio and video recording of group decision sessions.

Built into the front of the conference table is an Advent color video projector. Information concerned with the tree elicitation process is projected onto the large screen video display, located at the front of the room. The display is capable of showing lists of discussion items, bar charts, and attribute graphs, as well as partial and full decision trees which accentuate critical paths.

Each participant has an individual data entry terminal on the table in front of him. The terminal, shown in Figure 2-2, has the capability to accept numerical and YES/NO entries. A large 8-digit LED display shows the current numerical entry, as well as the previous entry for comparison. At the left of the keyboard are indicator lights that prompt the participants to enter specific types of data at the proper time. These indicators are:

(1) ENTER VALUE

(2) ENTER PROBABILITY

(3) ENTER LEVEL

FIGURE 2-1. A DECISION GROUP AND INTERMEDIATOR AT THE INSTRUMENTED CONFERENCE TABLE. THE ADVENT VIDEO PROJECTOR IS IN THE FOREGROUND.

FIGURE 2-2. A PARTICIPANT TERMINAL, SHOWING THE DESIGNATOR SIGNAL (ENTER CHOICE) AND LED FEEDBACK DISPLAY (3).

(4) ENTER CHOICE

(5) VOTE

(6) ERROR

(7) PRESS CLEAR

The data terminals are also capable of displaying auxiliary numerical information generated by the computer. This capability allows, for example, previously entered values to be re-displayed at a later time as a reminder of earlier estimates.

2.1.2 The Intermediator. The intermediator's terminal, shown in Figure 2-3, contains a full alpha-numeric keyboard and a small video display on which he receives program information essential to his functions and different from that shown on the large-screen display. The intermediator acts as the communications link between the group and the decision aiding system. Action alternatives and event outcomes that are generated by the group are entered into the group decision system by the intermediator, using the alpha-numeric keyboard. He also leads the group through the decision process using guidance messages appearing on his small-screen display and interpreting, when necessary, information appearing on the large screen display. The following enumerates some of the more important functions of the intermediator.

(1) Defines the value and probability scales to the group members.

(2) Enters names and/or abbreviations for decision alternatives and event outcomes as they are generated.

(3) Activates various data displays for the group when requested.

(4) Clarifies specific actions the group is to take at various points in the decision process.

(5) Performs editing functions on entered data.

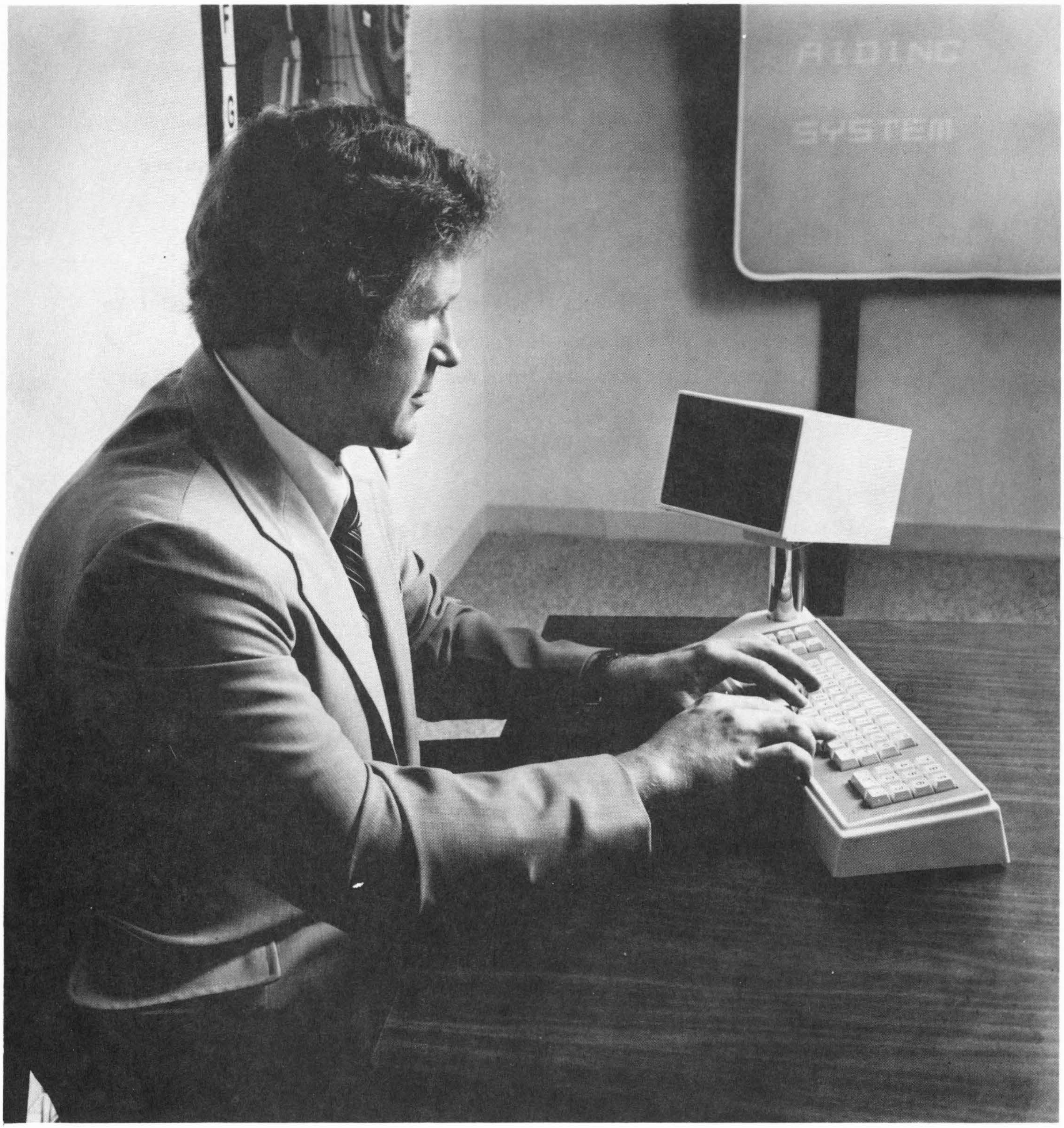


FIGURE 2-3. THE INTERMEDIATOR AT HIS TERMINAL, SHOWING THE FULL ALPHANUMERIC KEYBOARD AND PRIVATE COMPUTER FEEDBACK DISPLAY.

(6) Activates group conflict resolution procedure when required.

(7) Alerts group when numerical data entry is required.

(8) Requests hard copy of current decision tree as required.

2.2 Aiding Processes

2.2.1 Decision Cycle. The decision aiding procedure is organized into decision "cycles". A complete cycle represents the expansion of one node of the decision tree, and involves five major steps (See Figure 2-4):

(1) Node Selection

(2) Alternative and Outcome Generation

(3) Value Elicitation

(4) Conflict Resolution

(5) Decision Analysis

The first step in the cycle, node selection, is based on a system recommendation of the currently most critical node. Once the area of discussion has been established, the major action alternatives or event outcomes, as the case may be, must be generated. Each alternative or outcome is then assigned a utility value and, for outcomes, a probability value. If conflicts arise, the multi-attribute utility model is activated to resolve them. The current decision tree is then analyzed to determine the best decisions thus far, and to plan for the next decision cycle. This cycle is repeated for each node of the tree that is expanded. A recommendation for the best decision is available at the end of each cycle, and the group is free to terminate the session or continue.

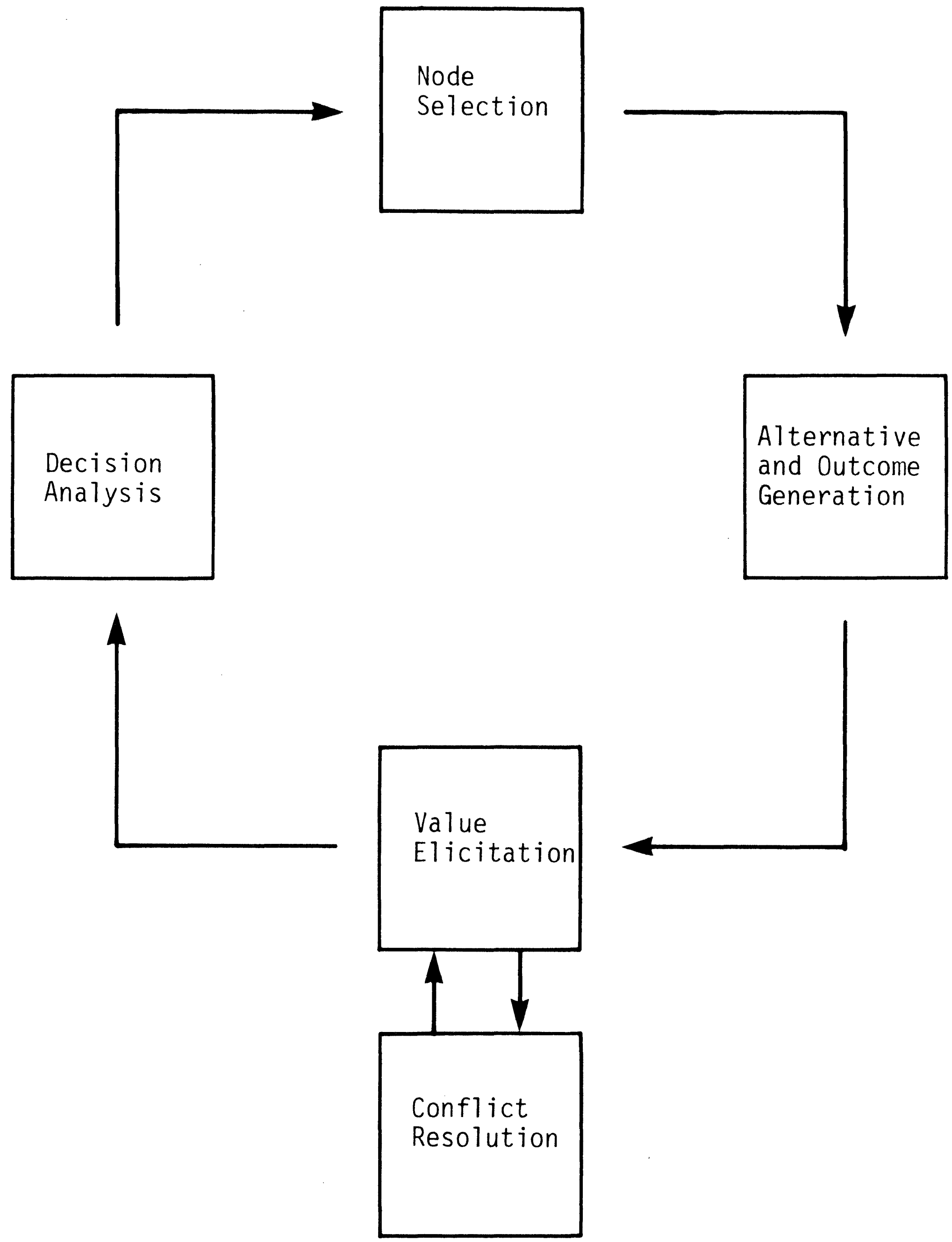


FIGURE 2-4. DECISION CYCLE

2.2.2 Attribute Selection. Before the decision cycles can begin, the group must prepare for discussion by establishing the relevant attributes of the particular decision problem. The "attributes" are the underlying issues that will ultimately form the basis for argument or agreement. For example, if the decision problem is whether or not to build a nuclear power plant,some relevant attributes might be: (1) effect on environment, (2) safety of nearby residents, (3) effect on local economy, (4) effect on energy requirements, etc. As the attributes are mentioned and discussed, the intermediator places them on the large screen display where they can be edited, and finally accepted for use during the decision making process.

All attributes are currently considered to have the same importance. That is, their "weights" with respect to each other are equal. This assumption was shown to be acceptable by Newman, Seaver, and Edwards (1976) provided there are no negatively correlated attributes. It is thus up to the intermediator to insure that the attributes are stated in such a way that a change in one will not cause another to change in the opposite direction. It is planned to incorporate a provision for differential weighting of attributes into a future version of the group system. Further, experimentation with the group system has shown that group members sometimes find one or more attributes irrelevant to the particular action or event under discussion, and thus wish to delete certain attributes and/or add new ones. Facilities for changing the attribute list at any time are also planned.

2.2.3 Next Node Selection. The aiding system uses a sensitivity analysis algorithm to determine the most critical tip node, and recommends it for expansion by displaying graphically the path from the root node to the recommended node. *The most "critical" tip node is defined to be the one that is most likely to cause a change in the currently best initial branch at the decision tree root.* The reasoning is as follows:

as the tree expands, values are placed on newly-generated action alternatives and event outcomes. These new values affect the values of the initial decision options, located at the beginning of the tree. The initial decision options are considered to be the most important, since the first action to be taken in the problem solution must be selected from among them. Since the root branch with the highest value is chosen as the system's recommendation for the best decision option, it follows that the tip node with the best chance of changing the currently highest root branch is the one that should be expanded. This tip node is defined as the most "sensitive", and is the one that is recommended by the system for discussion. Details of the sensitivity algorithm itself are given in Appendix A.

2.2.4 Alternative and Outcome Generation. When the group discusses the possible opportunities for decision actions and the possible events that may occur, the group members take into account the decision path as described by the sequence of nodes from the root to the current node being expanded. The discussion naturally leads to a determination of the preferred node type. At this point, an indicator light on the data entry terminals prompts each group member to vote on one of the following three choices:

(1) Decision Node

(2) Event Node

(3) Terminal Node

A vote for a decision node indicates the group's desire to consider possible action alternatives, while one for an event node shows a desire to list possible event outcomes. If the group chooses to terminate the path, the elicitation cycle is aborted and a new node is selected for expansion by the sensitivity analysis algorithm. A terminated path is dropped from consideration in subsequent cycles.

Through group discussion, relevant action alternatives or possible event outcomes (as the case may be) are generated and entered into the system by the intermediator. The list appears on the large screen display and may be changed or edited as the group wishes before final acceptance. The list of action alternatives should be mutually exclusive. This means that although a number of decision actions may be possible, only one from the list can be chosen. The intermediator guides the group in structuring the alternatives so they are mutually exclusive. Event outcomes must not only be mutually exclusive, but must also be exhaustive. That is, it should not be possible for (1) two outcomes to occur together or (2) an outcome to occur which is not in the list. If the lists of alternatives or outcomes are not mutually exclusive, calculation of the values of internal tree nodes from those at the tips is invalid. The intermediator aids the group in complying with these requirements.

2.2.5 Value Elicitation. The group members now enter their estimates of the utility or "worth" of the generated action alternatives (or event outcomes). Each alternative (or outcome) is taken, one at a time, (see Figure 2-5) and an indicator light on the data entry terminals prompts the group members to enter a value within the established range of 0 to 100. Each estimate is independent and unrelated to the others. Each, however, takes into account (1) the decision path in the tree leading to the situation, (2) the possible opportunities for future actions offered by the situation, and (3) the possible events, good or bad, which could occur as a result of the situation. Even though values for early actions should theoretically take into consideration all possible subsequent event outcomes, such values are actually "provisional", since they will most likely be refined at a later time by expansion of the action node into possible events. Holistic values for actions, or chains of actions, seem to be less reliable and accurate if no events have been established. Thus, the group is encouraged by the intermediator to expand events after actions. Individual values are averaged, in the absence of conflict, to achieve a group value.

DECISION PATH:

ACTION: ATTACK

What events might occur?

1. Lose hostages and Mandero City
2. Lose hostages and save city
3. Save hostages and lose city
4. Save both

VALUE ASSIGNMENT

0 ——————————————————— 100

Worst Effect ——— Best Effect

Enter a value and press the SEND key.

FIGURE 2-5. COMPUTER PRESENTATION OF UTILITY ESTIMATION FOR EVENT OUTCOMES

Probability estimation is required for event outcomes. Each event outcome is considered, one at a time, and its likelihood of occurrence (see Figure 2-6) is estimated. An indicator light on the data entry terminals prompts the group members to enter a probability for each outcome. The probabilities are entered in the form of percentages from 0% to 100%, where probabilities near 0% indicate an opinion that the outcome is unlikely to occur and probabilities near 100% mean that the particular outcome will very likely occur. Probability estimates, unlike utility estimates, are related in the sense that the sum of the entries must be 100% over all of the outcomes. After anonymous entry of probabilities, they are averaged and entered into the tree. It has been previously shown that averaging probabilities is the least biased aggregation method (Dalkey 1977), and that other methods do not give better estimates of group opinion (Winkler, Murphy, Katz, 1977).

2.2.6 <u>Conflict Resolution</u>. At some point in the elicitation of utilities for alternatives or outcomes, it is possible that members of the group will differ significantly on the values assigned. At this juncture, a closer look at the utilities associated with the node must be made. By closer, we mean a shift from "gestalt" or "holistic" value assignment to multi-attribute utility measurements (MAUM). The reason for this shift is that arguments over the assignment of utility usually reflect genuine disagreements about values. Multi-attribute utility measurement (breaking a holistic evaluation down into its component parts) can indicate explicitly the underlying values of each participant, show where and how much they differ, and in the process, frequently reduce the expanse of such differences. The system determines if a value conflict exists by calculating how far each group member is from the average. If there is group agreement, no further processing is necessary. However, if a conflict is detected, the Multi-Attribute Utility Model (MAUM) procedure is initiated. This procedure allows the group to decompose the alternatives in conflict into the underlying attributes that were established at the

DECISION PATH:

ACTION: ATTACK

What events might occur?

1. Lose hostages and Mandero City
2. Lose hostages and save city
3. Save hostages and lose city
4. Save both

PROBABILITY ASSIGNMENT

0	50	100
Cannot possibly occur	50-50 chance of occurrence	absolutely sure it will occur

Enter a value and press the SEND key

FIGURE 2-6. COMPUTER PRESENTATION OF PROBABILITY ESTIMATION FOR EVENT OUTCOMES beginning of the session (see Figure 2-7). By assigning utility judgments on each attribute separately, with respect to the overall alternative, it is hoped that the group can isolate their disagreement to one or two major issues and resolve the conflict by a detailed discussion.

The process of assigning utilities to each of the attributes may bring the group into immediate agreement with a quick resolution of the conflict. However, it is possible for the source of the conflict to come from one or more particular attributes. Figure 2-8 shows a histogram displaying the values entered by the group for each attribute. Each group member is represented by a differently colored bar. The attributes in conflict are identified by the system (by red titling) and become the targets for group discussion. Figure 2-9 shows a display of values for seven attributes in graph form, with the utility scale given at the left for reference. Each group member is represented by a differently colored line. At the bottom of the display, the attributes in conflict are shown in red.

After the group has had sufficient time to discuss the relevant issues surrounding each attribute in conflict, a procedural decision must be made. The group may:

(1) Re-enter values for those attributes in conflict.

(2) Re-enter values for all attributes.

(3) Average existing values.

The group may elect to re-enter values for one or more attributes, hoping to reach agreement (Figure 2-10). If there is still conflict, the MAUM procedure is repeated. Finally, the procedure is terminated when the group either reaches agreement, or decides to average the existing values and continue node expansion.

CONFLICT RESOLUTION

FOR THE EVENT

HOSTAGES KILLED

Estimate its effect on each value attribute.

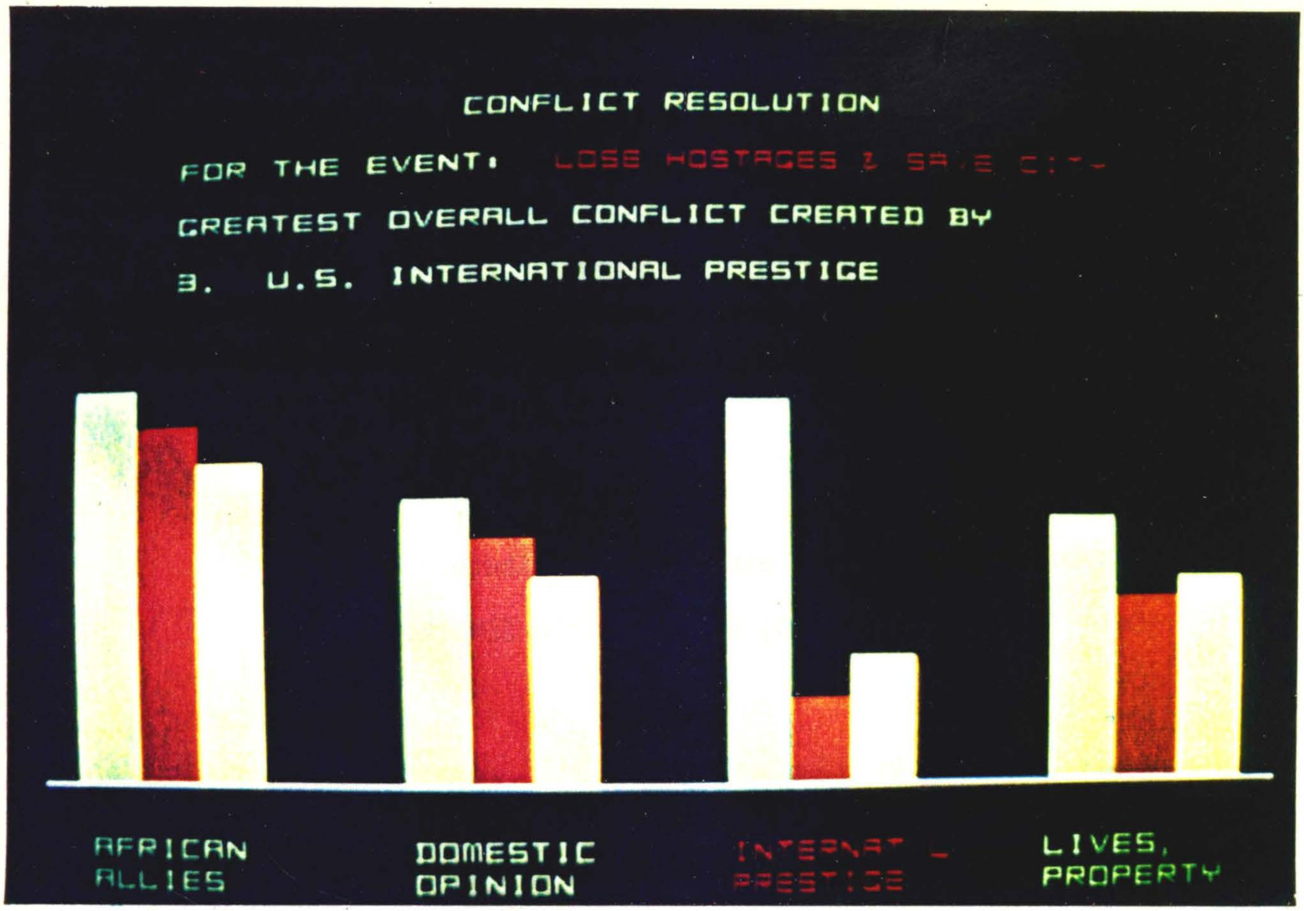
Enter a value (0 to 100) and press the SEND key.

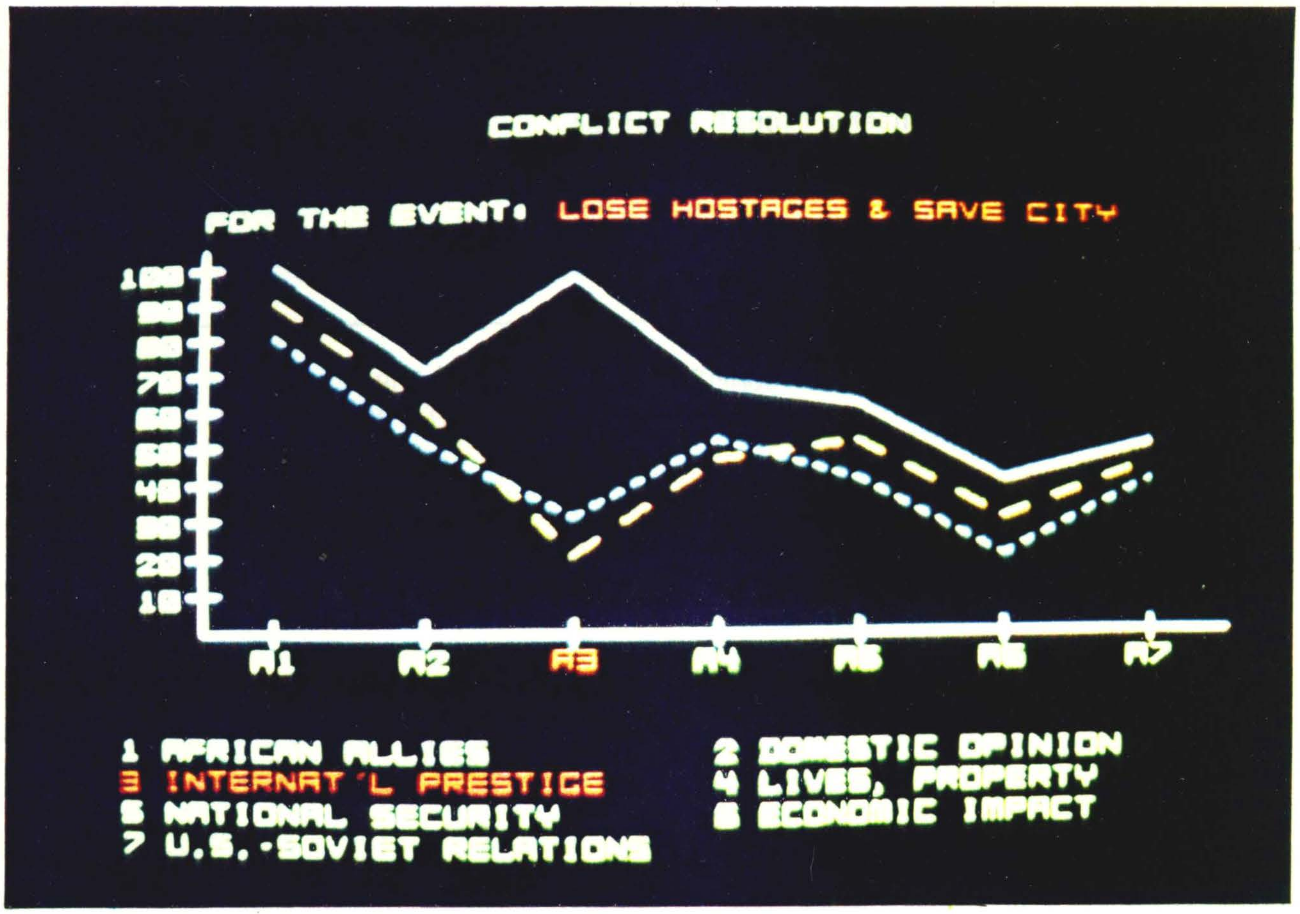
0	100
Best Effect	Worst Effect

1. Effect on African allies
2. Effect on domestic opinion
3. Effect on international prestige
4. Effect on lives and property

There is still conflict on this outcome.

FIGURE 2-7. COMPUTER PRESENTATION FOR MULTI-ATTRIBUTE UTILITY ASSESSMENT





FIGURES 2-8/2-9. ATTRIBUTE UTILITY CONFLICT DISPLAYS

CONFLICT RESOLUTION

Disagreement on the level of the attribute

"Effect on International Prestige"

The value you previously assigned to this attribute is displayed on your terminal.

The range of values assigned by the group is 10 to 55. Enter a revised attribute value and press the SEND key.

Agreement on this outcome

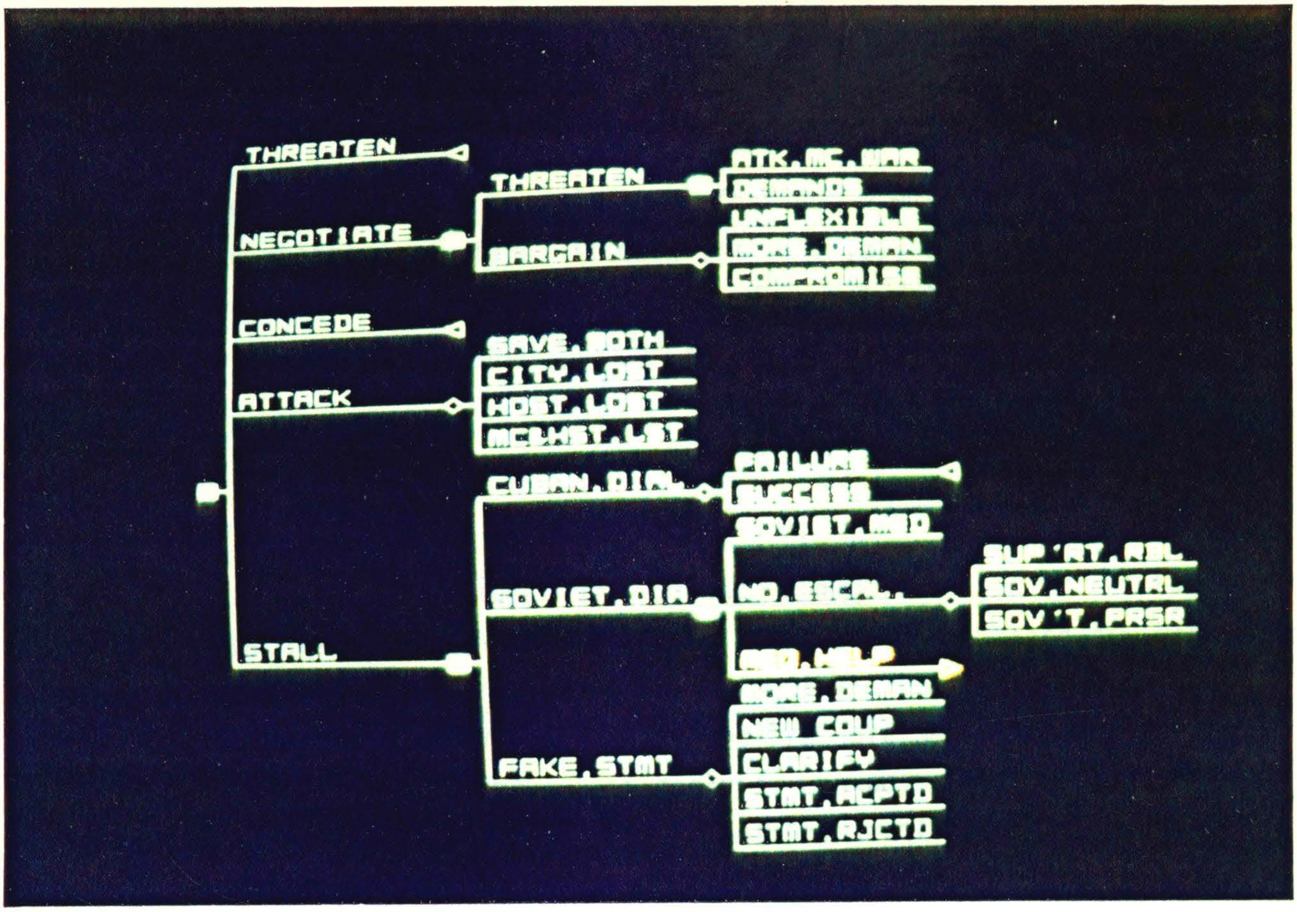
No further discussion is necessary.

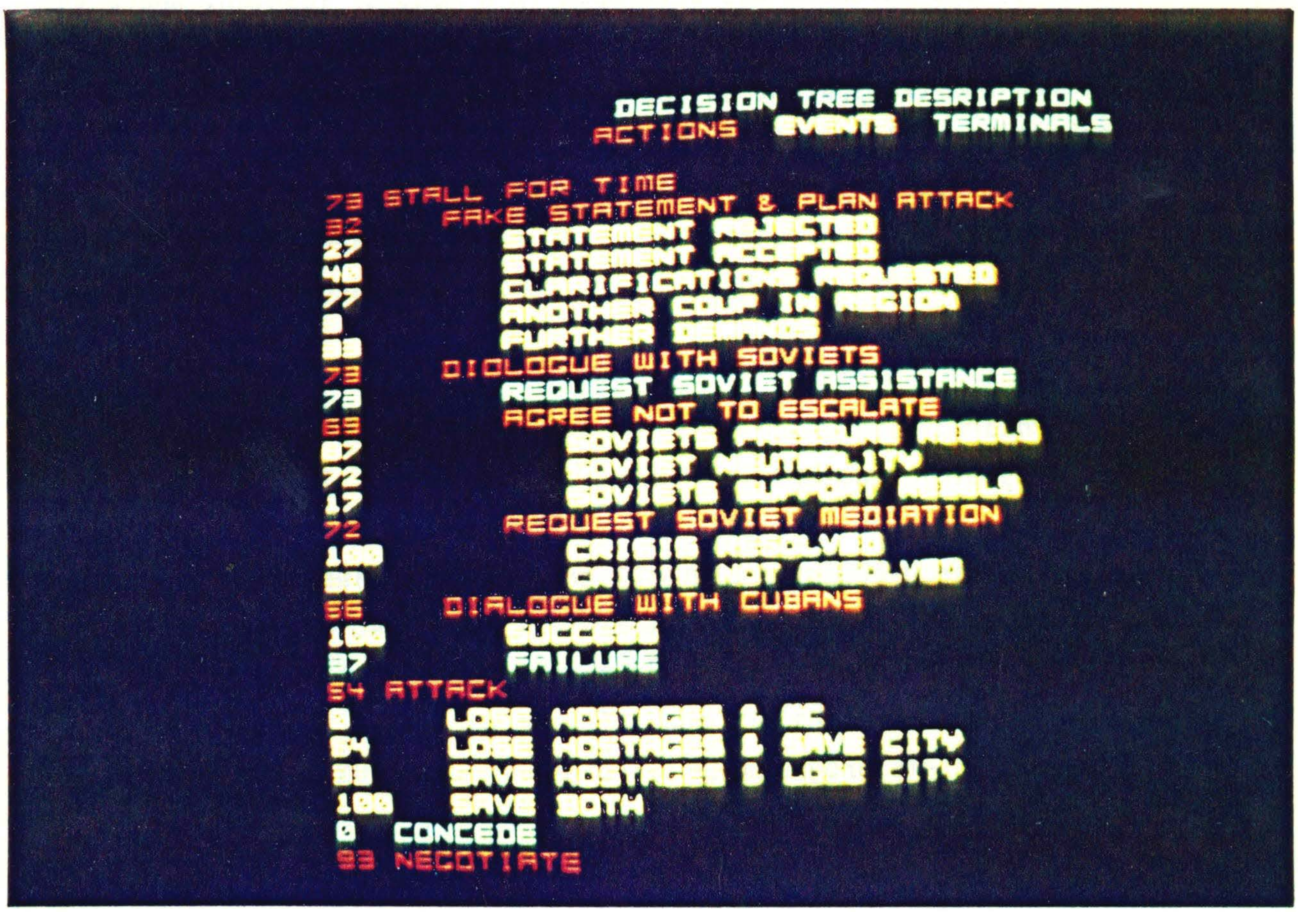
FIGURE 2-10. COMPUTER PRESENTATION OF AN ISOLATED CONFLICT ON A SINGLE ATTRIBUTE WITH SUBSEQUENT RESOLUTION

The conflict resolution procedure is described in detail in Appendix B. It should be noted that conflict resolution occurs for utilities only. There is, at present, no provision for probability conflict resolution; inclusion of such a capability is planned for the future. In addition, an alternative approach to conflict resolution, which is much closer to the philosophy of sensitivity analysis, is currently under investigation. Using this approach, a "conflict" would only occur when the values of each participant, taken individually, would cause a different in preference for one of the initial decision branches. A more detailed explanation of this approach may also be found in Appendix B.

2.2.7 Decision Analysis. At the end of each decision cycle, a number of different summary displays are available for analysis of the decision tree generated up to that point. The major display is a graphic representation of the full tree, showing node types and branches with abbreviated labels. Figure 2-11 shows a sample of this display. Decision nodes are shown as solid boxes, event nodes as circles, and terminal nodes as triangles. Open-ended branches indicate a potential place for further node expansion. On the right side of the figure near the center, a particular branch has been highlighted in yellow. This branch has been selected by the system as the most sensitive part of the tree and is recommended for expansion by the group on the next decision cycle. The tree may also be displayed in outline form, where the structure is shown by indentation. Figure 2-12 shows a sample outline-form tree with the current internal utility value displayed to the left of each node. Action nodes are shown in red, event nodes are in yellow, and terminal nodes are in green.

At this time, the system recommends the best decision thus far, based on all of the information input up to that point. The recommendation for the best decision is that root branch with the highest expected utility. This recommendation can be displayed along with the others for





FIGURES 2-11/2-12. DECISION TREE DISPLAYS comparison. If the group feels that the values of one or more decision options are too close, they may wish to continue expanding nodes until a clean distinction is reached or until the problem has been satisfactorily analyzed. Thus, the program may be continued or terminated at the completion of any decision cycle.

2.3 Computer Support

2.3.1 System Development Concept. Development of the group decision aid was based on a separation of the computer support system from the group decision facility itself. With this dichotomy in mind the conceptual framework of a decision aiding system was developed essentially independent of the computer resources required to support it. The color display system and participant terminals were chosen to best fit the decision making environment. Figure 2-13 shows the facilities arrangement. Consequently, the software was developed in a modular fashion, where the interfaces to the terminals used in the group decision facility were well-defined and transparent to the remaining aiding system. The interfaces are easily modified to accommodate different terminals. This development methodology enhances the transferability of the group aiding system to other decision facilities. The following sections describe the hardware resources and the software components used in implementing the system at Perceptronics.

2.3.2 Hardware. The group decision aiding system is implemented on a DEC PDP 11/45 minicomputer with 64K words of memory. The operating system used is UNIX, a versatile timesharing and multi-tasking system favored by research-oriented users of the PDP 11 series of computer. Capabilities of UNIX include full timesharing of 2-40 users, multi-tasking (spawning of independent processes), a comprehensive file-management system, and numerous compilers and software packages, including C, a Pascal-based systems programming language (in which UNIX itself is

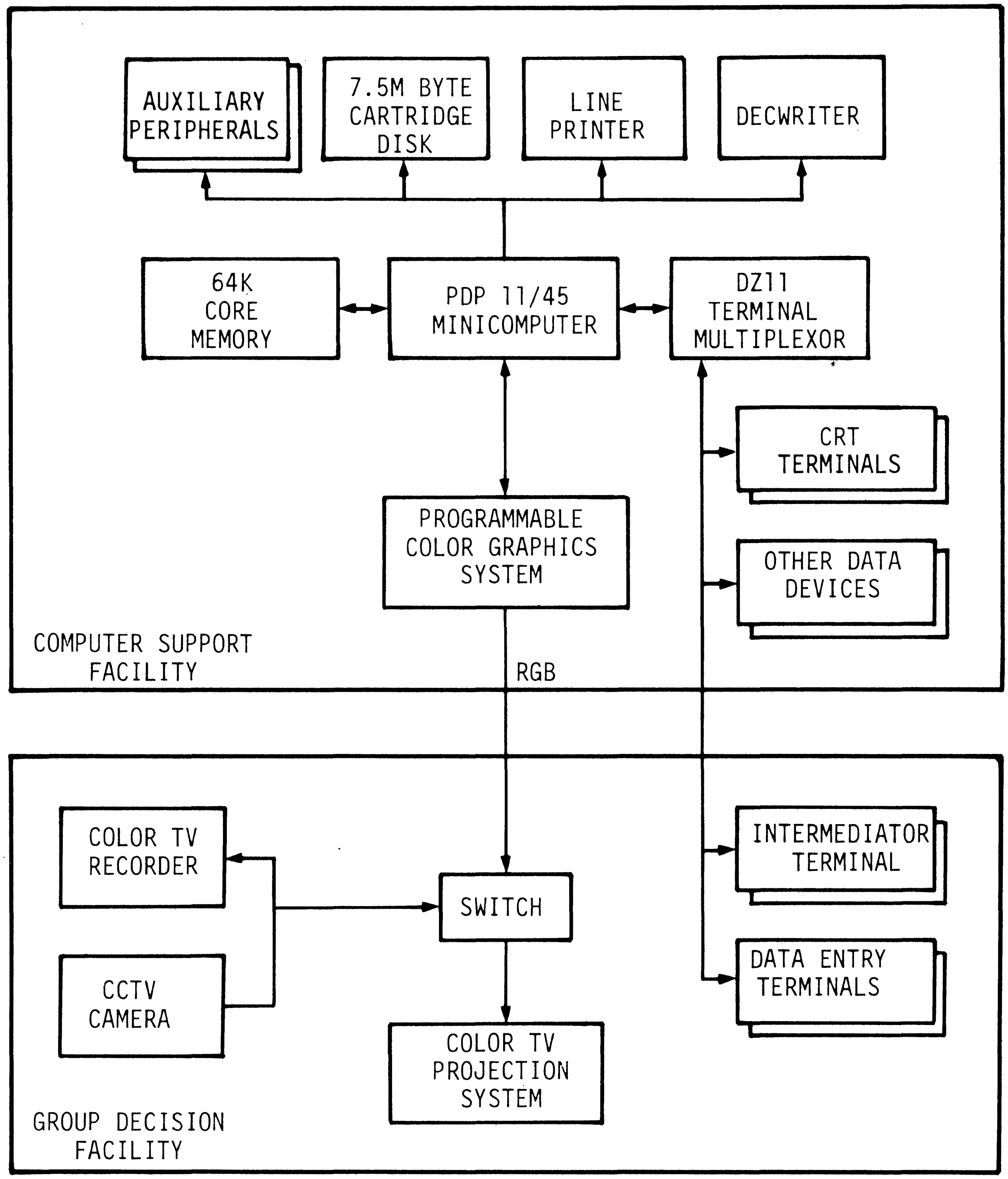


FIGURE 2-13. FACILITIES ARRANGEMENT

written). Support is provided by Bell Telephone Laboratories and by a large (100-150) user group.

Terminals. The decision makers and the intermediator are seated at a conference table facing the Advent large screen display system (see Figure 2-1). Situated in front of each participant is an Interface Technology 732 data entry terminal (DET) which is used for entry of numeric values and voting (see Figure 2-2). The DET's have an eight-digit LED display, numeric keypad, function keys, and eight indicator panels that are under program control.

The intermediator has an Informer D301 terminal equipped with a 16 line by 32 character CRT, full alphanumeric keyboard, and function keys. The display unit of the terminal can be rotated to obtain the optimum viewing angle. Using the Informer terminal, the intermediator can enter and edit lists of alternatives, query and direct the system, and receive reports from the computer aiding system on group performance.

Graphics Support. The Genisco Model GCT-3000 programmable graphics system generates a TV-compatible, 8-color, full-graphics display with a resolution of 512 x 512 raster units. The graphic system contains its own very high speed (150 ns cycle time) fully programmable microprocessor with 4K of static random access memory (RAM) for program storage plus direct memory access (DMA) to the PDP 11/45 main memory. Any graphics image of rectangles, circles, vectors, conics, polygons, or other shapes can be displayed in user selectable colors. These can further be overlaid or annotated with alphanumeric text in any display location.

The large screen display is the Advent 1000A color TV projection system which uses three color projection tubes to form a bright picture on a highly-reflective 7-foot diagonal screen. In the Perceptronics system, the Advent electronics are modified to accept the 10 MHz bandwidth output of the Genisco graphics display system. The projector is inset into the conference table.

2.3.3 Software. The group decision aiding software was implemented in the C language from a top down design which facilitates program modifications as new ideas are incorporated into the system. There are four major software components (see Figure 2-14) totalling 6000 lines of code, plus an additional 2600 lines of assembly code composing the Genisco graphics operating system. The major software components control the following:

(1) The images produced on the Advent large screen display.

(2) The internal decision tree structure and computational procedures that manipulate the tree.

(3) The interactions between group members and data entry terminals.

(4) The operation and display of the intermediators terminal.

Graphics Software. Three levels of software control the Genisco color graphics system. The lowest level functions, composed of Genisco assmbly instructions, provide the control interface between PDP 11 software and the graphics system. Another set of functions at the middle level provides X, Y raster positioning, color selection, and operation mode when displaying text or geometrical shapes. The top level procedures provide simple C program access to a formatted screen of n lines by m characters. The Genisco system is easily initialized to a display position by designating line numbers and/or character column positions. Other procedures at this level can then write text or draw vectors on the display.

Participant Interface. Data entry and display procedures control the interactive information flow between the decision makers and the system. Participants are prompted by lighted message windows for the

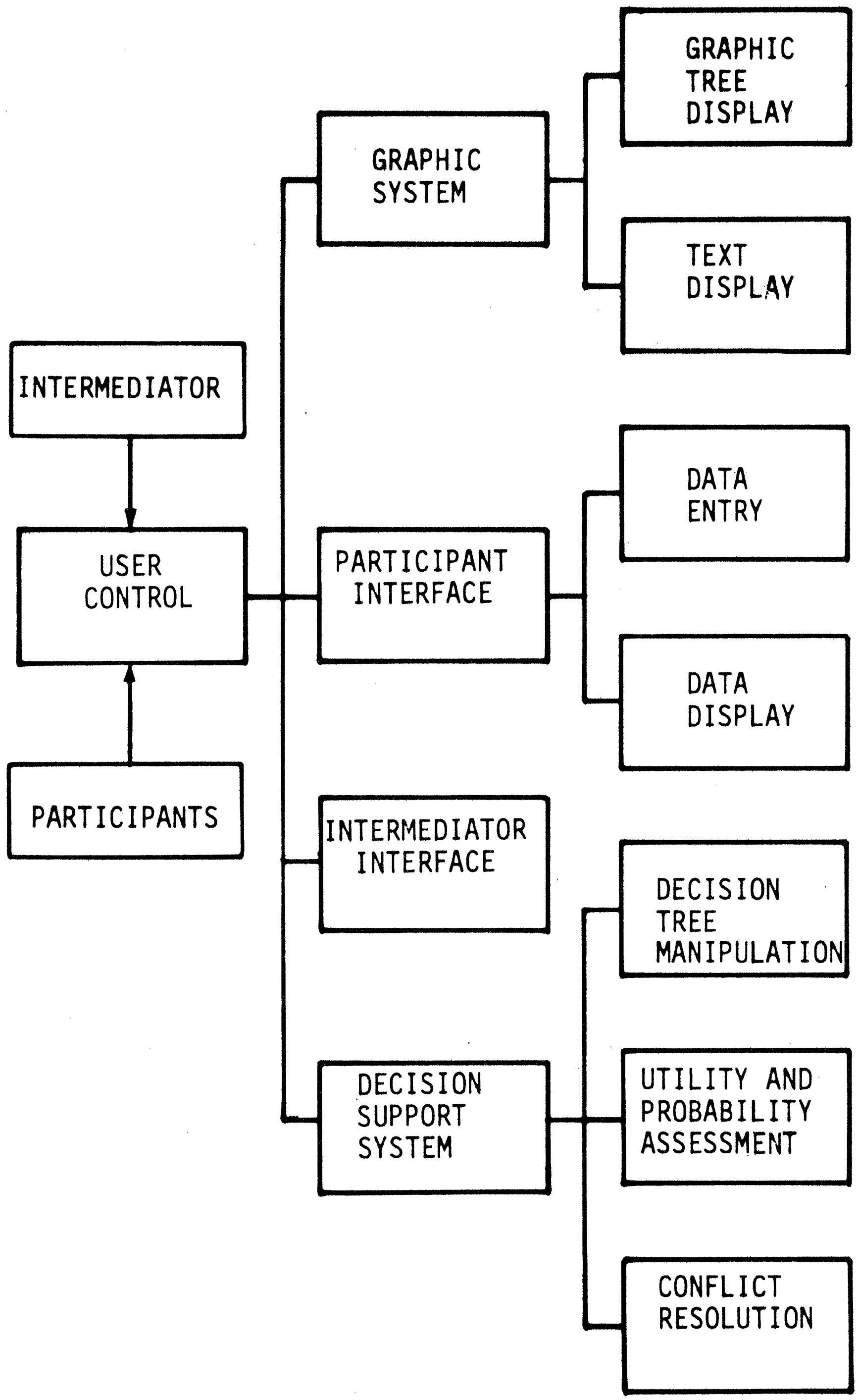


FIGURE 2-14. MAJOR SOFTWARE SYSTEMS

various inputs required by the system, e.g., utilities, probabilities, and vote response. Feedback control is maintained by these procedures and information is displayed on the individual participant terminals to effect ease of terminal operation.

Intermediator Interface. The software interface to the intermediator terminal provides system and group supervisory control. The intermediator is provided system processing information at all times. Option lists displayed on the terminal at various points in the elicitation and node expansion cycle provide immediate control over system operation. The intermediator also assumes prime responsibility for program pacing during the decision aiding session.

Decision Support System. The decision tree processing software expands the representative tree structure, elicits utilities and probabilities from individuals, analyzes values for conflicts, invokes the multi-attribute procedures to resolve conflicts, graphically displays histograms and line graphs to distinguish areas of conflict, and displays the graphical form of the decision tree on the large screen display. Other tree processing functions include rollback calcualtions and sensitivity analysis. There are also procedures to determine best path, select the best node for expansion, aggregate utilities and probabilities, and update the decision analysis profile during the decision making session.

The the group proceeds through the decision cycles, a complete record of the computer interaction is stored for later retrieval and analysis. This record is called the "audit trail" and includes:

(1) The list of initial selected attributes as well as those rejected.

(2) A record of every action alternative and event outcome considered.

(3) A listing of each utility and probability value input by the group members at each stage.

(4) A complete record of all conflict situations showing initial and modified attribute assessments.

(5) A complete listing of the decision tree after each decision cycle including all current internal node values and probabilities.

A sample audit trail is given in Appendix C.

3. TEST AND EVALUATION

3.1 Test Scenario

In order to test the capabilities of the Group Decision Aid, a reasonably complex and realistic scenario was required for the observation of user interface with the system, assessment of time required for completion of a complex task, and determination of the nature and degree of intermediator instruction and prompting required for efficient utilization of system features. A fictitious, but plausible, crisis scenario based on counter-terrorist actions was developed by CACI Federal under subcontract to Perceptronics. The guiding criteria for scenario design were:

(1) Credibility and interest to the military as well as to the test groups.

(2) Inclusion of options already familiar to the selected group participants.

(3) Reasonable complexity to allow a rich set of alternatives and events from which to choose.

(4) Existence of significant judgmental issues which might form the basis of intra-group conflict.

The resultant scenario is summarized below.

Scenario Summary. A U.S. B-52 carrying two nuclear weapons is flying in the vicinity of Shamba, a third-world ally of the United States. Due to problems with its onboard electrical system, the plane is forced to land at Shamba's capital city of Savin. U.S. technicians are expected to arrive in four hours to effect repairs. Two hours after the B-52's landing, Shamba's government is overthrown in a coup by leftist rebels. The plane and its payload are captured and its crew executed; the U.S. Embassy in Savin is occupied and its personnel taken as hostages. The rebels subsequently issue a list of demands and an ultimatum. The U.S. has four hours to accede in principle to their demands and 15 days to carry them out, otherwise U.S. hostages will be killed and a bordering neutral city-state, Mandero City, will be bombed with the B-52's payload. Two U.S. aircraft carriers equipped with surface-to-air missiles, attack air wings, and marine assault forces have been deployed to positions twelve miles from Mandero City. Joint Chiefs of Staff estimates indicate that these forces are adequate to either free the hostages or capture the plane and bombs. To accomplish both missions, these forces must be substantially augmented. The transfer of reinforcements could be completed within 2-3 days.

3.2 Test Procedures

Three informal tests have been conducted to date, each with a duration of approximately four hours. The primary objectives of these initial tests have been to observe user performance, to obtain participant evaluations of the utility of the system, to identify any remaining technical bugs, and to examine and further refine system features. Each test group has included three subjects. Two groups have been made up of research scientists, and one of graduate students in international relations. At the beginning of the test session, briefing booklets are distributed to participants, including simulated situation reports, cable traffic, press reports, and agency briefing updates, all designed to familiarize subjects with the scenario. The subjects have about 20 to 30 minutes to review and discuss their scenario briefing materials. The information provided in these materials has generally proven adequate, as few requests have been made for clarifications or additional information. Following their review of scenario briefing materials, the subjects are given a brief introduction to the equipment, the role of the intermediator, and the elicitation procedures to be used in the session. Such concepts as utility and probability estimation, attributes, actions, and events are also discussed.

At the conclusion of the session, subjects are asked to complete attitude survey questionnaires which elicit assessment of their satisfaction with the group decision-making process and the usefulness of the decision aid. Subjects are provided hard copies of the final decision tree to assist them in making their evaluations. An audit trail, detailing all participants and intermediator inputs to the system, is also available for subsequent analysis. To date, monitoring of participant reactions and responsiveness to system features has been carried out by the intermediator. In the future, video tape recording of sessions will be made to further aid in detailed analysis.

3.3 Results

In general, all three experimental groups worked quickly and efficiently with the decision aid. In all three sessions, groups were able to complete a 4 to 5 level tree, including 30 to 50 separate nodes, within their four-hour time limit. A typical decision tree is shown in Figure 3-1. Subjects required no background in formal decision analysis, nor familiarity with decision tree construction, to employ the aid with ease. Furthermore, participants exhibited no tendency to avoid complexity in the course of their decision task, indicating that system features sufficiently clarified and simplified decision procedures such that confusion was minimal.

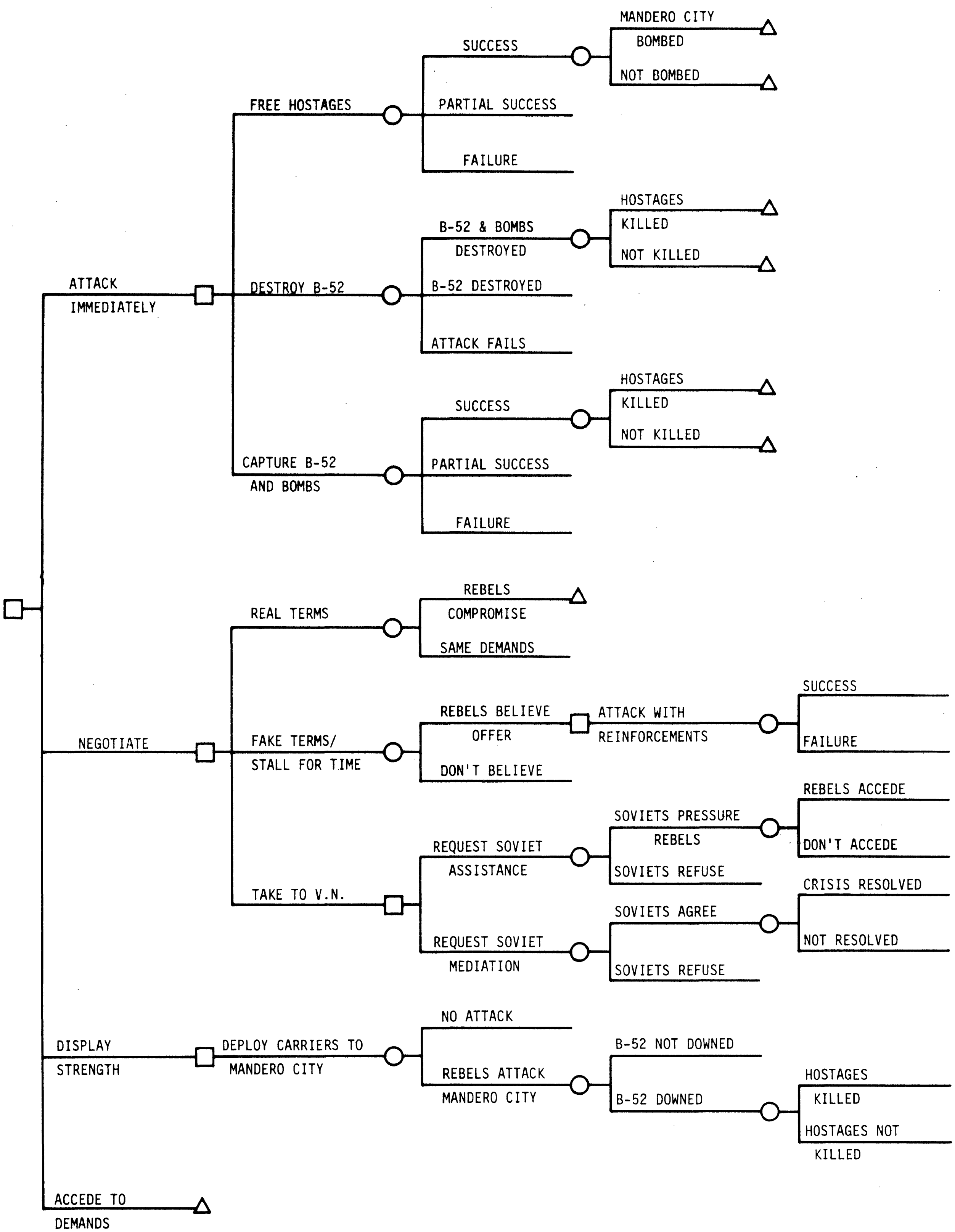


FIGURE 3-1. TYPICAL TREE DEVELOPED WITH GROUP AIDING SYSTEM

All three groups demonstrated a marked ability to adapt to the system and to use its features to best advantage in terms of time. Realizing that the conflict resolution process was rather time-consuming, for example, subjects tended to deliberate more before entering values, invoking the MAUM procedure only when actual value conflicts emerged. Finally, it was observed that participant attitudes changed during the course of the decision processes. Actions preferred at the beginning of the session were abandoned following deliberation and examination of possible subsequent events. Technically, subjects demonstrated no difficulty in interpreting system displays, nor in following the sequential logic of the program. The sense of "being lost" after substantial development of a complex tree was invariably overcome by a review of graphic and verbal displays of the group tree. Some forms of display were preferred over others, although not consistently across groups. Two groups preferred graphic representation of value conflict, for example, while the third relied primarily on histograms for resolution. In the course of initial runs, subjects often expressed the desire to restructure their trees. In addition, occasional terminal entry errors or immediate "second thoughts" highlighed the necessity for a re-entry capability as well as structural modification options. Implementation of such options is currently in progress.

Interactions with the intermediator were observed to occur smoothly. Experience has shown, however, that the intermediator must guard against participant attempts to include him in the decision-making process. There is often a fine distinction between resolving technical or procedural problems and arbitrating between substantive disagreements. For example, if three events are suggested by the group, one of which does not meet requirements of mutual exclusivity, caution must be exercised by the intermediator to ensure that no inference is made as to the relative worth of the suggested events.

3.4 Performance Evaluation Measures

As pointed out previously, evaluation is an essential part of system development. Methodologies for evaluating the group decision aid must meet two sets of criteria. First, they must assess both the objective and subjective dimensions of group performance. Second, they must provide timely results, which can be used to influence decisions concerning the immediate development of the decision aiding system. Subjective measures are generally well defined, and not difficult to obtain.

The objective dimension of group performance, which concerns the quality of deliberations, is more difficult to measure. It involves analyzing such structural properties of group deliberations as:

(1) The number of alternatives considered by each experimental group (differentiation),

(2) The extent to which each alternative considered is developed (for example, the amount of time and consideration devoted to each brance or subbranch), and

(3) The integration of alternatives within a complete tree structure (for example, the relative development of branches considered in the early and later portions of the experimental session).

In addition to examining the quality of the *process* of deliberation and decision-making, some "quasi-objective" assessments can also be made of the *content* and *correctness* of the decision reached by the experimental groups. The term "objective" must be qualified in this usage because there is no single decision "solution" for most realistic crisis management problems;

decision-makers with different values and objectives can and will come to different decisions. In this respect crisis management problems differ from intelligence questions, where there is an objective standard (ground truth) against which estimates can be evaluated. However, by using expert and experienced personnel, a set of "good" solutions can be generated. Using these "solutions" as standards, the quality of the final decisions reached by experimental groups, as well as the quality of the factors that they consider while arriving at these decisions, can be evaluated.

In summary, the overall objective of further formal tests and experiments will be to determine, by quantitative as well as qualitative measures, the capabilities of the group decision aid in assisting decision makers in solving real-world decision problems, and to determine the extent to which the aid facilitates the decision process. It appears that such determination might be facilitated by using a multi-attribute scheme, much like that employed in the aid itself, both for the elicitation of subjective judgments and for the combination of subjective with objective measures.

4. CONCLUSIONS

4.1 Advantages

The specific advantages of the Perceptronics computer-based decision aiding system can be summarized as follows:

(1) Natural Group Format
(2) Structured Discussion
(3) Domain-Independent Application
(4) Equalized Participation
(5) Selective Problem Expansion
(6) Graphic Resolution of Value Conflict
(7) Continuous Decision Recommendation

The decision tree, while a formal structure, is general enough to be applied to a wide variety of decision problems. Any decision problem which can be thought of in terms of actions and events can be accommodated. Through the incorporation of sensitivity analysis, potentially large combinations of interacting actions and events are reduced to a workable set of critical issues. Each group member has an opportunity to voice his opinion (through the input of values) on the importance of each major issue. When conflicts do arise, they are treated efficiently, allowing the group to concentrate on quickly arriving at an optimal course of action.

4.2 System Improvements

The initial system tests, as outlined in Chapter 3, were highly successful. The major development goals of the system were realized, in that experienced groups were able to work effectively with the aid toward the solution of a realistic and representative decision problem. At the same time, these trials identified a number of system areas in which existing features could be modified, or new features added, in order to improve overall system performance and power. A number of the most important areas of improvement are listed below:

(1) New conflict resolution approach (described in Appendix B) would provide a less arbitrary method of identifying conflicts while focusing on resolution when it is really necessary.

(2) Modifiable attribute list would allow the deletion of irrelevant attributes and the inclusion of new attributes based on the specific alternative or outcome in conflict.

(3) Weighting of attributes according to importance would provide a more accurate conflict resolution result.

(4) Identification of probability conflicts as well as utility conflicts might provide for the more accurate representation of final outcome values.

(5) Restructuring Procedures that would allow the group to modify previously defined paths of the tree would permit more flexibility in action and event expansion.

(6) Consistency checks and data validation algorithms would provide assurance that the value estimates given by the group were as good as possible.

(7) Weighting of participant values before averaging would allow greater levels of expertise or authority to be reflected in the decision-making process.

4.3 Development Areas

Consideration has also been given to more basic questions in the development of the group aid. Among the major development areas identified are the following.

New Problem Domains. Experience with decision problems in other domains is necessary to determine the commonalities and differences with respect to problem representation in the form of decision trees. Problems in medicine, business, negotiation, education, law, etc., as well as tactical and strategic military planning may have idiosyncrasies which must be accommodated. For example, a problem in business decision making may benefit from a monetary value scale rather than a utility scale. Further trials with groups making actual decisions in realistic or real-life environments would help identify some of these peculiarities.

Data Base Integration. It is clear that the overall decision making process would benefit if the group decision aid were integrated with a computerized data base related to the problem at hand. With such integration, the group would have access to pertinent information at each stage of tree construction. For example, when considering the actions to take at a decision node, the group might survey actions taken previously in similar situations; or when trying to decide on what events might occur as a result of an action, the group might review the current local state-of-the-world as a guide to likely occurrences.

Several options exist for effecting an integration with existing or developmental data bases. The simplest, but least appealing, option is just to run separate programs -- group decision aid and data base access -- without any inter-system communication. This precludes any automatic searching of the data base tied to the developing decision tree, and complicates use of the system displays. A second option for existing data bases would be to link individual users, or the intermediator, with the data base program and use Unix filter and pipe facilities to control communication and output between the two programs. With this alternative, the user would effectively switch among systems and system interfaces. Ideally, however, users of the group aiding system could access the data base individually through their terminals, or by consulting the intermediator, as an integral part of the group aiding system. Access to the auxiliary data base would thus be with a well-engineered interface, compatible with that of the group aid itself.

The last option, while most attractive operationally, might well require extensive revision of the current aiding program for each separate data base dealt with. A compromise approach is the establishment of general-purpose "hooks" from the aiding program to the outside world. These hooks would make it feasible to attach the aiding program to a variety of data bases without extensive revision, and with an acceptable interface structure.

Individual Tree Elicitation. In the current system, all group members must be physically present in a single conference room to construct a group tree. This appears to be an overly severe restriction in today's world of decentralized command and management. Two ways to remove this restriction appear feasible: (1) group members meet at the same time, but at different places, and communicate through teleconferencing facilities; and (2) group members work individually, probably at different times and places, to create separate trees; these trees are then merged to form a group tree, which may then be worked on further by the group members, locally or remotely.

The first concept poses few problems, and could be readily implemented using available technology. The second, that of individual tree merging, offers considerably more challenge, but promises greater rewards. The primary advantage of this approach, aside from its self-paced nature, lies in the opportunity for incorporating more creative solutions by individuals working totally outside the group structure. The primary difficulty lies in devising a merging method that preserves the individual qualities of the trees and at the same time results in a fair and useful composite. Preliminary analysis indicates that merging cannot be wholely automatic, but must include a human element. The following paragraphs describe a preliminary scheme for computer-assisted tree merging, carried out within the general configuration of the present aiding system.

The elicitation of a decision tree from an individual could be performed using a simplified version of the group elicitation program. The procedures for sensitivity analysis and outcome calculation are applicable to an individual as well as a group. For comparability of trees among participants, however, some additional rules are necessary. These rules need not be overly restrictive, but should result in some communality of tree structuring, without impacting the individualized analysis of the decisions. It is envisioned that each decision maker will interact with a small graphics terminal. The terminal should have capabilities of tree presentation, keyboard input, error analysis, sensitivity analysis and probabilitiy and utility aggregation. Also, a hard-copy printout of the resultant tree would be useful.

Distillation of a "fair" composite tree from the set of individual trees can best be accomplished by a single decision analyst working at an interactive graphics terminal. Two operations are required: (1) identification and merging of structural components of the trees; and (2) aggregation of individual parameter estimates.

Structural differences among the individual trees will emerge in spite of adherence to tree development rules. These differences will involve node labeling, degree of branching, and composition of the attribute sets. Distillation of the composite tree will be facilitated through the use of guiding rules similar to the following:

(1) Merging of the tree should proceed form left to right. Merging of the parent nodes is most important since the treatment of later nodes will be conditional on this resolution.

(2) Inclusion of actions in the composite tree will depend on their importance and representation in the individual trees. If a majority of the individuals include an action in their formulations and evaluate the action highly, the action should be included. If an action is not well represented and is of low import, it should be deleted.

(3) Actions that overlap or are otherwise related between trees may often be analyzed from the resulting events. Set theory constructs may be used to recombine branches to arrive at comparable action sets. Similarly, event sets may be manipulated according to subsequent branches.

Once the composite tree structure is established, the calculation of event probabilities, outcome utilities, and attribute levels is straightforward. The following rules are suggested:

(1) Probability Aggregation. If, for a given action, common events are present across all participants, the probability estimates can be aggregated using simple rules. Dalkey (1977) notes that either the arithmetic or harmonic mean are suitable estimators for aggregating such judgments. For later dialogue, a confidence interval may be assigned to the aggregated value depending on the variance of the individual judgments.

(2) Utility Aggregation. Aggregation of the holistic utility judgments for actions or outcomes may be derived by averaging.

Huber and Delbecq (1972) state that the arithmetic mean is an efficient and unbiased estimator. Comparability is present since the judgments are made according to an externally defined scale.

(3) Attribute Levels. The attribute levels need to be examined only for those outcomes that are found to be pivotal, i.e., in which the range of individual utilities is wide enough to favor competing actions. Comparison of the attributes will presumably entail rescaling, since the anchoring points will differ between participants.

The procedures outlined in this preliminary specification for tree merging require both human and machine contribution. The human is expected to use his pattern recognition capabilities to recognize morphological relationships and identify common elements. The computer aids by displaying tree structures and by providing an interactive medium for reorganization of the structures. Computer aiding is also used for sensitivity analysis, rescaling, aggregations, and error tests. The man, finally, assumes responsibility for direction and evaluation of the effort. As machine capabilities improve and as the tree-merging process becomes more tightly defined, the machine responsibilities will increase.

The composite tree produced by the above methodology may be used in a variety of ways. It may be (1) used directly as an expression of group policy, (2) returned to each individual for modification and/or parameter estimation, or (3) used as an initial structure when convening the group.

Direct use is justified if substantial agreement was evident during the merging process, or if time and resources make further modifications impossible. If substantial agreement on decision structure is present but large differences in parameter estimation exist, then the composite tree may be returned to each individual for re-estimation. This is somewhat analogous to the Delphi procedure for achieving group consensus. Such an individualized re-estimation process has the advantage of being lower in cost and complexity than full convening of the group. The final possibility, convening the group for actual dialog, may be necessary if major differences in tree structure must be ironed out, or if irreconcilable conflicts in parameter estimation are still present. The composite tree then serves as a guide for the group dialog.

In fact, a composite tree used in this way might well provide an advantageous starting point for the type of computer-aided group discussion described in the preceding chapters, regardless of whether large differences are present or absent. That is, a group working with a composite tree structure could focus on refinement of options and exploration of judgmental values, using their time together to establish a tree of greater precision and acceptability.

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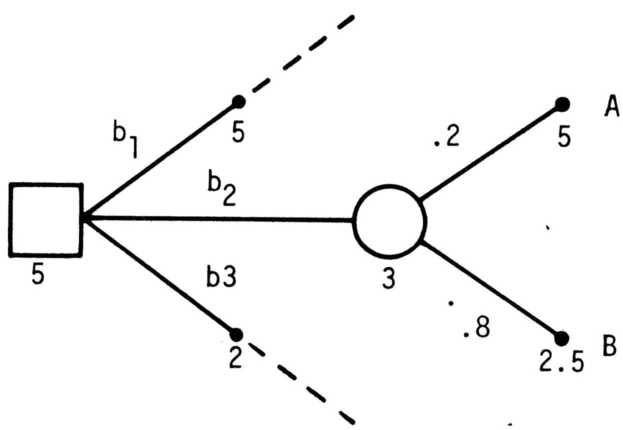
APPENDIX A
SENSITIVITY ANALYSIS

Traditional decision analysis demands expansion of the "complete" decision tree before utilities are assigned to the tip nodes and probabilities are assigned to the internal event nodes. If, however, utility and probability values are assigned as the tree is being expanded, it is possible to perform a sensitivity analysis on the partially constructed tree in order to determine the most critical (sensitive) places (Leal, 1976). Once determined, the most critical tip node can then be recommended for expansion and a great deal of time is saved by not expanding those parts of the tree that are not crucial to the initial decision.

Such an early value estimation follows the same philosophy as that of tip node value assessment. The value should reflect the situation as described by the path to the node as well as an account of possible future events and action opportunities. Every value estimate is placed on a current "tip" node of the tree. Later, as the tree is grown, the tip node will become an internal node due to its expansion. At this time, its former value is replaced by the expected value of the subtree extending outward from it. Thus, initial value estimates are called "provisional" in the sense that later they will be replaced by more accurate estimates.

Sensitivity analysis attempts to locate the most critical ("sensitive") node, that is, the node whose value must be changed the least in order to cause a drastic change in the current state of the tree. Figure A-1 shows a simple tree which will provide an example for the description of the sensitivity analysis procedure. The root node has three main branches, labeled b1, b2, and b3. It is the objective of the decision analysis to choose one of these three alternatives. Assume that branch b1 leads to a subtree (not shown) with a roll-back value of 5; branch b3 has a roll-back value of 2 from its sub-tree (not shown). Branch b2 leads to one event node with two outcomes: A and B. It has been previously estimated by the



REQUIRED VALUE	SENSITIVITY DIFFERENTIAL
15	10
5	2.5

FIGURE A-1. BASIC SENSITIVITY DIFFERENTIAL group that outcome A has a provisional value of 5 with a .2 probability of occurrence. Similarly, outcome B has a provisional value of 2.5 with a probability of occurrence of .8. With these values, the event node has an expected value of $(5 \times .2) + (2.5 \times .8) = 3$. Thus, b1 is the currently best decision with the highest value of 5.

Suppose that tip node A is chosen for future expansion. It's provisional value of 5 would then be replaced by a new value that comes from an aggregation of the new expanded tip nodes. If the newly replaced value at A is high enough, branch b2 could overtake branch b1 and become the leading candidate for final choice. How high must the value of A be pushed before b1 goes from 3 to 5 (the currently highest initial value)? Node A must be raised from 5 to 15 -- an increase of 10. It may be said, then, that the "sensitivity differential" of node A is 10 since its value must be raised by 10 in order to cause a "decision switch" at the root node. If the sensitivity differential is calculated for all tip nodes in the tree, then the node with the lowest differential is the most sensitive, and it should be recommended for expansion.

The formula for calculating the sensitivity differential can be expressed in terms of a recursive function that begins at the root node and computes the sensitivity for each node out to the tips. Thus, sensitivity calculations are carried out in a forward direction as contrasted with expected utility which is computed backwards from the tip nodes toward the root. The computation formula is:

$$S(\Gamma(n)) = \begin{cases} \dfrac{S(n)}{P(n)} & \text{for event nodes} \\ S(n) + V(n) - V(\Gamma(n)) & \text{for decision nodes} \end{cases}$$

$$S\ (\text{root}) = 0$$

where $S(n)$ is the sensitivity of node n, $\Gamma(n)$ is the successor to n, $P(n)$ is the probability along the branch from n to $\Gamma(n)$ and $V(n)$ is the current provisional value of n. The above procedure will, of course, produce a sensitivity differential of zero for all nodes connected to the highest initial branch. Thus, these nodes are compared with the second highest initial branch to determine how much they must be <u>lowered</u> in order to produce a decision switch at the root.

APPENDIX B
CONFLICT RESOLUTION

Figure B-1 illustrates a typical conflict situation. Three alternatives have been identified at a node. On two of these, the three group members are in good agreement with respect to overall value, and a mean value can be easily assigned. On the third alternative, the differences are much greater, and the conflict must be resolved in another way.

The first task, then, is for the group decision aiding system to determine if a conflict actually exists. The current algorithm permits the participants to be within 10 value points (utility units) of the group mean (on the average) without causing a conflict. Conflict occurs when,

$$\text{for:} \quad \bar{X} = \frac{\sum_{i=1}^{M} X_i}{M}$$

$$\frac{\sum_{j=1}^{M} |X_j - \bar{X}|}{M} > 10$$

on a scale of 0 to 100 where X_i is the value input by the ith participant and M is the total number of participants. This means that a conflict is caused on an alternative when the average deviation from the group mean is above 10. When this situation occurs, the MAUM procedure is invoked for each alternative conflict.

The basic idea of multi-attribute utility measurement is quite familiar (see, for example, Raifa, 1969). Every action has a value on a number of different dimensions or "attributes". The technique is to discover those values, one dimension at a time, and then to aggregate them across dimensions using linear average. Averaging utilities does the least

	Group Member Utilities			Group Utilities	
	1	2	3		
Alternative 1	40	50	40	43.3	
Alternative 2	70	60	80	70	
Alternative 3	2	25	78		← Conflict

FIGURE B-1. TYPICAL CONFLICT SITUATION

"damage" to individual utility estimates according to Huber and Delbecq (1972). Although Gardiner (1975) and Dalkey (1977) suggest a weighted average aggregation of participant values, the weighting would depend on participant expertise. However, in the absence of differences in expertise, a straight averaging is recommended.

Each group member is asked to consider the alternative under discussion and the level of performance of this alternative on each identified importance dimension. Then each group member, individually, assigns a utility value between zero and one hundred (the range of the utility scale), dimension by dimension, reflecting the utility of the alternatives performance on each dimension. At the conclusion of this step we will have a "decomposed" version of Figure B-1 such as shown in Figure B-2 for one particular alternative.

The overall branch utility for each group member is calculated by using a simple average:

$$u_j = \frac{\sum_i U_{ij}}{M}$$

where U_{ij} is the utility of the ith attribute dimension for the jth group member. Any conflicts in attribute levels can then be displayed as shown in Figures 2-8 and 2-9. If conflicts are not resolved, the group may elect to re-enter the MAUM procedure, or simply average the existing value and proceed with further tree expansion.

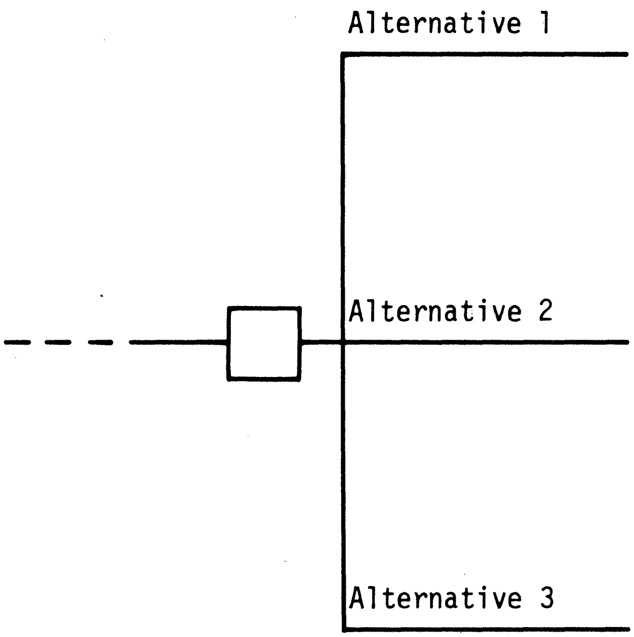
An alternative approach to conflict identification and resolution is currently being explored. This approach adopts the philosophy taken by the existing sensitivity analysis algorithm which searches for the most "critical" tip node (i.e., the one that has the most chance of causing a decision switch at the root of the tree), while avoiding the somewhat arbitrary rule based on average deviation from the group mean.

	Importance Dimension ("attribute")	1 Utility	2 Utility	3 Utility
Alternative	1	50	90	95
in	2	75	05	05
Conflict	3	20	50	40
	4	65	50	55

FIGURE B-2. DECOMPOSED UTILITY ESTIMATES

Consider an example of a decision node (Figure B-3) that has just been expanded. It is assumed, because this node was just expanded, that the sensitivity algorithm has chosen it as the most likely to cause a decision switch at the root node. In fact, the information regarding exactly how much the node's value must be altered in order to cause such a switch is stored in the computer memory at the node itself in the form of the sensitivity. If the values of each group member were taken separately (as though he were the only decision maker) it could be determined which member's values would actually cause a decision switch. If no one causes a switch, the group "agrees" in the sense that they all prefer the current initial alternative. Similarly, if all members cause a decision switch, they again "agree" since they all prefer a different initial alternative. However, if some cause a switch and others do not they "disagree" and the MAUM procedure can be invoked.

This approach is much closer to the overall aim of tree construction which is to arrive at an agreed initial course of action for the particular problem at hand. When a conflict does arise, the MAUM procedure must then be applied to all alternatives simultaneously. There will no longer be an opportunity to select individual alternatives in conflict. This disadvantage is offset, however, by the advantage that the MAUM procedure will only be invoked when absolutely necessary. Furthermore, it will be easier to assign attribute values when considering all available alternatives rather than one or two in isolation, since each attribute can be held constant while comparing across alternatives.



	Estimated Utility Values		
	Member 1	Member 2	Member 3
Alternative 1	43	62	50
Alternative 2	22	30	21
Alternative 3	5	50	80

FIGURE B-3. EXAMPLE DECISION NODE

APPENDIX C

SAMPLE AUDIT TRAIL

The following computer output is a sample of the audit trail. It is taken from one of the preliminary experiments with the Group Decision Aid using the terrorist scenario. Each decision cycle is shown, along with utility and probability values entered by each of the three group members.

EXPERIMENT #2

Suggested Attribute List

1. EFFECT ON INTERNATIONAL RELATIONS
2. EFFECT ON DOMESTIC RELATIONS
3. EFFECT ON MILITARY POSITION
4. EFFECT ON DIRECT EXPENDITURE
5. EFFECT ON ECONOMIC POSITION
6. EFFECT ON PRESTIGE
7. EFFECT ON MORALITY

Attributes Considered

SAFETY OF HOSTAGES
SAFETY OF MANDERO CITY
RANGE OF B-52
U.S. MILITARY CREDIBILITY
U.S. INTERNATIONAL PRESTIGE
DOMESTIC OPINION
POSSIBLE NUCLEAR THREAT
IMPACT ON SHAMBA

Final Attribute List

1. SAFETY OF HOSTAGES
2. SAFETY OF MANDERO CITY
3. RANGE OF B-52
4. U.S. MILITARY CREDIBILITY
5. U.S. INTERNATIONAL PRESTIGE
6. DOMESTIC OPINION
7. POSSIBLE NUCLEAR THREAT
8. IMPACT ON SHAMBA

Initial Actions

1. ATTACK
2. NEGOTIATE / DELAY
3. ACCEDE TO DEMANDS
4. TAKE TO U.N.

DECISION TREE DESCRIPTION
Node value precedes the node identifier
Node probability follows node description
A: ACTIONS E: EVENTS T: TERMINALS

0 A: ATTACK. 0
0 A: NEGOTIATE / DELAY. 0
0 A: ACCEDE TO DEMANDS. 0
0 A: TAKE TO U.N.. 0

Node Selected for Expansion
'ATTACK'

Alternative Actions

1. FREE HOSTAGES
2. DESTROY AIRPLANE
3. CAPTURE PLANE AND BOMBS
4. CARRIER PROTECTION OF M.C.
5. DISPLAY STRENGTH

Initial Utility Values

	P1	P2	P3	adm	conflict
alt1	60	90	80	11	1
alt2	80	50	85	14	1
alt3	100	100	95	2	0
alt4	35	70	95	21	1
alt5	0	40	0	18	1

Method of Resolution
1. MAUM
2. MAUM
4. MAUM
5. MAUM

Resolve Conflict on Alternative
'FREE HOSTAGES'

Attribute Values

	P1	P2	P3	adm	conflict
att1	50	100	85	19	1
att2	25	30	0	12	1
att3	25	20	0	10	1
att4	65	90	75	9	0
att5	90	90	80	4	0
att6	65	100	80	12	1
att7	15	0	10	6	0
att8	50	50	50	0	0
NewU	48	60	48	5	0

Resolve Conflict on Alternative
'DESTROY AIRPLANE'

Attribute Values

	P1	P2	P3	adm	conflict
att1	10	0	0	4	0
att2	100	80	0	40	1
att3	100	100	100	0	0
att4	90	60	85	12	1
att5	75	60	60	7	0
att6	70	50	50	9	0
att7	65	40	50	9	0
att8	50	50	50	0	0
NewU	70	55	49	8	0

Resolve Conflict on Alternative
'CARRIER PROTECTION OF M.C.'

Attribute Values

	P1	P2	P3	adm	conflict
att1	50	20	50	13	1
att2	70	100	100	13	1
att3	50	30	100	27	1
att4	25	70	100	27	1
att5	40	65	100	21	1
att6	20	50	100	29	1
att7	10	20	40	11	1
att8	70	90	80	7	0
NewU	42	56	84	16	1

Method of Attribute Conflict Resolution
"Re-evaluate attributes in Conflict"

Attribute Values

	P1	P2	P3	adm	conflict
att1	50	50	50	0	0
att2	80	90	90	4	0
att3	70	70	70	0	0
att4	40	50	40	4	0
att5	40	60	50	7	0
att6	40	50	50	4	0
att7	40	40	50	4	0
att8	70	90	80	7	0
NewU	54	62	60	3	0

Resolve Conflict on Alternative
"DISPLAY STRENGTH"

Attribute Values

	P1	P2	P3	adm	conflict
att1	10	30	0	11	1
att2	20	60	50	16	1
att3	20	20	20	0	0
att4	60	75	100	14	1
att5	50	60	60	4	0
att6	60	50	60	4	0
att7	30	20	0	11	1
att8	0	10	0	4	0
NewU	31	41	36	3	0

DECISION TREE DESCRIPTION
Node value precedes the node identifier
Node probability follows node description
A: ACTIONS E: EVENTS T: TERMINALS

```
98 A: ATTACK.  0
    52 A: FREE HOSTAGES.  0
    58 A: DESTROY AIRPLANE.  0
    98 A: CAPTURE PLANE AND BOMBS.  0
    59 A: CARRIER PROTECTION OF M.C..  0
    36 A: DISPLAY STRENGTH.  0
 0 A: NEGOTIATE / DELAY.  0
```

0 A: ACCEDE TO DEMANDS. 0
0 A: TAKE TO U.N.. 0

Node Selected for Expansion
'NEGOTIATE / DELAY'

Alternative Actions

1. REAL TERMS
2. DELAY FOR REINFORCEMENTS
3. DELAY FOR WORLD OPINION

Initial Utility Values

	P1	P2	P3	adm	conflict
alt1	10	80	0	33	1
alt2	30	90	100	29	1
alt3	50	20	100	29	1

Method of Resolution

1. MAUM
2. MAUM
3. MAUM

Resolve Conflict on Alternative
'REAL TERMS'

Attribute Values

	P1	P2	P3	adm	conflict
att1	90	90	100	4	0
att2	90	90	100	4	0
att3	40	90	100	24	1
att4	10	50	50	18	1
att5	10	50	50	18	1
att6	10	50	40	16	1
att7	40	90	100	24	1
att8	48	76	100	18	1
NewU	42	73	80	15	1

Method of Attribute Conflict Resolution
'Re-evaluate attributes in Conflict'

Attribute Values

	P1	P2	P3	adm	conflict
att1	90	90	100	4	0
att2	90	90	100	4	0
att3	60	85	90	12	1
att4	20	40	30	7	0
att5	20	40	40	9	0
att6	40	50	50	4	0
att7	50	70	70	9	0
att8	90	100	100	4	0
NewU	58	71	72	6	0

Resolve Conflict on Alternative
'DELAY FOR REINFORCEMENTS'

Attribute Values

	P1	P2	P3	adm	conflict
att1	60	70	50	7	0
att2	60	50	50	4	0
att3	40	50	80	16	1
att4	20	40	40	9	0
att5	35	30	40	3	0
att6	30	20	50	11	1
att7	50	60	70	7	0
att8	80	80	80	0	0
NewU	47	50	58	4	0

Resolve Conflict on Alternative
'DELAY FOR WORLD OPINION'

Attribute Values

	P1	P2	P3	adm	conflict
att1	75	10	50	23	1
att2	60	50	50	4	0
att3	30	40	40	4	0
att4	20	10	0	7	0
att5	30	10	0	11	1
att6	30	10	30	9	0
att7	50	20	35	10	1
att8	60	0	50	24	1
NewU	44	19	32	8	0

DECISION TREE DESCRIPTION
Node value precedes the node identifier
Node probability follows node description
A: ACTIONS E: EVENTS T: TERMINALS

```
98 A: ATTACK.  0
    52 A: FREE HOSTAGES.  0
    58 A: DESTROY AIRPLANE.  0
    98 A: CAPTURE PLANE AND BOMBS.  0
    59 A: CARRIER PROTECTION OF M.C..  0
    36 A: DISPLAY STRENGTH.  0
67 A: NEGOTIATE / DELAY.  0
    67 A: REAL TERMS.  0
    52 A: DELAY FOR REINFORCEMENTS.  0
    32 A: DELAY FOR WORLD OPINION.  0
 0 A: ACCEDE TO DEMANDS.  0
 0 A: TAKE TO U.N..  0
```

Node Selected for Expansion
'ACCEDE TO DEMANDS'

DECISION TREE DESCRIPTION

Node value precedes the node identifier
Node probability follows node description
A: ACTIONS E: EVENTS T: TERMINALS

```
98 A: ATTACK.  0
    52 A: FREE HOSTAGES.  0
    58 A: DESTROY AIRPLANE.  0
    98 A: CAPTURE PLANE AND BOMBS.  0
    59 A: CARRIER PROTECTION OF M.C..  0
    36 A: DISPLAY STRENGTH.  0
67 A: NEGOTIATE / DELAY.  0
    67 A: REAL TERMS.  0
    52 A: DELAY FOR REINFORCEMENTS.  0
    32 A: DELAY FOR WORLD OPINION.  0
 0 T: ACCEDE TO DEMANDS.  0
 0 A: TAKE TO U.N..  0
```

Node Selected for Expansion
'TAKE TO U.N.'

Estimated Probabilities

	P1	P2	P3
alt1	70	60	70
alt2	30	35	25
alt3	0	5	5

Alternative Events

1. CARRY OUT THREATS
2. MODIFY DEMANDS
3. THREATS NOT CARRIED OUT

Initial Utility Values

	P1	P2	P3	adm	conflict
alt1	0	0	0	0	0
alt2	75	80	100	10	1
alt3	60	95	100	17	0

Method of Resolution
2. MAUM

Resolve Conflict on Alternative
'MODIFY DEMANDS'

Attribute Values

	P1	P2	P3	adm	conflict
att1	90	80	100	7	0
att2	90	90	100	4	0
att3	70	60	100	16	1
att4	40	50	50	4	0
att5	60	75	80	8	0
att6	50	75	80	12	1
att7	60	75	80	8	0

att8	80	90	80	4	0
NewU	68	74	84	6	0

DECISION TREE DESCRIPTION
Node value precedes the node identifier
Node probability follows node description
A: ACTIONS E: EVENTS T: TERMINALS

```
98 A: ATTACK.  0
    52 A: FREE HOSTAGES.  0
    58 A: DESTROY AIRPLANE.  0
    98 A: CAPTURE PLANE AND BOMBS.  0
    59 A: CARRIER PROTECTION OF M.C..  0
    36 A: DISPLAY STRENGTH.  0
67 A: NEGOTIATE / DELAY.  0
    67 A: REAL TERMS.  0
    52 A: DELAY FOR REINFORCEMENTS.  0
    32 A: DELAY FOR WORLD OPINION.  0
 0 T: ACCEDE TO DEMANDS.  0
25 A: TAKE TO U.N..  0
     0 E: CARRY OUT THREATS.  66
    75 E: MODIFY DEMANDS.  30
    85 E: THREATS NOT CARRIED OUT.  3
```

Node Selected for Expansion
"DELAY FOR REINFORCEMENTS"

Estimated Probabilities

	P1	P2	P3
alt1	65	40	45
alt2	20	30	30
alt3	15	30	25

Alternative Events

1. CARRY OUT THREATS
2. SUCCESSFUL OPERATION
3. MODIFY DEMANDS

Initial Utility Values

	P1	P2	P3	adm	conflict
alt1	0	0	0	0	0
alt2	100	100	100	0	0
alt3	50	60	50	4	0

DECISION TREE DESCRIPTION
Node value precedes the node identifier
Node probability follows node description
A: ACTIONS E: EVENTS T: TERMINALS

```
98 A: ATTACK.  0
```

```
     52 A: FREE HOSTAGES.  0
     58 A: DESTROY AIRPLANE.  0
     98 A: CAPTURE PLANE AND BOMBS.  0
     59 A: CARRIER PROTECTION OF M.C..  0
     36 A: DISPLAY STRENGTH.  0
 67 A: NEGOTIATE / DELAY.  0
     67 A: REAL TERMS.  0
     38 A: DELAY FOR REINFORCEMENTS.  0
          0 E: CARRY OUT THREATS.  50
        100 E: SUCCESSFUL OPERATION.  26
         53 E: MODIFY DEMANDS.  23
     32 A: DELAY FOR WORLD OPINION.  0
  0 T: ACCEDE TO DEMANDS.  0
 25 A: TAKE TO U.N..  0
      0 E: CARRY OUT THREATS.  66
     75 E: MODIFY DEMANDS.  30
     85 E: THREATS NOT CARRIED OUT.  3
```

Node Selected for Expansion
'REAL TERMS'

Estimated Probabilities

	P1	P2	P3
alt1	33	33	33
alt2	33	33	33
alt3	33	33	33

Alternative Events

1. CARRY OUT THREATS
2. DO NOT CARRY OUT THREATS
3. MODIFY DEMANDS

Initial Utility Values

	P1	P2	P3	adm	conflict
alt1	0	0	100	44	1
alt2	70	80	100	11	1
alt3	40	75	50	13	1

Method of Resolution

1. MAUM
2. MAUM
3. MAUM

Resolve Conflict on Alternative
'CARRY OUT THREATS'

Attribute Values

	P1	P2	P3	adm	conflict
att1	0	0	0	0	0
att2	0	0	0	0	0
att3	20	20	20	0	0
att4	0	0	0	0	0
att5	0	0	0	0	0

att6	0	0	0	0	0
att7	20	0	0	9	0
att8	0	0	0	0	0
NewU	5	2	2	1	0

Resolve Conflict on Alternative
'DO NOT CARRY OUT THREATS'

Attribute Values

	P1	P2	P3	adm	conflict
att1	70	90	80	7	0
att2	60	80	100	13	1
att3	50	80	100	18	1
att4	60	60	100	18	1
att5	60	90	100	16	1
att6	50	80	100	18	1
att7	60	90	100	16	1
att8	80	100	100	9	0
NewU	61	84	98	13	1

Method of Attribute Conflict Resolution
'Re-evaluate attributes in Conflict'

Attribute Values

	P1	P2	P3	adm	conflict
att1	70	90	80	7	0
att2	80	80	100	9	0
att3	50	50	50	0	0
att4	50	50	60	4	0
att5	70	75	80	3	0
att6	60	65	90	12	1
att7	65	80	90	9	0
att8	80	100	100	9	0
NewU	66	74	81	5	0

Resolve Conflict on Alternative
'MODIFY DEMANDS'

Attribute Values

	P1	P2	P3	adm	conflict
att1	60	65	50	6	0
att2	60	65	50	6	0
att3	50	50	50	0	0
att4	30	40	40	4	0
att5	40	40	40	0	0
att6	40	50	65	9	0
att7	60	50	60	4	0
att8	80	65	50	10	1
NewU	52	53	51	1	0

DECISION TREE DESCRIPTION
Node value precedes the node identifier

```
    Node probability  follows node description
   A: ACTIONS  E: EVENTS  T: TERMINALS


 98 A: ATTACK.  0
     52 A: FREE HOSTAGES.  0
     58 A: DESTROY AIRPLANE.  0
     98 A: CAPTURE PLANE AND BOMBS.  0
     59 A: CARRIER PROTECTION OF M.C..  0
     36 A: DISPLAY STRENGTH.  0
 43 A: NEGOTIATE / DELAY.  0
     43 A: REAL TERMS.  0
          3 E: CARRY OUT THREATS.  33
         74 E: DO NOT CARRY OUT THREATS.  33
         52 E: MODIFY DEMANDS.  33
     38 A: DELAY FOR REINFORCEMENTS.  0
          0 E: CARRY OUT THREATS.  50
        100 E: SUCCESSFUL OPERATION.  26
         53 E: MODIFY DEMANDS.  23
     32 A: DELAY FOR WORLD OPINION.  0
  0 T: ACCEDE TO DEMANDS.  0
 25 A: TAKE TO U.N..  0
      0 E: CARRY OUT THREATS.  66
     75 E: MODIFY DEMANDS.  30
     85 E: THREATS NOT CARRIED OUT.  3

  Node Selected for Expansion
    'DELAY FOR WORLD OPINION'

  CARRY OUT THREATS
  NOT CARRY OUT THREATS

      Estimated Probabilities

        P1   P2   P3
alt1    60   80   60
alt2    40   20   40


     Alternative Events

 1.  CARRY OUT THREATS
 2.  NOT CARRY OUT THREATS

      Initial Utility Values

        P1   P2   P3     adm  conflict
alt1     0    0    0       0     0
alt2    80  100  100       9     0


     DECISION TREE DESCRIPTION
    Node value precedes the node identifier
    Node probability  follows node description
   A: ACTIONS  E: EVENTS  T: TERMINALS


 98 A: ATTACK.  0
     52 A: FREE HOSTAGES.  0
     58 A: DESTROY AIRPLANE.  0
```

```
    98 A: CAPTURE PLANE AND BOMBS.  0
    59 A: CARRIER PROTECTION OF M.C..  0
    36 A: DISPLAY STRENGTH.  0
43 A: NEGOTIATE / DELAY.  0
    43 A: REAL TERMS.  0
         3 E: CARRY OUT THREATS.  33
        74 E: DO NOT CARRY OUT THREATS.  33
        52 E: MODIFY DEMANDS.  33
    38 A: DELAY FOR REINFORCEMENTS.  0
         0 E: CARRY OUT THREATS.  50
       100 E: SUCCESSFUL OPERATION.  26
        53 E: MODIFY DEMANDS.  23
    31 A: DELAY FOR WORLD OPINION.  0
         0 E: CARRY OUT THREATS.  66
        93 E: NOT CARRY OUT THREATS.  33
 0 T: ACCEDE TO DEMANDS.  0
25 A: TAKE TO U.N..  0
     0 E: CARRY OUT THREATS.  66
    75 E: MODIFY DEMANDS.  30
    85 E: THREATS NOT CARRIED OUT.  3
```

Node Selected for Expansion
"CARRIER PROTECTION OF M.C."

SUCCEED IN BOMBING M.C.
SHOOT DOWN B-52
NO ATTACK ON M.C.

Estimated Probabilities

	P1	P2	P3
alt1	20	25	30
alt2	60	45	45
alt3	20	30	25

Alternative Events

1. SUCCEED IN BOMBING M.C.
2. SHOOT DOWN B-52
3. NO ATTACK ON M.C.

Initial Utility Values

	P1	P2	P3	adm	conflict
alt1	0	0	0	0	0
alt2	65	75	80	6	0
alt3	50	50	50	0	0

DECISION TREE DESCRIPTION
Node value precedes the node identifier
Node probability follows node description
A: ACTIONS E: EVENTS T: TERMINALS

```
98 A: ATTACK.  0
    52 A: FREE HOSTAGES.  0
    58 A: DESTROY AIRPLANE.  0
    98 A: CAPTURE PLANE AND BOMBS.  0
```

```
     49 A: CARRIER PROTECTION OF M.C..  0
          0 E: SUCCEED IN BOMBING M.C..  25
         73 E: SHOOT DOWN B-52.  50
         50 E: NO ATTACK ON M.C..  25
     36 A: DISPLAY STRENGTH.  0
 43 A: NEGOTIATE / DELAY.  0
     43 A: REAL TERMS.  0
          3 E: CARRY OUT THREATS.  33
         74 E: DO NOT CARRY OUT THREATS.  33
         52 E: MODIFY DEMANDS.  33
     38 A: DELAY FOR REINFORCEMENTS.  0
          0 E: CARRY OUT THREATS.  50
        100 E: SUCCESSFUL OPERATION.  26
         53 E: MODIFY DEMANDS.  23
     31 A: DELAY FOR WORLD OPINION.  0
          0 E: CARRY OUT THREATS.  66
         93 E: NOT CARRY OUT THREATS.  33
  0 T: ACCEDE TO DEMANDS.  0
 25 A: TAKE TO U.N..  0
      0 E: CARRY OUT THREATS.  66
     75 E: MODIFY DEMANDS.  30
     85 E: THREATS NOT CARRIED OUT.  3
```

Node Selected for Expansion
'CAPTURE PLANE AND BOMBS'

ATTACK SUCCEEDS
ATTACK FAILS
PARTIAL SUCCESS

Estimated Probabilities

	P1	P2	P3
alt1	45	70	65
alt2	5	5	0
alt3	50	25	35

Alternative Events

1. ATTACK SUCCEEDS
2. ATTACK FAILS
3. PARTIAL SUCCESS

Initial Utility Values

	P1	P2	P3	adm	conflict
alt1	100	100	100	0	0
alt2	20	0	0	9	0
alt3	40	50	50	4	0

DECISION TREE DESCRIPTION
Node value precedes the node identifier
Node probability follows node description
A: ACTIONS E: EVENTS T: TERMINALS

```
 77 A: ATTACK.  0
     52 A: FREE HOSTAGES.  0
```

```
     58 A: DESTROY AIRPLANE.  0
     77 A: CAPTURE PLANE AND BOMBS.  0
        100 E: ATTACK SUCCEEDS.  60
          7 E: ATTACK FAILS.  3
         47 E: PARTIAL SUCCESS.  36
     49 A: CARRIER PROTECTION OF M.C..  0
          0 E: SUCCEED IN BOMBING M.C..  25
         73 E: SHOOT DOWN B-52.  50
         50 E: NO ATTACK ON M.C..  25
     36 A: DISPLAY STRENGTH.  0
 43 A: NEGOTIATE / DELAY.  0
     43 A: REAL TERMS.  0
          3 E: CARRY OUT THREATS.  33
         74 E: DO NOT CARRY OUT THREATS.  33
         52 E: MODIFY DEMANDS.  33
     38 A: DELAY FOR REINFORCEMENTS.  0
          0 E: CARRY OUT THREATS.  50
        100 E: SUCCESSFUL OPERATION.  26
         53 E: MODIFY DEMANDS.  23
     31 A: DELAY FOR WORLD OPINION.  0
          0 E: CARRY OUT THREATS.  66
         93 E: NOT CARRY OUT THREATS.  33
  0 T: ACCEDE TO DEMANDS.  0
 25 A: TAKE TO U.N..  0
      0 E: CARRY OUT THREATS.  66
     75 E: MODIFY DEMANDS.  30
     85 E: THREATS NOT CARRIED OUT.  3
```

Node Selected for Expansion
'DESTROY AIRPLANE'

BOMBS & PLANE DESTROYED
PLANE DESTROYED
ATTACK FAILS

Estimated Probabilities

	P1	P2	P3
alt1	40	60	30
alt2	55	35	40
alt3	5	5	0

Alternative Events

1. BOMBS & PLANE DESTROYED
2. PLANE DESTROYED
3. ATTACK FAILS

Initial Utility Values

	P1	P2	P3	adm	conflict
alt1	95	90	100	3	0
alt2	65	75	80	6	0
alt3	0	0	0	0	0

DECISION TREE DESCRIPTION
Node value precedes the node identifier
Node probability follows node description

```
A: ACTIONS  E: EVENTS  T: TERMINALS


77 A: ATTACK.  0
    52 A: FREE HOSTAGES.  0
    72 A: DESTROY AIRPLANE.  0
        95 E: BOMBS & PLANE DESTROYED.  43
        73 E: PLANE DESTROYED.  43
         0 E: ATTACK FAILS.  3
    77 A: CAPTURE PLANE AND BOMBS.  0
       100 E: ATTACK SUCCEEDS.  60
         7 E: ATTACK FAILS.  3
        47 E: PARTIAL SUCCESS.  36
    49 A: CARRIER PROTECTION OF M.C..  0
         0 E: SUCCEED IN BOMBING M.C..  25
        73 E: SHOOT DOWN B-52.  50
        50 E: NO ATTACK ON M.C..  25
    36 A: DISPLAY STRENGTH.  0
43 A: NEGOTIATE / DELAY.  0
    43 A: REAL TERMS.  0
         3 E: CARRY OUT THREATS.  33
        74 E: DO NOT CARRY OUT THREATS.  33
        52 E: MODIFY DEMANDS.  33
    38 A: DELAY FOR REINFORCEMENTS.  0
         0 E: CARRY OUT THREATS.  50
       100 E: SUCCESSFUL OPERATION.  26
        53 E: MODIFY DEMANDS.  23
    31 A: DELAY FOR WORLD OPINION.  0
         0 E: CARRY OUT THREATS.  66
        93 E: NOT CARRY OUT THREATS.  33
 0 T: ACCEDE TO DEMANDS.  0
25 A: TAKE TO U.N..  0
     0 E: CARRY OUT THREATS.  66
    75 E: MODIFY DEMANDS.  30
    85 E: THREATS NOT CARRIED OUT.  3
```

Node Selected for Expansion
"FREE HOSTAGES"

SUCCESS
FAILURE
PARTIAL FAILURE

Estimated Probabilities

	P1	P2	P3
alt1	25	20	27
alt2	20	15	13
alt3	55	65	60

Alternative Events

1. SUCCESS
2. FAILURE
3. PARTIAL FAILURE

Initial Utility Values

P1   P2   P3   adm   conflict

alt1	100	100	100	0	0
alt2	0	0	0	0	0
alt3	70	70	50	9	0

DECISION TREE DESCRIPTION
Node value precedes the node identifier
Node probability follows node description
A: ACTIONS E: EVENTS T: TERMINALS

```
77 A: ATTACK.  0
    62 A: FREE HOSTAGES.  0
       100 E: SUCCESS.  24
         0 E: FAILURE.  16
        63 E: PARTIAL FAILURE.  60
    72 A: DESTROY AIRPLANE.  0
        95 E: BOMBS & PLANE DESTROYED.  43
        73 E: PLANE DESTROYED.  43
         0 E: ATTACK FAILS.  3
    77 A: CAPTURE PLANE AND BOMBS.  0
       100 E: ATTACK SUCCEEDS.  60
         7 E: ATTACK FAILS.  3
        47 E: PARTIAL SUCCESS.  36
    49 A: CARRIER PROTECTION OF M.C..  0
         0 E: SUCCEED IN BOMBING M.C..  25
        73 E: SHOOT DOWN B-52.  50
        50 E: NO ATTACK ON M.C..  25
    36 A: DISPLAY STRENGTH.  0
43 A: NEGOTIATE / DELAY.  0
    43 A: REAL TERMS.  0
         3 E: CARRY OUT THREATS.  33
        74 E: DO NOT CARRY OUT THREATS.  33
        52 E: MODIFY DEMANDS.  33
    38 A: DELAY FOR REINFORCEMENTS.  0
         0 E: CARRY OUT THREATS.  50
       100 E: SUCCESSFUL OPERATION.  26
        53 E: MODIFY DEMANDS.  23
    31 A: DELAY FOR WORLD OPINION.  0
         0 E: CARRY OUT THREATS.  66
        93 E: NOT CARRY OUT THREATS.  33
 0 T: ACCEDE TO DEMANDS.  0
25 A: TAKE TO U.N..  0
     0 E: CARRY OUT THREATS.  66
    75 E: MODIFY DEMANDS.  30
    85 E: THREATS NOT CARRIED OUT.  3
```

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

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Sensitivity Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a program centered on the demonstration of an interactive computer aid for group decision making. The report includes: (1) an overview of the system operation, (2) descriptions and theoretical bases for the system's principal decision analysis algorithms, (3) a report on the system software structure and major hardware components, and (4) a description of scenario materials and results of evaluation studies.