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AN INTERACTIVE COMPUTER AIDING SYSTEM FOR GROUP DECISION MAKING

Prepared For:

Cybernetics Technology Office
Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, Virginia 22209

VOLUME I
TECHNICAL

PERCEPTRONICS

6271 VARIEL AVENUE • WOODLAND HILLS • CALIFORNIA 91364 • PHONE (213) 884-7470

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Approved By:

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TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

TABLE OF CONTENTS CONTINUED

1. INTRODUCTION

1.1 Summary

This proposal is for a two-year program of research and development. The purpose of the program is to improve group decision making through the use of a computerized, interactive decision aiding system which essentially guides the decision making group through the problem at hand. The aiding methodology combines natural-language elicitation of decision trees, on-line sensitivity analysis, real-time assessment of multi-attribute values for decision outcomes, and direct visual feedback on areas of intra-group conflict. Such aiding allows the group to focus constantly on the decision path of greatest potential payoff, and on the critical differences of opinion along that path. As a result, the quality as well as the speed of group decision making is significantly enhanced.

The specific objectives of the proposed program include the following:

(1) Develop computer programs for efficient, comprehensive, elicitation of decision trees from a decision making group.

(2) Develop computer programs for identifying structural and numerical differences among the contributions of individual group members, for merging these contributions and for resolving the points of conflict.

(3) Develop effective means for displaying to the group the results of the elicitation procedures and conflict analyses.

(4) Integrate the various programs and techniques into a complete aiding system which can be readily transferred to other test environments.

(5) Experimentally test the group decision aid, using a variety of representative military decision problems, to demonstrate its advantages under realistic conditions of use.

(6) On the basis of the development effort and the experimental results, establish guidelines and recommendations for future military applications of the group decision aiding methodology.

The proposed program differs from previous and present decision aiding work in several ways. For one, it deals explicitly with the decision making group, rather than the individual decision maker. Secondly, it features the use of interactive computer support in the problem formulation phase of decision analysis, rather than in the optimization phase, as is the usual case. Furthermore, emphasis is placed on methods for guidance and control of communication between the group members. Third, and most important, it introduces new adaptive computer techniques, such as on-line sensitivity analysis, to the decision analysis process, and integrates these techniques with other computational approaches to form a complete decision aiding system.

While the proposed development represents a new concept in aiding group decision making, scientifically and technically it rests on a solid base of previous accomplishment. Of particular relevance is the recent successful use of multi-attribute utility feedback by Gardiner and Edwards to identify and resolve conflicts in group decision tasks, and the recent demonstration by Leal and Pearl of an interactive computer program for conversational elicitation of complete decision structures. Perceptronics includes on its program team the principal investigators of both these projects, and has complete access to the methodology involved. This factor, along with Perceptronics' broad capability in decision analysis, and in computerized decision aiding, will help insure the success of the proposed program.

1.2 Technical Approach

1.2.1 Problem Statement. Constant escalation in weapons cost and effectiveness, as well as the increasing complexity of international relations, makes military decision making more critical today than ever before. In today's military environment, most upper-level decisions are made by committees and staff groups. Typically, such groups contain experts from several speciality 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. Consequently the group is unable to consider the maximum set of alternatives, conflicts are not resolved in an optimum manner, and 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. Decision analysts are often called upon 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. Thus their contributions are confined primarily to the phases of formalization and optimization. While optimization is usually computer assisted, the formalization phase invariably has been accomplished manually, using lengthy interviews of persons more familar with the problem area. This approach is generally incompatible with the conditions of command group decision making.

Accordingly, it would be highly worthwhile to automate the formalization phase, using an interactive computer system to interrogate the group members 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. The supporting concepts and research evidence for an automated group decision aid are in existence. The present proposal describes how such an aid will be developed and tested, and reviews some of the major anticipated benefits.

1.2.2 Decision Aiding Methodology. The proposed group decision aiding system incorporates four main contributions. These are:

(1) Interactive elicitation of decision trees, including on-line sensitivity analysis.

(2) Multi-attribute analysis of group utility values at critical points in the tree.

(3) Computer support system, including continuous feedback of group decision responses by means of large-screen, color graphics display.

(4) Use of "intermediator" personnel to optimize interaction of the group with the aiding programs.

These contributions are summarized briefly below.

Interactive Tree Elicitation. Perceptronics plans to adapt for group use Dr. Antonio Leal's existing computer program for elicitation of decision structures (Leal, 1976; Leal and Pearl, 1976). This program, which is described in Section 2.3, uses an English-like conversational mode to build a decision tree by interrogating the decision maker regarding his decision alternatives, and the associated probabilities and utilities. Sensitivity analysis, based on heuristic tree search, is used to identify the most sensitive areas of the tree during the building process. This allows time and attention to be concentrated on expanding only the critical scenarios (sets of alternatives) within the large overall structure.

Automated tree elicitation can be applied to group decision making using two main elicitation modes.

(1) Elicit complete trees individually from all group members. Merge the individual trees during group interaction.
(2) Elicit a single group tree during group interaction.

Technical approaches to each mode are discussed in Section 2.5. It it shown that they have in common many programming requirements, but that the first mode involves considerably more technical difficulties, associated primarily with merging trees having inherent structural differences. On the whole, it would be more cost-effective to implement the most practical mode first, evaluate it, and modify it or move on to the other on the basis of actual test data concerning group reaction and decision making performance. Accordingly, it was decided to implement the second mode -- single group trees -- during the first-year program, because this approach involves the most direct extension of existing software, the most powerful application of on-line sensitivity analysis, the most straightforward use of multi-attribute utility measurement, and consequently, the highest immediate chance of decision performance improvement. At the same time, it is planned to analyze further the technical details of tree merging, and to use the aiding program to elicit trees from individuals for comparison with the group product.

This analysis and comparison will provide insight into the potential advantages and problems associated with the elicitation and merger of complete individual trees.

Multi-Attribute Utility Analysis. One can expect several types of intra-group conflicts during the tree-building process. Conflicts regarding decision alternatives and their possible outcomes are easily resolved by merger or trimming. Conflicts regarding probabilities can also be handled in standard fashion. Conflicts regarding utilities, however, are anticipated to produce the most severe disagreements during group interaction, because they directly reflect differences in the value structures that group members bring to the decision problem. In such cases, multi-attribute utility analysis provides a means for arriving at the required single utility by decomposing the specific alternative or outcome into its constituent attributes or dimensions.

Gardiner and Ford (1976), as well as Sheridan and Sicherman (1976), have shown that through group elucidation of values on each attribute separately, a more accurate picture of the utility conflict is achieved, and therefore agreement can be more readily reached. The process allows each decision maker to present his own viewpoint on the critical aspects of the problem, while leading the group as a whole to an eventual consensus. (Such a local decomposition is, of course, not necessary if everyone agrees immediately on global utility assignments for the set of alternatives.) Section 2.4 describes multi-attribute utility analysis as it applies to the proposed group decision aid. A good part of the development effort will be devoted to selecting the best way of representing to the group members the dimensions of conflict and the means recommended for resolution.

Support System. The group-aiding computer programs will be developed on a DEC PDP/11 minicomputer under the UNIX operating system. This will insure maximum transferability of the programs among ARPA contractors and other potential military users. A version of the LISP programming language has been located which runs under UNIX. The tree elicitation program is presently written in LISP, and availability of this language will simplify its adaptation to the present application. Members of the decision making group will interact with the program through alpha-numeric terminals. These units will be selected to permit quick entry and verification of numerical as well as written data. Feedback of decision information to the group as a whole will be by means of large-screen color display. It is planned to configure an economical and effective display by driving an Advent Videobeam™ color television projector with the newly available DEC Model VT30 color video display controller. The VT30 controller attaches directly to the PDP/11 unibus, and with its associated software, permits simple creation of alpha-numeric and graphical materials in eight colors. The resulting displays are ideal for the proposed aiding system.

The Intermediator. A procedural, rather than technical, innovation is the proposed use of a trained "intermediator" to mediate between the aiding program and the actual decision makers. The intermediator is not a decision analyst, but is highly familiar with all program operations, and is consequently able to dispense with some of the lengthier man-computer dialogue necessary to elicit data from completely naive individuals. Sheridan (1975) has stressed the importance of the skilled moderator in successful applications of his Electronic Voting and Discussion Technique (EVDT). Preliminary discussions by Perceptronics with command-level military personnel revealed a quick acceptance of the intermediator concept as a means of overcoming resistance to computer aiding, and inefficiencies in the aiding process, which come from unfamiliarity with the interactive procedures themselves. If properly employed, the intermediator should help speed decision making while imposing no outside pressure on the decision making group.

1.2.3 Empirical Evaluation. It is planned to evaluate the decision aiding methodology, as it is developed, through observation of its use by representative decision-making groups in solving actual decision problems. The system factors which can be varied in such evaluation include:

(1) Tree Elicitation Mode
(2) Intermediator's Role
(3) Interactive Configuration
(4) Presentation Format
(5) Group Composition
(6) Decision Problem Area

Of these, the last, "decision problem area", is of particular interest. The decision problem area selected should: (a) be credible and of actual interest to the military as well as to the specific group; (b) involve options that are already familiar to or easily explainable to the selected subject population; (c) reasonably complex, to allow a good number of alternative actions and move-response sequences, but not beyond several hours solution time; (d) have a value structure which includes significant judgmental elements.

The area selected for the initial year's effort is that of counter-terrorist activity. It is felt that this subject is current, important, and meets all of the above criteria. A typical problem set-up, for example, would be that an airliner has been commandeered by terrorists, or a facility has been occupied, and the command group has convened to decide how to deal with the problem. Intelligence on the terrorists and their geographical location is available. The starting options of negotiation, force, waiting, etc., spread out rapidly to a rich decision tree, which includes a large number of highly charged outcomes -- death of hostages, political loss of face, etc. -- which require multi-attribute utility analysis. Use of such scenarios should provide a maximum amount of information on system and group effects. Other problem areas will be included for comparison purposes in the second-year work.

1.2.4 Effectiveness Analysis. As presented in Section 3.6, analysis of available evidence indicates that the proposed aiding technology will lead to a significant improvement in group decision making performance. Improvement will come from two sources:

(1) Decision Quality
(2) Decision Time.

These are treated separately in the following paragraphs.

Decision Quality. Improvement in decision quality is expected to arise from (1) increased participation of group members in the decision making process; and (2) the effects of multi-attribute decision modeling. A number of related studies have shown that better decisions follow fuller and more even participation of group members, and that direct feedback of decision responses facilitates group interaction. The proposed group tree elicitation procedure insures full participation of the group, while the proposed immediate response feedback through a large-screen graphics display provides the means for presentation and resolution of group conflicts. More complete explication of group opinion, a better route to concensus, and less "noisy" decisions, also result from the use of multi-attribute modeling. And numerous studies, including several at Perceptronics, have shown that including a decision model in a closed-loop aiding system greatly improves the consistency and payoff of the resultant decisions.

Decision Time. Improvements in decision making time are expected from (1) reduced ambiguity in problem formulation due to computer guidance of discussions, (2) primary attention to critical decision areas through sensitivity analysis, and (3) efficient resolution of group conflicts through multi-attribute decision analysis and response feedback. Active computer guidance is the key to decision aiding success. Automatic specification of needed inputs minimizes the time spent floundering, defining terms, and clearing misunderstandings. Sensitivity analysis greatly reduces the area of the decision tree which must be investigated, thus reducing the associated discussion time. Finally, the time spent in resolving utility value disagreements is minimized by presenting cleanly the various attributes of the choice.

Improvement Ratio. Preliminary analysis of existing experimental data indicates an improvement ratio of between 4:1 and 9:1 for decision quality, and between 3:1 and 5:1 for decision time. Assuming a multiplicative relationship for the overall aiding system improvement ratio, we estimate a range of improvement in group decision making performance between 12:1 and 45:1. Taking into account that there is some interdependence of quality and time factors, we can use 25:1 as an initial estimate of overall performance improvement.

1.2.5 Program Plan. The two-year program calls for the following division of major program goals:

(1) First Year - Group aiding system initial implementation and evaluation. Final planning, detailed design, programming, equipment acquisition and installation of system to elicit and analyze group decision trees. Initial system test using a number of three-man and four-man groups and several versions of counter-terrorist decision problems. Comparison of group solutions with those elicited by computer from individuals. Evaluation report.

(2) Second Year - Program expansion and modification as required, to include individual tree elicitation if desirable. Full-scale empirical investigation of major system variables, using additional problem areas for comparison. Final

preparation of software in transferable form. Formulation of guidelines for future development and application.

It is planned that the first-year effort itself will result in an aiding system that could be transferred to another suitable computer system, i.e., PDP/11 series with similar feedback display capabilities. The second-year development, however, will finalize the system, condensing the programs where possible and adding documentation directed specifically toward the applied user.

1.3 Capabilities

Perceptronics brings to this program a background of experience and expertise in a number of directly related R&D areas; these include:

(1) Decision Aiding and Analysis
(2) Adaptive Information Systems
(3) Human Factors Design and Experimentation
(4) On-Line Software Development

As a result, Perceptronics is able to provide this program with a particularly strong development team. The program will be directed by Dr. Amos Freedy, who has previously directed development of all adaptive software at Perceptronics. Principal Investigator will be Dr. Antonio Leal, who developed the first computer program for interactive elicitation of decision trees while at UCLA, and who has been involved in the application of on-line, adaptive decision programs while at Perceptronics. Consultation in the area of decision and sensitivity analysis will be provided by Dr. Judea Pearl of UCLA, co-developer with Dr. Leal of the prototype tree elicitation program. Consultation in the area of multi-attribute utility measurement will be provided by Dr. Peter Gardiner of USC, who has worked directly in the group decision making area for the past several years. Human factors inputs to group display design will be coordinated by Dr. William Crooks, wh heads Perceptronics' engineering psychology group. Members of the support team will be selected from Perceptronics staff of system analysts, programmers, and engineers. Similar Perceptronics teams have performed and are now performing successfully on a number of related research and development programs for Navy, Army, Air Force, ARPA, NASA and industrial contractors.

Additional expertise in the area of decision analysis is provided by Perceptronics' Decision Research Branch, in Eugene, Oregon. Decision Research Personnel include Dr. Paul Slovic, Dr. Sarah Lichtenstein and Dr. Baruch Fischhoff. They are among the foremost investigators in the psychology of judgment and decision making. Their broad background of experience provides a valuable source of theoretical and empirical information directly related to group decision aiding.

Finally, the proposed program will be supported by a number of ongoing programs at Perceptronics. Included are: (1) Development of a computer-based supervisory system for managing information flow in C3 systems, being conducted for ARPA; (2) Development of adaptive decision aids for airborne ASW operations, being conducted for NADC and ONR; (3) Development of adaptive engagement and control logic for ballistic missile defense, being conducted for the Army's BMC under subcontract to TRW; (4) studies of man/computer communications in remotely controlled systems, conducted separately for ONR, and for NASA under subcontract to JPL; and (5) Study of requirements and methodology for decision training in operational systems being conducted for the Naval Training Equipment Center, Orlando. On these, and on all previous programs, the company has shown its ablility to adhere to firm schedules of achievement and cost.

2. TECHNICAL BACKGROUND

2.1 Overview

This chapter is an initial presentation of the several technical areas which will directly affect the planned development and evaluation of a computerized group decision aid. Beginning with a brief description of the underlying decision structure, it describes two existing methodologies relevant to computerized group decision aiding: elicitations of individual decision trees, and measurement of multi-attribute utilities in groups. Following this, means are discussed for extending automatic tree elicitation procedures to groups, and a method selected for initial implementation. Finally, a preliminary analysis is made of the benefits expected from the proposed aiding approach.

2.2 Structure of Group Decisions

Group decisions are taken with regard to a large number of problems. However, we can consider that in many cases of military importance, the fundamental structure which models the decision making process is the decision tree. The basic building blocks of the decision tree are (1) decision nodes and (2) event nodes. Decision nodes represent a set of plausible, mutually exclusive alternatives. These have associated with them utility values that represent the worth of the particular alternative to the decision maker(s). Event nodes, on the other hand, represent possible consequences of the various alternatives the outcomes of which may not be under the direct control of the decision makers. Thus, in the process of tree building, events must be assigned estimates for the probability of their occurrence as well as utility values for their outcomes.

The decision tree is in essence a structured relationship among decision nodes and event nodes, which defines possible future situations.

These situations (paths in the tree) are termed "scenarios", since they describe future real-world configurations that may or may not come to pass. It is precisely the exploration and comparison of many scenarios that allows the best currently available alternative to be chosen. The main objective of tree expansion is to determine which of the available scenarios is the best choice; that is, which has the highest expected utility value. In automated tree elicitation as proposed here, it is the purpose of sensitivity analysis to insure that only the most fruitful and critical scenarios are explored to a sufficient level of detail for confident solutions, and the purpose of multi-attribute utility analysis to permit quick resolution of value conflicts within the exploration process.

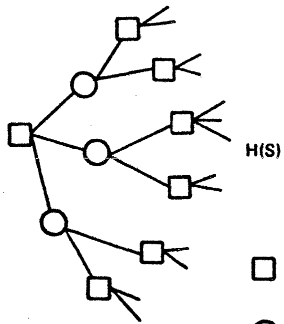
2.3 Computerized Elicitation of Decision Trees

2.3.1 General. This section describes an interactive computer program for eliciting decision trees from decision makers, using an English-like conversational mode. The program was developed and implemented by Dr. Antonio Leal of Perceptronics as part of his Ph.D. program at UCLA, under the supervision of Professor Judea Pearl. A full description of this program can be found in Dr. Leal's thesis (Leal, 1976); a shorter version will be published soon (Leal and Pearl, 1977).

2.3.2 Rationale. Complex decision structures, or decision trees, are generally elicited through personal interviews by decision analysts with the actual decision makers. From a practical viewpoint, the major drawback of such interviews is their length and cost. Since real-time analysis of decision trees is beyond the limitation of human computational capability, it invariably happens that many hours of interviews are spent eliciting portions of the decision tree which do not have decisive bearing on the problem at hand. This fact can only be discovered at a later stage, once the problem structure is formalized and a sensitivity analysis has been conducted on a computer. Therefore, if the computer could be brought into the elicitation process itself, it would not only eliminate the need for a highly trained analyst in attendance, but would also improve the effectiveness of the basic analysis procedure.

2.3.3 Heuristic Search. The approach to automated elicitation described here centers on the realization that the process of conducting an elicitation dialogue is structurally identical to conducting a heuristic search on game trees, as is commonly practiced in Artificial Intelligence programs. Figure 2-1 illustrates this analogy. Heuristic search techniques, when applied to tree elicitation, permit real-time rollback and sensitivity analysis as the tree is being formulated. Thus, it is possible to concentrate effort on expanding those parts of the tree which are crucial to the resolution of the solution plan. Heuristic search requires the decision maker to provide provisional utility values at each intermediate stage in the tree construction. These estimate the promise of future opportunities open to him from that stage. The provisional values serve a role identical to a heuristic evaluation function in selecting the next node (scenario) to be explored in more detail.

What do such provisional values actually represent? They are no different than values placed at the tip nodes of the completed tree; i.e., estimates of the relative worth of the opportunity provided by each node. Since all utilities are merely estimates of the rollback value of a complete tree emanating from that particular point on, the difference between provisional utilities and final utilities is only their degree of accuracy. The former can be regarded as consisting of the latter plus a noise term due to deficiencies in mental aggregation procedures. Nevertheless, if the decision maker is requested to provide values for nodes as they are being expanded, the information can be used to determine a node expansion order. As the tree expands, these provisional values become (by rollback) more "refined", that is, closer to the "true", automatically processed, value.

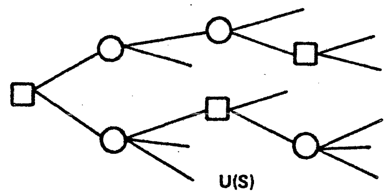


□ FIRST PLAYER'S TURN TO MOVE

○ SECOND PLAYER'S TURN TO MOVE

HEURISTIC SEARCH ON GAME TREES

- OBJECT IS TO FIND THE PATH (PLAN) WITH THE HIGHEST HEURISTIC VALUE H(S) WITH THE MINIMUM NUMBER OF NODE EXPANSIONS.
- COMPLETE TREE UNAVAILABLE EXPLICITLY. (IMPLICITLY CONTAINED IN GAME RULES.)
- EXPANSION FOLLOWS STATE TRANSITION RULES (LEGAL MOVES).
- HEURISTIC FUNCTION PROVIDED BY ANALYST.
- HEURISTIC FUNCTION GUIDES SEARCH.
- MINI-MAX ROLLBACK.
- TERMINAL NODES DETERMINED BY RULES. (WIN/LOSS.)



□ DECISION NODE

○ EVENT NODE

DECISION TREE ELICITATION

- OBJECT IS TO FIND THE PATH (PLAN) WITH THE HIGHEST UTILITY U(S) WITH THE MINIMUM NUMBER OF QUESTIONS.
- COMPLETE TREE UNKNOWN TO THE ANALYST. (RESIDES IN THE DECISION MAKER'S KNOWLEDGE.)
- EXPANSION FOLLOWS THE DECISION MAKER'S PERCEPTION OF EVENT/ACTION RELATIONSHIPS.
- PROVISIONAL VALUES PROVIDED BY DECISION MAKER.
- PROVISIONAL VALUES DETERMINE NEXT QUESTION.
- EXPECTI-MAX ROLLBACK.
- TERMINAL NODES DETERMINED BY DECISION MAKER.

FIGURE 2-1
ANALOG BETWEEN HEURISTIC SEARCH
ON GAME TREES AND DECISION TREE ELICITATION

2.3.4 Sensitivity Analysis. The actual order of node expansion is determined by sensitivity analysis. Since the only effect of expansion is to refine the provisional value assigned to the expanded node, it is reasonable to focus the expansion effort on those nodes which, if they suffer a change of value, would be most likely to influence the plan selection -- namely those most likely to impact the top contending alternative courses of action. This is accomplished by ranking all the available tip nodes in order of sensitivity.

The sensitivity measure is obtained by estimating the amount of change (differential) in a given provisional node value necessary to cause a change in the currently best initial decision. For example, in Figure 2-2, a partial tree is shown with initial decision branches b_1, b_2, and b_3. Branch b_2 is shown with an expanded event node that has two outcomes A and B. Assume that from a previous rollback calculation, the values of the three decision branches are 5, 3, and 2 respectively. Thus, b_1 represents the currently most promising decision.

To calculate the sensitivity differential of node A, the following question is posed, "How much should the value of node A (currently 5) be raised so that the value of the initial branch leading to node A (i.e., b_2) will equal the currently highest branch (i.e., b_1)?" Branch b_2 must obviously be incremented by at least 2, but node A is only contributing 20% of its value to it. Node A must be raised to a total higher than 15 in order to cause b_2 to exceed b_1. Thus, the sensitivity differential of node A is 10. Similarly, B must be raised to 5 (assuming no other changes) in order to cause b_2 to become preferred to b_1. Since A must be raised more than B, A may be said to be more "robust" than B. The general procedure for finding the sensitivity differential $\Delta(n)$ for any node n is given by the following recursive relation:

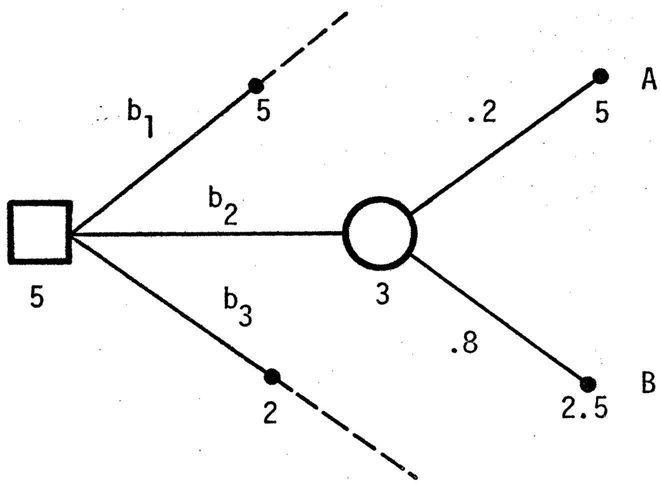


FIGURE 2-2
BASIC SENSITIVITY DIFFERENTIAL

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$$\Delta(\Gamma(n)) = \begin{cases} \dfrac{\Delta(n)}{P(n)} & \text{for an event node } n \\ \Delta(n)+V(n)-V(\Gamma(n)) & \text{for a decision node } n \end{cases}$$

where $\Gamma(n)$ is a successor of node n and $P(n)$ is the probability along the branch from n to $\Gamma(n)$, and $V(n)$ is the value of node n.

2.3.5 Conversational Elicitation. The elicitation program as currently implemented constructs and expands a decision tree by gaining information from a decision maker operating at an interactive computer terminal. Figure 2-3 shows the main parts of the procedure for expanding each node. The first step (1) is to choose a node for expansion on the basis of sensitivity analysis. The decision maker, after being alerted to direct his attention to a specific area of the tree, is interrogated about the characteristics of the node (2). The node is automatically classed as a decision or an event, and elicitation of decision alternatives or event outcomes, respectively, then begins (3).

Using the decision maker's responses for feedback, the provisional values (4), probabilities (5), and costs (6) are requested as necessary. After a request (see below) for experimentation (7), the chosen node is said to be "expanded". Enough information has been obtained to permit rollback. The elicitation procedure is repeated when a new node is chosen.

Experiment Node. To give the decision maker an opportunity to improve his probability estimates, a mechanism is provided in the elicitation program to represent the option of gathering information about uncertain events. This information gathering usually takes the form of an experiment with the following properties:

1. SELECT NEXT NODE FOR EXPANSION
2. DETERMINE NODE TYPE
3. ELICIT ALTERNATIVES OR OUTCOMES
4. DETERMINE IF MUTUALLY EXCLUSIVE
5. ELICIT PROVISIONAL VALUES
6. ELICIT PROVISIONAL PROBABILITIES
7. ELICIT COSTS
8. REQUEST FOR EXPERIMENTATION

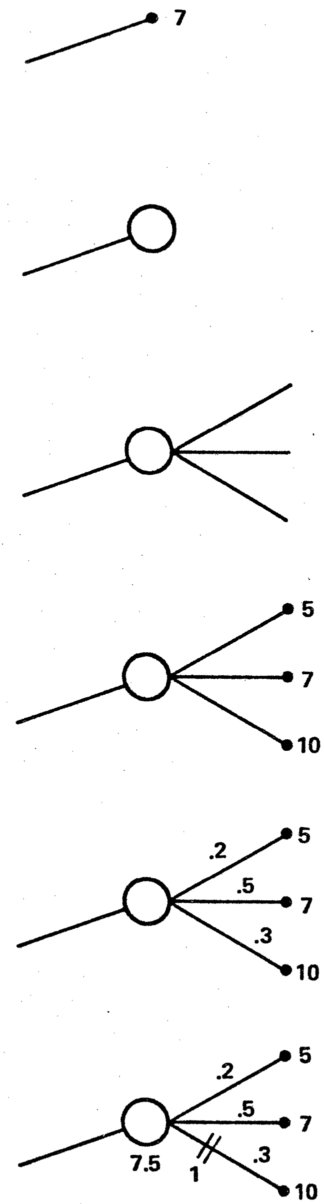


FIGURE 2-3
ELICITATION PROCEDURE

(1) The possible observations (experimental results) are known and are mutually exclusive.

(2) The relations between the observations and the uncertain event are expressible in probabilistic terms.

(3) If the experiment has a cost, it must be known.

The "experiment" may represent either an actual physical act (search for data) or an internal mental act (recall pertinent information). The interactive program elicits the above information from the decision maker and incorporates it into the current tree by inserting an "experiment node" at the proper place. Then, the decision maker is requested to supply conditional probabilities relating each observation to each event outcome. This allows calculation (by Bayes rule) of the value of the experiment (if it involves a physical act) and of the refined (*a posteriori*) probability once the observations become known.

Information gathering acts can result in excessive repetition, since the trees emanating from each experimental outcome are usually identical in structure. To eliminate difficulties connected with subtree duplication the entire experiment structure is represented by a single (diamond shaped) node with a single branch. Since the probability and value labels on the duplicated subtrees are not identical, but vary with the experimental outcome, these labels are represented in the form of vectors with one entry dedicated to each experimental outcome. This representation results in a "cleaner" tree structure, which more closely matches the user's perception of the decision problem.

2.3.6 Example. Figure 2-4 reproduces directly the beginning of a conversation between the elicitation program and a decision maker. The decision under consideration is whether to send a project proposal to government agency Y

```
WHAT'S YOUR PROBLEM?
*SENDING THE PROPOSAL TO AGENCY Y OR WAITING.
PLEASE LIST THE ALTERNATIVES THAT YOU HAVE, ONE
  AT A TIME.
1. *SUBMIT TO AGENCY Y IMMEDIATELY
2. *WAIT FOR TWO MONTHS
3. *NO MORE
ARE THE ALTERNATIVES MUTUALLY EXCLUSIVE?
*YES
NOW CONSIDER "SUBMIT TO AGENCY Y IMMEDIATELY".
  ASSUMING THAT THE CURRENT SITUATION WERE TRUE,
  TRY TO ESTIMATE HOW GOOD IT IS INDEPENDENTLY OF
  OTHER POSSIBILITIES.  YOU MAY USE MONEY AS A
  SCALE OR ONE OF YOUR OWN CHOOSING, HOWEVER, YOU
  MUST BE CONSISTENT AND USE THE SAME SCALE
  THROUGHOUT THE INTERVIEW.
DO YOU WISH TO USE MONEY AS A SCALE?
*YES
ENTER YOUR ESTIMATE.
*50000
ARE THERE ANY HIDDEN COSTS NOT TAKEN INTO ACCOUNT
  IN THE PREVIOUS VALUE ESTIMATION?
*NO
LET'S LOOK AT "WAIT FOR TWO MONTHS"
WHAT VALUE WOULD YOU GIVE TO THIS SITUATION?
*70000
WHAT IMMEDIATE COST IS EXPECTED?
*0
SUPPOSE THAT YOU HAD CHOSEN TO WAIT FOR TWO MONTHS
CAN YOU THINK OF THINGS THAT MAY HAPPEN AS A
  RESULT?
*NO
IS THERE A DECISION TO BE MADE AT THIS POINT?
*YES
STATE THE CHOICES THAT YOU HAVE.
1. *SEND TO X
2. *SEND TO Y
3. *DONE
DOES THE CHOICE OF ONE ALTERNATIVE EXCLUDE THE
  OTHERS?
*YES
NOW CONSIDER "SEND TO X"
TRY TO PLACE A NUMERIC VALUE ON THIS SITUATION.
*70000
WHAT WOULD BE THE IMMEDIATE COST, ASSUMING THIS
  SITUATION?
*0
LET'S LOOK AT "SEND TO Y"
HOW WOULD YOU EVALUATE THIS SITUATION?
*50000
HOW MUCH EXPENSE IS ANTICIPATED?
*0
ASSUMING THAT "SUBMIT TO AGENCY Y IMMEDIATELY" WAS
  PICKED, ARE EVENTS ABOUT TO HAPPEN OVER WHICH
  YOU HAVE NO CONTROL?
*NO
DO YOU HAVE A CHOICE OF ALTERNATIVES?
*NO
DO YOU WISH TO STOP EXPLORING FURTHER IN THIS
  DIRECTION?
*OK
SUPPOSE THAT "SEND TO Y" IS YOUR CHOICE,
ARE THERE SOME EVENTS THAT MAY HAPPEN?
*YES
PLEASE LIST THE OUTCOMES.
1. *ACQUIRE FUNDING FROM Y
2. *Y REJECTS PROPOSAL
3. *DONE
ARE THESE EVENTS MUTUALLY EXCLUSIVE?
*YES
NOW CONSIDER "ACQUIRE FUNDING FROM Y"
ESTIMATE THE VALUE IF YOU WERE IN THIS POSITION.
*50000
TRY TO ESTIMATE THE PROBABILITY THAT THIS EVENT
  WILL HAPPEN.
*0.8
IF THERE IS AN ASSOCIATED COST, WHAT IS IT?
*0
LET'S LOOK AT "Y REJECTS PROPOSAL"
WHAT IS THE SITUATION WORTH TO YOU?
*0
STATE THE IMMEDIATE COST IF THERE IS ONE.
*0
CAN YOU IMPROVE THESE PROBABILITY ASSIGNMENTS
  BY PERFORMING AN EXPERIMENT?
*NO
SUPPOSE THAT "ACQUIRE FUNDING FROM Y" HAPPENED.
ARE THERE SOME OPTIONS AVAILABLE TO YOU?
*NO
COULD UNCONTROLLABLE OUTCOMES OCCUR?
*NO
HAS THERE BEEN ENOUGH DETAIL EXPRESSED SO FAR?
*YES
WHAT IF "Y REJECTS PROPOSAL" OCCURS?
WOULD THERE BE OPPORTUNITIES OPEN TO YOU NOW?
*NO
CAN YOU THINK OF THINGS THAT MAY HAPPEN AS A
  RESULT?
*NO
SHALL WE TERMINATE THE INTERVIEW?
*NO
WHAT IF YOU CHOOSE TO SEND TO X?
ARE EVENTS ABOUT TO HAPPEN OVER WHICH YOU HAVE NO
  CONTROL?
*YES
EXACTLY WHAT EVENTS COULD OCCUR?
1. *FULL FUNDING FROM X
2. *PARTIAL FUNDING FROM X
3. *X REJECTS PROPOSAL
4. *NO MORE
DOES THE OCCURRENCE OF ONE EVENT EXCLUDE THE
  OTHERS FROM HAPPENING?
*YES
NOW CONSIDER "FULL FUNDING FROM X"
  .
  .
  .
```

FIGURE 2-4
COMPUTERIZED INTERROGATION (Leal and Pearl, 1976)

immediately for $50K, or in two months to agency X, for $100K. An asterisk is the signal from the computer that it is ready to receive input from the user. Thus, text immediately following an asterisk was typed by the decision maker. Figure 2-5 shows the full decision tree as elicited, and Figure 2-6 shows the condensed structure with experiment nodes inserted. The choice indicated is to wait for two months and submit to agency X, since the expected payoff from this action is $72.6K, against $50K from agency Y.

2.4 Multi-Attribute Utility Measurement

2.4.1 Intra-Group Conflict. At some point in the discussion of utilities attributable to alternatives or outcomes, it is likely that members of the group will differ significantly on the values assigned. At this juncture a closer look at the utilities associates with that node must be made. By closer we mean shifting from "gestalt" or "holistic" value assignment to multi-attribute utility measurement (MAUM). The reason for this is that arguments over the assignment of utility usually reflect genuine disagreements about values. Multi-attribute utility measurement, by breaking a holistic evaluation down into its component parts, can spell out explicitly what the values of each participant in the group are, show how and how much they differ, and in the process frequently reduce the expanse of such differences.

Figure 2-7 illustrates a typical conflict situation. Three alternatives have been identified at a node. On two of these, the five 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.

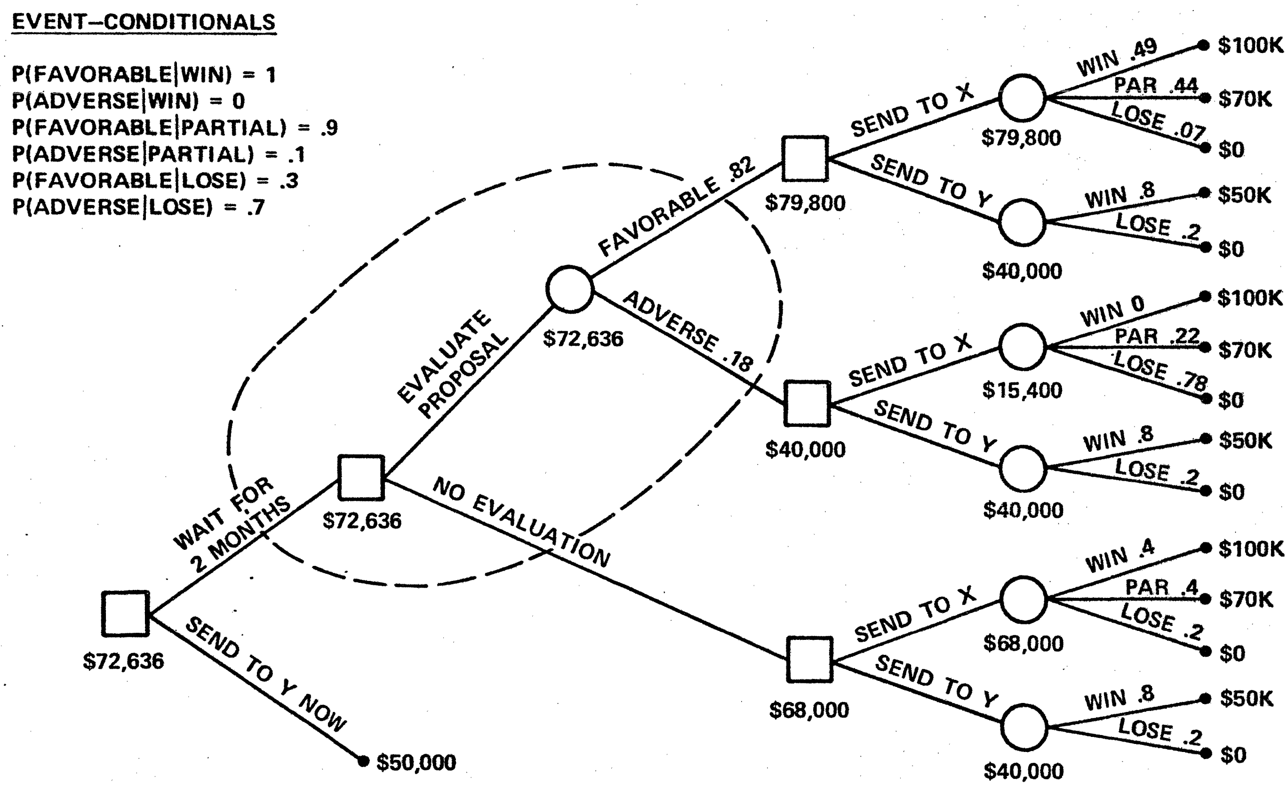


FIGURE 2-5
THE FULL DECISION TREE

PERCEPTRONICS

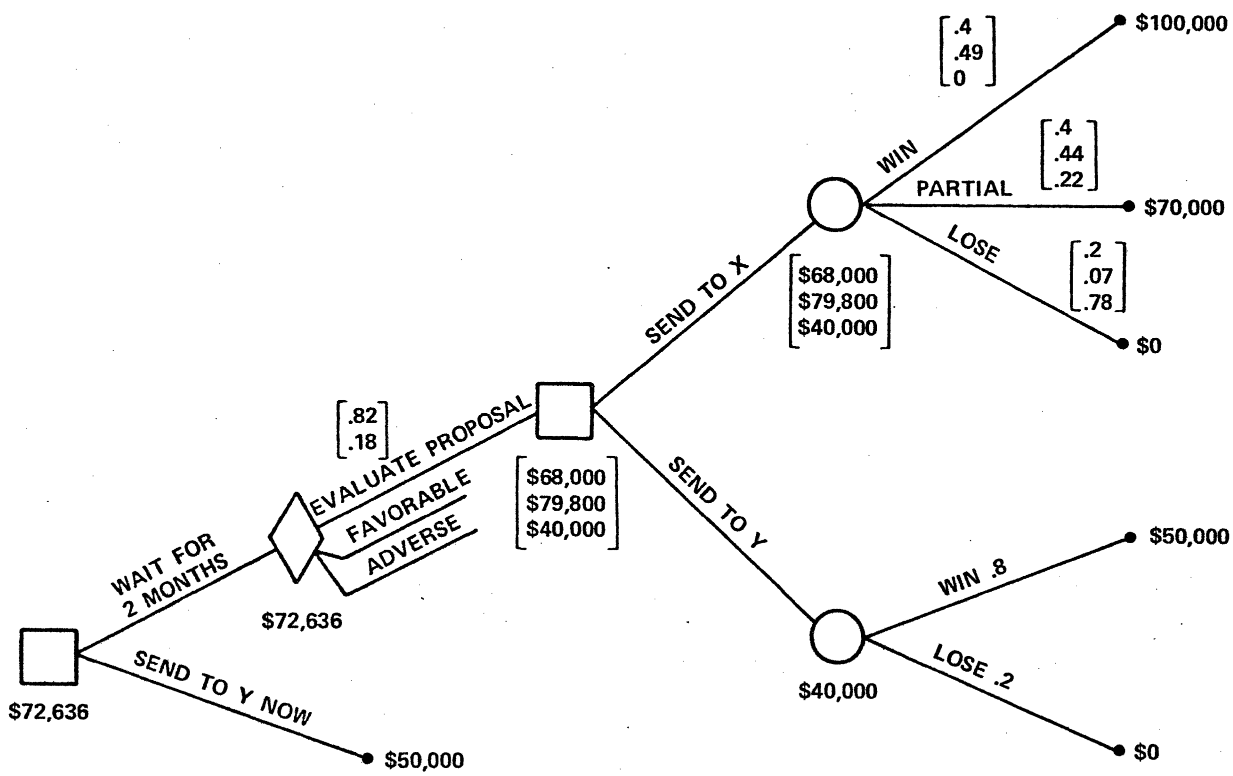
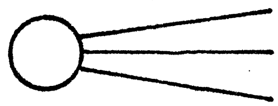


FIGURE 2-6
THE CONDENSED DECISION STRUCTURE

PERCEPTRONICS



Group Member Utilities 1	2	3	4	5	Group Utilities
4	5	4	6	6	5.0
7	6	7	7	6	6.7
2	25	18	3	6	?

Figure 2-7. VALUE ASSIGNMENT BY GROUP MEMBERS

The approach is to pause in the assignment of value, shift to developing a group MAUM model, and use the group MAUM model to assign the overall value required. The overall value so obtained will emerge in one of several ways: (1) by group agreement fostered by use of the MAUM technique; (2) by a reselected combination rule; or (3) by the senior member of the group assigning the value (as any commander weighs the contributions of his staff to arrive at an overall group evaluation). At this point the program receives an overall value for the alternative and the tree elicitation process continues as before.

2.4.2 Developing a Group MAUM Model. The basic idea of multi-attribute utility measurements is quite familiar (see, for example, Raifa, 1969). Every outcome of an action may have value on a number of different dimensions or attributes. The technique, in any of its numerous versions, is to discover those values, one dimension at a time, and then to aggregate them across dimensions using a suitable aggregation rule. Probably the most widely used type of aggregation consists of simply taking a weighted linear average. Only that procedure will be discussed here, since theory, simulation computations, and empirical experience all indicate that weighted linear averages yield satisfactory values, while remaining easiest to elicit and understand. The technique consists of ten steps, as follows (Gardiner and Ford, 1976):

Step 1: Identify the group whose utilities are to be measured. In a military setting this group is frequently the senior officer and his staff. Usually, several staff members have a stake in voicing a decision.

Step 2: Identify the issue or issues to which the utilities needed are relevant. In this instance, the issue is formed by the "context" in which we are assigning utilities to the nodes of our decision tree. For example, an intelligence or logistics operation could be driving the decision process.

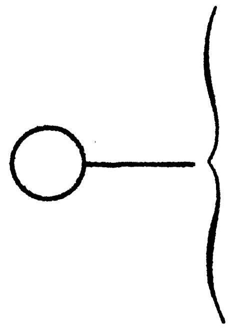
Step 3: Identify the entities to be evaluated. The entities here are the branches of the example tree in Figure 2-7. Specifically, we focus on the branch where the large disagreement occurs about what utility to assign to the branch. The attempt is to try and figure out the reason for the utility differences (and if possible resolve them) by breaking down the holistic utility estimate into dimension-by-dimension estimates.

Step 4: Identify the relevant dimensions (attributes) of value the group considers in evaluating and assigning utility to the node branches. Here it would be practical and useful to establish a preliminary "menu" of military dimensions, and select those which apply in each particular instance.

Step 5: Rank the dimensions in order of importance. This ranking task, like step 4, can be performed by each individual in the group separately, or by all members acting together as a group. We plan to use an individual process, and this is the first step where different values tend to emerge. For example, Bauer, Gebert and Meise (1973) found that individuals could agree on what constituted the goal fabric (i.e., importance dimensions). Disagreement in values began to emerge only when they were asked to rate dimensions in importance and evaluate difference levels of performance on each.

Step 6: Sum the importance weights, divide by the sum, and multiply by one hundred. This is a purely computational step which converts the importance weights to numbers that, mathematically, are rather like probabilities. The choice of one to one hundred scale is complete arbitrary.

Step 7: Measure the utility of the branch on each dimension. In the usual application of MAUM, dimension-by-dimension utility curves are constructed for each group member by having each member draw a graph where the x-axis represents the range of performance for the entities being evaluated and the y-axis represents the utility associated with the corresponding x-axis performance. In this application, we abbreviate the approach. The fundamental reason for having a utility curve on each importance dimension is to be able to determine the dimension-by-dimension contribution of utility for any number of decision alternatives. In this instance, where each time we use MAUM we have only one entity to be evaluated (i.e., the branch where the holistic utility assignment cannot be agreed upon), we do not need the whole utility curve for each dimension. We only need one point on each curve. The easiest way to obtain this single utility point for each dimension is simply to ask each group member for it directly. Each group member will be asked to consider the branch under discussion and the level of performance of this branch on each importance dimension identified. Then each group member, individually, assigns a utility number between zero and one hundred (the range of the utility scale) dimension by dimension reflecting the utility of the branch's performance on each dimension. At the conclusion of this step we will have a "decomposed" version of Figure 2-7 such as shown in Figure 2-8.



Importance Dimension	Group Member 1 Weight/ Utility	2 Weight/ Utility	...	5 Weight/ Utility
1	.2/50	.7/90		.05/95
2	.2/75	.2/05		.05/05
3	.3/20	.05/50		.30/40
4	.3/65	.05/50		.60/55

Figure 2-8. DECOMPOSED UTILITY ESTIMATES

For each importance dimension identified we have an importance weight and a utility estimate for how the branch performs on that dimension. And we have this for each group.

Step 8: Calculate the overall branch utility for each group member by using a simple weighted average:

$$U_{bi} = \sum_{d=1}^{4} w_d u(b_{di})$$

where U_{bi} is the utility of the branch for the ith group member, d is the number of importance dimensions, w_d is the importance weight for the dth importance dimension, and $u(b_{di})$ is the utility of the branch for the ith person on the dth importance dimension.

Step 9: Assigning the branch a utility. The results of the computation in Step 8 will produce one of three possible outcomes: (1) the individual utilities of the branch calculated according to the procedure of Step 8 will produce numbers so close for each member of the group that further discussion is not needed and the group mean is simply assigned to the branch and the process returns to the previous mode of operation; (2) the individual utilities will differ and when plotted will produce a plot as shown in Figure 2-9; (3) the individual utilities will differ and when plotted will produce a plot as shown in Figure 2-10.

2.4.3 Group Consensus. We expect that in some instances, Outcome 1 will actually happen. The mere process of going through the refined process of assigning a utility to a branch will "foster" agreement. This phenomenon has been observed in previous MAUM applications. For example, Gardiner (1974) compared the evaluation of 14 individuals, where the same list of 15 alternatives, each with 8 importance dimensions, were evaluated first by group Gestalt evaluations and secondly by group MAUM evaluations as proposed here. Gardiner found and reported (Gardiner and Edwards, 1975) that the use of a group MAUM value model for evaluation instead of their intuitive Gestalt evaluation turned disagreement into substantial agreement. In a typical case, groups were observed to differ by 100% on the total worth of an alternative when the worth was determined holistically. The difference was reduced to 17% when worth was determined by MAUM procedures.

Why? Here is a plausible answer. Making Gestalt evaluations, group members with strong points of view tend to concentrate on those aspects of the entities being evaluated that most strongly engage their biases. The multi-attribute procedure does not permit this; it separates judgment of the importance of a dimension from judgment of where a particular outcome falls in that dimension. While different views may cause different thoughts about how good a procedural level of performance on some dimension may be, evaluation of other dimensions will be more or less independent of viewpoints. Agreement about those other dimensions tends to reduce the impact of disagreement on a controversial dimension. That is, multi-attribute utility measurement procedures do not provide an opportunity for any one or two dimensions, or any one or two group members, to become so salient that they

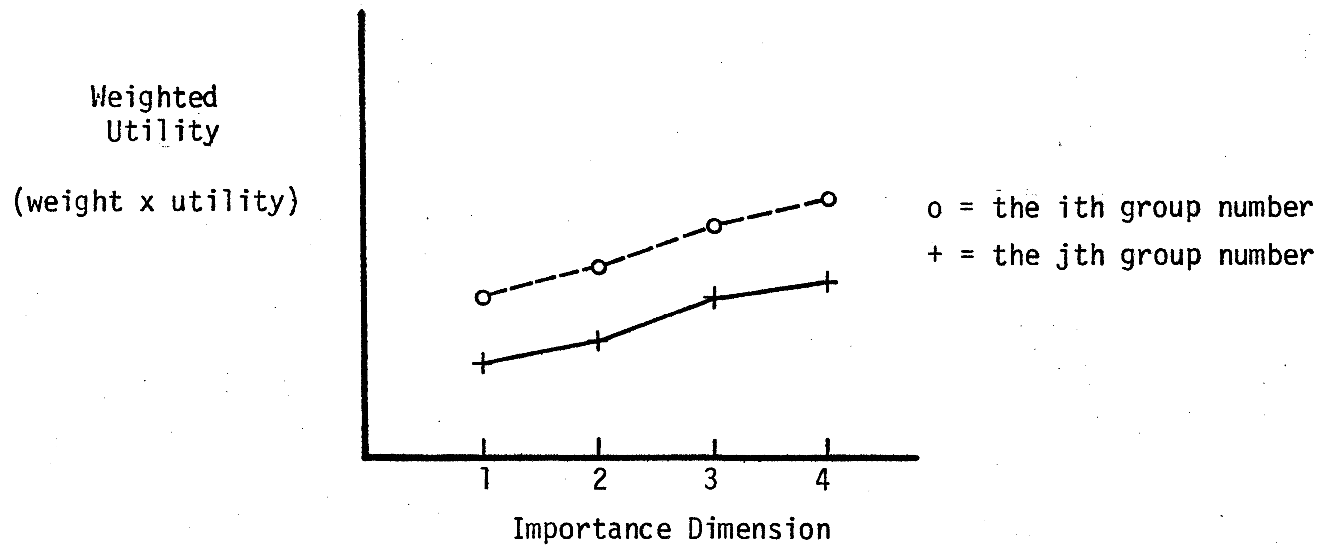


FIGURE 2-9. A CONSTANT UTILITY BIAS

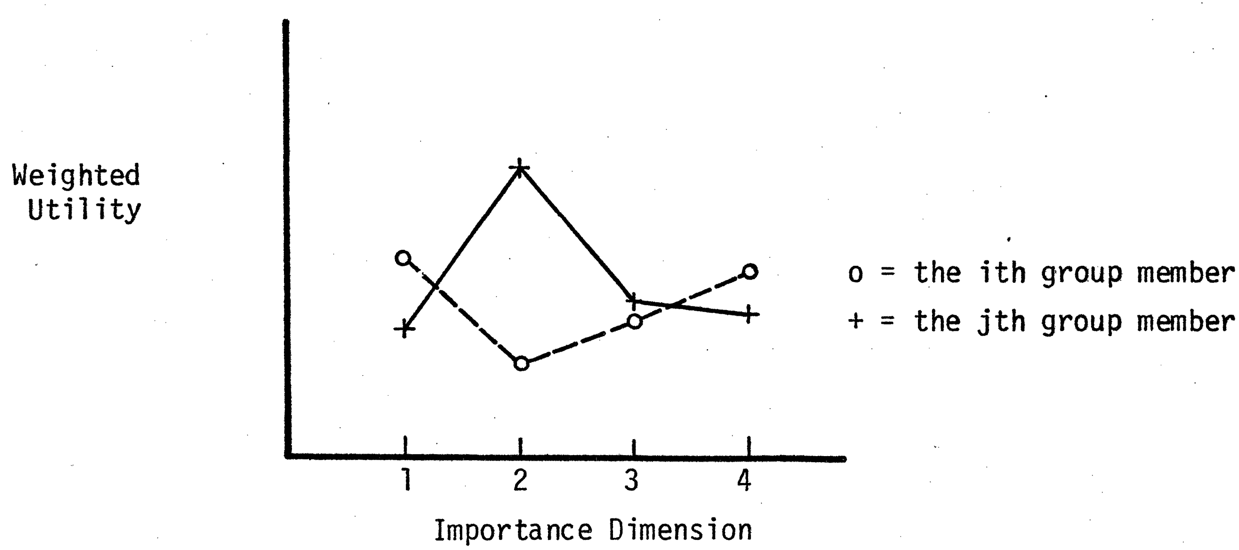


FIGURE 2-10. A UTILITY DISAGREEMENT ON SPECIFIC DIMENSION(S)

exaggerate existing sources of conflict and disagreement. While there may well be differences in importance weights assigned and utilities, when the dimension-by-dimension utilities are aggregated, these differences are washed out and different MAUM models of different individuals end with assigning the same overall worth.

2.4.4 <u>Group Conflict</u>. One cannot rely on characteristic MAUM to foster agreement, or even a majority, of cases. We guess that either the outcomes shown in Figures ~~2-3~~ 2-9 or ~~2-4~~ 2-10 will be more likely. In the instance of Figure 2-9, the plot shows that two group members differ on the contribution of utility that the branch's performance on each dimension contributes to overall branch utility. But the difference is relatively constant and in the same direction. One possible explanation is an evaluation bias (e.g., the ith member just likes to assign higher value numbers than the jth member for any dimension). We suspect that if this kind of profile shows up, that a compromise can easily be reached, particularly if the constant evaluation bias explanation holds up, and that the compromise will involve some sort of "meeting each other halfway".

In the instance shown in Figure 2-10 there is a "genuine" utility conflict with respect to importance dimension 2 with respect to branch performance. And this conflict (as well as other if present) can be examined for their effect on overall utility assignment conflicts for the branch. If (as in the example shown in figure 2-4) most of the overall utility disagreement can be attributed to a single importance dimension the debate is focused for the group. Perhaps a short discussion can help clarify and resolve the disagreement. Perhaps the disagreement cannot be amicably resolved. At this point any one of a number of strategies can be employed by the group leader to resolve the conflict (see Keeney, 1972).

Feedback Display. Of particular importance is the group feedback display. As shown by Bauer, Gebert & Meise (1973), the dimension-by-dimension values should be displayed for the entire group. That is, the list of options to be assigned values should be displayed according to how they rate on each dimension, as seen by each member of the group. Sensitivity analysis can be performed to determine the exact importance dimensions (or single dimension) where the individual value assignments create the overall disagreement. In such instances, the one or two conflicting dimensions can be isolated and identified for further discussion.

Bauer and Vegener illustrate how such a display can be produced. With its aid, the senior member of a group (or the intermediator) can focus discussion on the crucial dimension. In the end, a group judgment can still be reached either by vote (see Sheridan and Sicherman, 1972) or by the senior member present announcing his decision based on the kind and magnitude of value conflict clearly outlined in the MAUM displays, and on the relative value he places on his individual staff members.

2.5 Decision Tree Elicitation From Groups

2.5.1 General. The discussion of Section 2.3 showed that the decision making process can be enhanced by using computer techniques of decision tree elicitation and aggregation. These techniques include interactive decision tree elicitation, sensitivity analysis, utility aggregation, probability aggregation, and tree merging. The permit computer-directed "conversations" to focus on critical issues relevant to the decision problem at hand. Such conversations are guided by information obtained from the individual decision maker as he interacts with the elicitation program. The final result is a completed decision tree.

This form of decision aiding can be applied to decision making groups in two main ways:

(1) Complete trees are elicited from all group members; group interaction is used to progressively merge and resolve the individual trees.

(2) A single complete tree is elicited during group interaction; immediate individual contributions of all members are merged and resolved at each step of the elicitation process.

Each approach is discussed separately below.

2.5.2 Individual Trees. The first approach requires decision trees from each member of the group before discussion begins. Once the collection of individual trees has been obtained, a tree merging program begins the construction of the group tree by matching the various decision alternatives, event outcomes, utilities, and probabilities. Differences of opinion and conflicts in tree structure detected during the tree merging process are resolved in real-time by identifying the elucidating critical issues in the group tree and directing group discussion toward these areas. The critical issues separate into two major types: structural differences and numerical discrepancies, in utilities and probabilities. The resolution of numerical discrepancies at a node has been discussed above. Accordingly, we turn our attention to the question of structural differences.

Structural Differences. A structural difference occurs when one group member has alternatives or events in his decision tree that are not present in trees of other members. In these cases, automatic sensitivity analysis provides the basis for conflict resolution. The tree merging program has the complete individual decision trees of the group members available at all times. It identifies the earliest point (node) at which a structural difference occurs, and uses sensitivity analysis to calculate the importance of the various decision alternatives at that node with respect to each separate tree. Using these importance measures, the computer guides group discussion toward selection of a mutually agreeable set of alternatives from those occurring on the individual trees. For example, a unique alternative found to be relatively unimportant to the associated decision maker is suggested for deletion. Conversely, an alternative occurring in most of the individual trees, and found to be generally important, is strongly recommended for retention. If two or more group members have widely varying opinions on the importance of a specific alternative, the program directs the involved individuals to dissect the issue and reach an agreement, as described in Section 2.4. The final set of alternatives in the group tree will then be a subset of the union of alternatives from the individual trees. Other local structural differences, such as disagreements on the time-sequencing of events, are addressed in a similar manner.

2.5.3 Group Trees. The second approach is based on the interactive elicitation of a group decision tree from beginning to end during the group meeting. As the computer directs the decision making process, the group members enter their initial alternatives and numerical value estimates individually, and the program supervises conflict resolution at each point in the tree-building process. Sensitivity analysis is used as before to continuously focus on the most critical parts of the tree and to terminate discussion when it has been determined that further detail and expansion will not significantly affect the overall result. This approach essentially treats the entire group as an individual, since only one tree is constructed and there is no merging necessary. However, the techniques for conflict resolution described above are still required and applicable.

2.5.4 Mode Selection. It appears best to select one elicitation mode for initial implementation and evaluation. Since they share many required software features, and will involve many similar aspects of group decision behavior, it is more cost-effective to implement the most practical method first, evaluate it extensively, and use the evaluation results for modification or progression to the other. Of the two modes, elicitation of a single group tree, in which the group is treated as one individual (with occasionally divergent opinions), involves the most direct extension of the existing tree-elicitation software, the strongest application of sensitivity analysis, and the most direct use of multi-attribute utility measurement. Conversely, merger of individual trees raises a number of problems, primarily in the resolution of extreme structural differences. While solutions to these problems appear feasible, more data both about group interaction during aiding, and about individual trees, would be helpful. Accordingly, it was decided to implement the group tree approach during the first year program, but at the same time elicit trees from individuals, and examine them for insights into optimum merging procedures.

2.6 Benefit Analysis

2.6.1 Overview. Evidence from a variety of sources related to group decision making shows that significant improvement in the decision process can be expected through the use of the proposed aiding technology. This improvement can be measured in terms of two major performance factors: (1) decision time and (2) decision quality. The next sections provide a discussion of the benefits that can be expected in each of these areas.

2.6.2 Reduced Decision Time. Overall reduction in group decision time can be expected from three sources: (1) computer guidance; (2) multiattribute utility analysis; and (3) sensitivity analysis.

Computer Guidance. Computer guidance of group discussions explicitly highlights the major areas for consideration. Since the system display structures and guides the decision process, the attention of the group members is focused on specific aspects of the decision problem. Thus, there is less ambiguity about the topic of conversation and less time is wasted clearing misunderstandings.

Multi-Attribute Utility Analysis. Group attention to specific value conflicts reduces the noise associated with discussing decision situations. This brings the group to a closer agreement about their utility values. This fact has been shown by Gardiner & Edwards (1975) in comparing the choices of two sets of groups. One set was aware of the attributes of each decision choice and the other used strictly holistic judgments. The study showed a three-to-one improvement in the deviation of values for choices between sets of groups. In other words, the groups that made choices based on multi-attribute utility analysis were three times closer in value agreement than the groups that used strictly holistic methods. This improvement clearly indicates that awareness of the attributes of decision alternatives reduces disagreements dramatically.

Sheridan and Sicherman (1977) have recently shown that if a group is treated as a single decision maker, and utility measurement is made using electronic voting procedures, a complete multi-attribute utility function can be quickly obtained. In accord with our previous discussion of MAUM procedures and benefits (Section 2.4) Sheridan and Sicherman state:

> *The time required to obtain (a utility function) from a group is quite small. Depending upon the problem, some minutes of discussion are required to clarify the variables of the situations which are being compared. The group does not need to know anything of the theory. In the two-attribute example described only four votes were necessary, each of which took about two minutes of meeting time. The procedure can easily be extended to larger groups or situations of 3 or 4 dimensions. When a group proves to be*

heterogeneous, so that calibration of a utility function is not valid, the process reveals useful bounds for sensitivity analysis and specifies the degree to which final decisions concur with group preference.

Sensitivity Analysis. The use of sensitivity analysis during the tree elicitation process saves a considerable amount of time since the computer is continually guiding the group members toward the most critical issues. Valuable time is not spent arguing about unimportant topics. Although no experimental data is available concerning the exact amount of time saving, the sensitivity analysis approach is similar in many respects to the alpha-beta pruning technique used to limit search time on game trees. It has been shown by Nilsson that using alpha-beta tree pruning allows a tree to be searched twice as deep as would otherwise be possible (Nilsson, 1971). As Nilsson states:

> .... *the number of tip nodes of depth D that would be generated by optimal alpha-beta search is about the same as the number of tip nodes that would have been generated at depth D/2 without alpha-beta. Therefore, for the same storage requirements, the alpha-beta procedure, with perfect successor ordering, allows search depth to be doubled.* (p. 148)

Since it has been proven that the use of alpha-beta pruning does not alter the final decision, this storage savings can be directly translated into a time savings.

For example, consider a decision tree with three branches per node that extends four levels deep. The number of tip nodes in such a tree is $3^4 = 81$. With alpha-beta pruning, the optimal result can be obtained by generating only the number of nodes appearing at level 2, that is, $3^2 = 9$.

Thus, there is a 9-to-1 time savings for this particular tree. With larger trees, the savings would be much more. In fact, it increases exponentially. This ratio assumes that the complete tree would have been expanded without tree pruning. At typical group meetings, the members subjectively prune their "tree" during the discussion. However, the issues that are discussed are usually far from the optimal ones. Thus, even if no time savings is realized by use of sensitivity analysis, the group can be certain that the topics of attention are indeed the most crucial ones.

2.6.3 Decision Quality Improvement. Decision quality is related to the rationality of the final decision, in terms of the potential of the selected alternatives to provide the highest expected gain. Nickerson and Feehrer (1975) have attempted to discriminate between two aspects of quality -- effectiveness and soundness:

> *Effectiveness is determined after the fact. The logical soundness of a decision depends on the extent to which the decision maker's choice of action is consistent with the information available to him at the time the decision was made, and with the decision maker's own preferences and goals.* (p.170)

At Perceptronics, a similar differential has been established between external system performance measures (effectiveness) and internal decision measures (soundness). The current analysis, however, does not warrant so fine a distinction, and accordingly both concepts have been used in arriving at an overall estimate. Decision quantity improvement is expected to arise from two sources:

(1) Increased participation of group members.
(2) Multi-attribute decision modeling.

The following is a discussion of each of these aspects.

<u>Member participation</u>. Related work in group decision making indicates that decision quality can improve by increasing the participation of the group. In a command group which consists of various specialists, optimum decisions require all points of view to be considered and all aspects of the problem to be evaluated. Thus, if the system can increase the participation of the group members it can be expected that decision quality will improve.

The important effects of direct feedback on individual participation and opinion considerations have been shown by Sheridan (1975). Sheridan has developed an Electronic Voting and Discussion Technique (EVOT), which utilizes an electronic voting scheme and specially designed meeting procedures. Every participatant is able to make an anonymous coded response to questions posed by the moderator, and to observe instantaneously a tally of how many members voted in each category. The purpose is to get a rapid appraisal of areas of consensus and areas of controversy. This allows participants to reveal their ignorance anonomously, to deal with controversial questions without intimidation, and generally to make the discussion more responsive to the real interests and needs of the group. The technique has been used in configuration with real-time visual feedback display of a purely numerical type.

For example, in three independent experiments covering race issues with groups of 12 to 15 participants, it was found by Pizano (1974) that group participation increased by a factor of 2.5 when the EVOT aid is used. For a specific experimental group using EVOT, 90% of the time was used by slightly less than 50% of the participants. In contrast, for a control group that did not use the feedback, 90% of the time was used by less than 20% of the participants. (Bearing in mind that in some cases, as much as 80% of the time was used by one person.) It can be concluded from these experiments that more individuals will contribute to the decision when group decision aiding technology is employed.

Positive effects of group participation on decision quality have also been shown in experiments with Delphi techniques by Dalkey & Helmer (1963) and by Huber (1974) in studying combined judgment of individuals in decision conferences. According to Dalkey, when each group member's view is genuinely considered in a non-dominating way, the decision quality improves with respect to an external criteria (Dalkey & Helmer, 1963). The implication from this is, again, that mechanisms which increase the effective participating of the group will improve decision quality. Huber (1974) showed great sensitivity between (1) the number of individual opinions that are actively considered in a group decision and (2) the error associated with the decision. His research was concerned with the problem of combining the judgment of a number of group members into a single group judgment using the Delphi technique. Results have shown that decision error was reduced by a factor of 2 when the number of individual participants increased from 2 to 5 and further decreased by 25% when 5 additional participants were included. This indicates greater sensitivity for small groups as, for example, may be encountered in command posts. The implication from this data is that at small group levels (5 or less) decision quality is expected to improve markedly with increased participation.

Decision Modeling Effect. Multi-attribute decision analysis is a major factor which will contribute to decision quality. In particular, the use of the multi-attribute model as a criteria to evaluate group utility affords a considerable advantage over holistic approaches. Newman (1975) analyzed data from different studies and showed that multi-attribute utility assessment procedures are more reliable, valid and generalizable than holistic assessment procedures. In one study involving allocation of air strike missions in a tactical environment (Miller, Kaplan, and Edwards, 1967, 1969), a performance improvement ratio of 1.23 was found in favor of the multi-attribute approach. In another application concerning group evaluation and decision making with regard to land development applications (Gardiner, 1974), an improvement ratio of 1.69 was obtained.

Significant improvements in decision effectiveness have been observed when interactive computer aiding is used to generate action alternatives. Individual operators in a simulated ASW tracking task (Freedy, Davis, Steeb, Samet and Gardiner, 1976) were found to exhibit 86% greater performance effectiveness when aided by a computer based on their observed preferences. The improvement was measured by an external criteria which quantitatively combined submarine detection score against false alarm rate and cost.

The use of the decision model and elicited utilities is another major factor that improves decision quality. The early bootstrapping approach of Dawes (1971) and Goldberg (1970) resulted in up to 20% improvement in decision effectiveness, apparently due to a lessening of operator inconsistency or "noise" (Fischer, 1972). Similarly, Miller and his associates (1967) demonstrated the efficiency of combining human value judgments and machine policy selection in a tactical air command system. The interaction was found to result in 90% of the attainable optimum performance compared to roughly 50% of optimum performance by the operators alone, an improvement of 1.8.

A direct comparison of decision makers with their individual decision models has been made possible by research at Perceptronics dealing with the use of adaptive techniques in computer assisted maintenance training (May, Crooks, Purcell, Lucaccini, Freedy, Weltman, 1974). The cumulative cost of the tests used to diagnose an electronic circuit provided the performance measure. For each subject, a comparison is made between <u>his</u> mean cost, observed in experimental trials, and the mean cost accumulated by <u>his model</u>, tested in computer simulation. The model's costs are on the average 0.70 of the individual's costs, indicating a performance improvement ratio of 1/.70 = 1.43. For the less skilled individuals, the improvement offered by the model is markedly greater.

2.6.4 Effectiveness Measure. A compound measure for the effectiveness of group decision aiding can be formulated in terms of the expected improvement in the system performance variables. The effectiveness can be established by aggregating available research data. The efficiency measure is expressed

$$\text{Effectiveness of Group Decision Aiding} = f\left[\text{Decision Time Reduction}, \text{Decision Quality Improvement}\right]$$

where Decision Time Reduction is in turn a function of: (1) reduction of conflict and noise, (2) concentrated discussion in areas where real value difference exists, and (3) reduction of tree size and number of argument points which are required to reach a conclusion. The improvement in decision quality is due to (1) increased participation and (2) decision aiding effect. An overall improvement ratio can then be defined as:

$$\text{Improvement Ratio} = \text{Decision Quality Improvement Ratio} \times \text{Decision Timing Improvement Ratio}$$

Table 3-2 summarizes the improvement ratios estimated by the above sections. The data is based on individual experiments where each variable was studied independently. This will probably not be the case in a complete aiding system. Accordingly, we can reduce the expected improvement somewhat to account for interdependence, and estimate a ratio in the vicinity of 25:1.

Factor	Sources	Improvement Ratios (Min-Max)
Decision Time	Conflict reduction Tree Sensitivity Analysis Reduction of noise	3 - 5
Decision Quality	Increased Participation Aiding Effect	4 - 9
Improvement Ratio		12 - 45

Table 3-2. EXPECTED DECISION IMPROVEMENT

3. TECHNICAL APPROACH

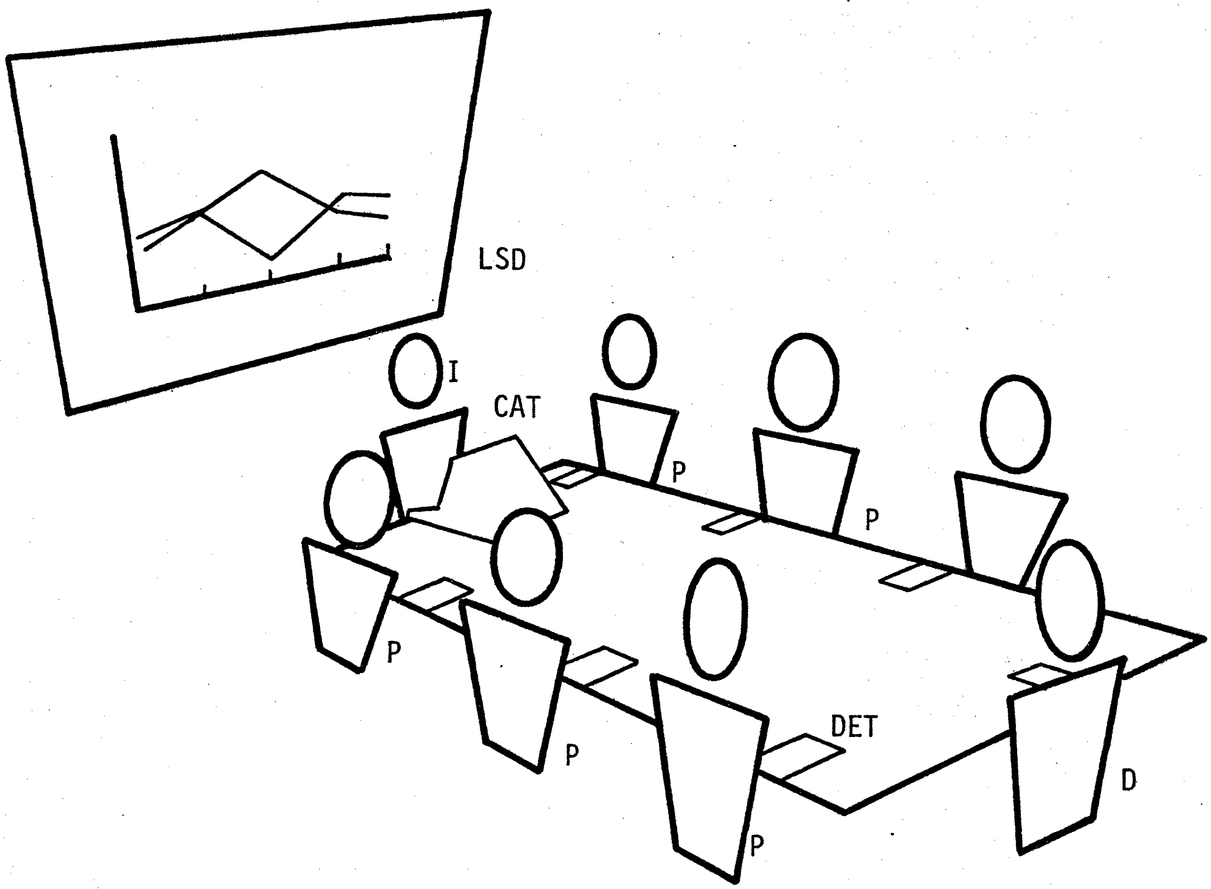
3.1 Aiding System Description

3.1.1 Aiding Functions. Figure 3-1 shows in conceptual fashion the decision making group in the conference room. Group interaction centers around the large screen display (LSD), which provides guidance information and group action feedback. The group may be led by a director (D). It is assisted by an intermediator (I), whose functions are to coordinate the computer interactive process, to control the information flow, and to initiate discussion phases, display programs, and data processing via the computer access terminal (CAT). Each group participant (P) has a data entry terminal (DET) to enter his responses and information requests. Interaction around the table is both verbal and display-directed.

Figure 3-2 shows the basic group decision making process in block-diagram form. The process is driven by an existing decision problem that requires group interaction to lead to a viable solution. This is shown at the top of the figure by the progression from the decision problem through the group decision making process to the problem solution. The interactive process itself is comprised of a cycle of four major aiding steps. These basic aiding steps are as follows:

(1) Node Selection
(2) Node Expansion
(3) Value Elicitation
(4) Tree Analysis

Each cycle through the four steps corresponds to the complete expansion of one node in the group decision tree. At the end of each cycle, the group reviews the current progress and determines if more information is necessary (i.e. growing the tree by completing more cycles) or if an acceptable



LSD LARGE SCREEN DISPLAY
CAT COMPUTER ACCESS TERMINAL
DET DATA ENTRY TERMINAL
I INTERMEDIATOR
D DIRECTOR
P PARTICIPANT

FIGURE 3-1
THE DECISION MAKING GROUP

solution exists at the current time. This stopping point can be determined by group concensus or can result from sensitivity analysis. For example, if it has been found for all tip nodes that minor alterations in value will not have an impact on the final decision, the computer can immediately recommend that the group terminate its interaction. The aiding steps themselves are described separately in the following sections.

3.1.2 Node Selection. The first step in the group decision making process cycle is node selection. During the group interaction, sensitivity analysis is used to determine the most critical and important topics for discussion. The most critical topic is that which has the most chance, by a change in its value, to alter what is currently the most promising solution. It is this topic that is brought to the attention of the group so that it may be explored in more detail. However, it is always possible for the group to choose a mutually agreeable topic for discussion, rejecting the one recommended by the system. In this case, the intermediator overrides the computer's choice and enters the group choice. The computer will then automatically compare the sensitivity value of the chosen topic with its own recommendation and comment on the appropriateness of the selection. For example, a typical comment resulting from such a criticality comparison might be:

> THE VALUE OF THE CHOSEN TOPIC FOR DISCUSSION MUST BE TRIPLED BEFORE ANY DIFFERENCE IS MADE IN THE CURRENT TREE.

Such comparisons will be quite helpful in encouraging fruitful discussions and discouraging unproductive ones. The computer output from the Node Selection step will generally be a recommendation, in text form, for a topic of discussion. The input required is either a confirmation of the selection or another desired topic.

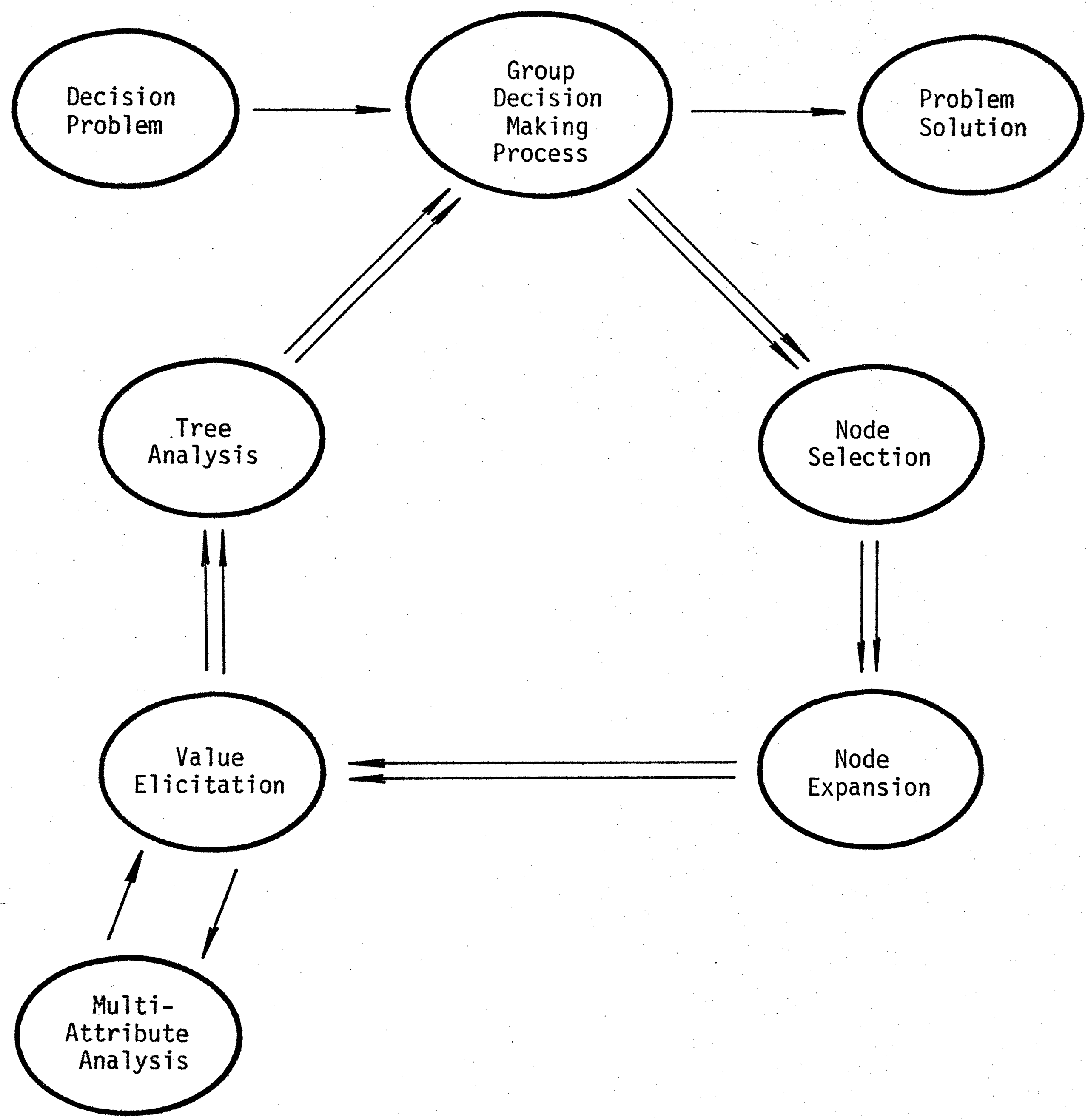


FIGURE 3-2
GROUP DECISION MAKING PROCESS

3.1.3 Node Expansion. The second step in the aiding process is node expansion. During this step, the group is asked to supply a list of decision alternatives or event outcomes. This list must contain mutually exclusive items, due to the nature of the decision tree formalism. Aid in determining satisfaction of the mutually exclusive condition can be provided by the intermediator if necessary.

The interaction between the group and the computer system may require a relatively sophisticated response interpretation mechanism, since elicitation here is characterised by English text input. The text is composed of keywords and phrases that describe the basic decision alternatives or event outcomes. It will be necessary to compare labels on branches so that repetitive or redundant alternatives can be identified. This process must be oriented toward keyword search and matching, since the group decision aiding system is assumed to be domain-independent.

If preliminary individual decision trees are available, they can be used as an initial source for decision alternatives or event outcomes by subjecting them to a tree merging process. After the location of the current topic has been found in each tree, the union of the branches of all trees will form a basic set from which to work. If there is a disagreement as to node type (i.e. decision or event), this must be resolved by the group as a separate issue.

3.1.4 Value Elicitation. Once the major decision alternatives and event outcomes have been established, utilities, probabilities, and costs must be determined for each one. Through computer guidance, each alternative or outcome is displayed and discussed, one at a time, in order to define these values. Utilities and costs are necessary for decision alternatives as well as event outcomes; probabilities are necessary only for event outcomes. If utilities are given on a relative scale, rather than in money, then costs are assumed to be contained within the utility estimate and do not have to be elicited separately. If the group agrees on approximate values immediately, no further processing is necessary. However, the values entered into the individual input terminals may differ greatly. In such cases, a conflict exists and it must be resolved before tree elicitation can continue.

When the computer detects a genuine conflict in utility values, the multi-attribute utility model is activated to help resolve the conflict by decomposing the issue into its constituent parts and assigning utility values to the parts. Then, an aggregation algorithm determines a final value from the decomposed parts. (Section 2.4 describes the procedure for recognizing conflict and obtaining multi-attribute utility values from groups.) Conflicts in probability assessment and in costs can be handled with a similar model.

3.1.5 Tree Analysis. The last major step in the process cycle is a purely computational one. With the completion of node expansion, the tree is ready for expected-value rollback analysis to determine the best decision with the currently available information. This computation not only allows the group to see the progress of the interaction, it also prepares the tree for sensitivity analysis in the first step of the next cycle.

The rollback is the primary means of determining the best decision thus far. The calculation is made starting at the tips of the tree and progresses back toward the single root. At each decision node, the maximum of the values of the branches is assumed to be the value of the node. This is becasue the decision makers have a choice and would naturally pick the alternative with the highest utility. At each event node, the expected value of the branches is taken as the value of the node (the sum of the products of each utility with its corresponding probability). This function is used because the decision makers do not have the choice of which event will occur.

The outcome is out of their control. When these calculations reach back to the root, the branch with the highest computed utility value is the currently best choice to take.

3.1.6 System Organization. Figure 3-3 shows the planned organization of the group decision aiding system. The computer access terminal (CAT) of the intermediator and the data entry terminals (DET) of the group members are connected to the function control module. This module is the system supervisor, which is responsible for controlling the following functions:

(1) large screen display output
(2) terminal input and message routing
(3) data base access
(4) group decision making process cycle.

The large screen display is shown under the control of a display format module. This module is necessary since the screen may be divided into more than one active area.

The group decision process cycle as described in previous sections is shown in Figure 3-3 as a series of separate modules (steps) each with a corresponding algorithm. The node selection function uses sensitivity analysis. The node expansion function uses tree merging if preliminary trees are available from each group member. The value elicitation function uses multi-attribute utility analysis if value conflicts arise. Finally, the tree analysis function uses expected-value rollback calculations. Each of these functions has access to the data base where the group tree is stored.

In addition to the four basic process functions, the function control module can activate a separate direct access path to the data base. In many cases, the group will wish to interrogate the data base to aid in its decision

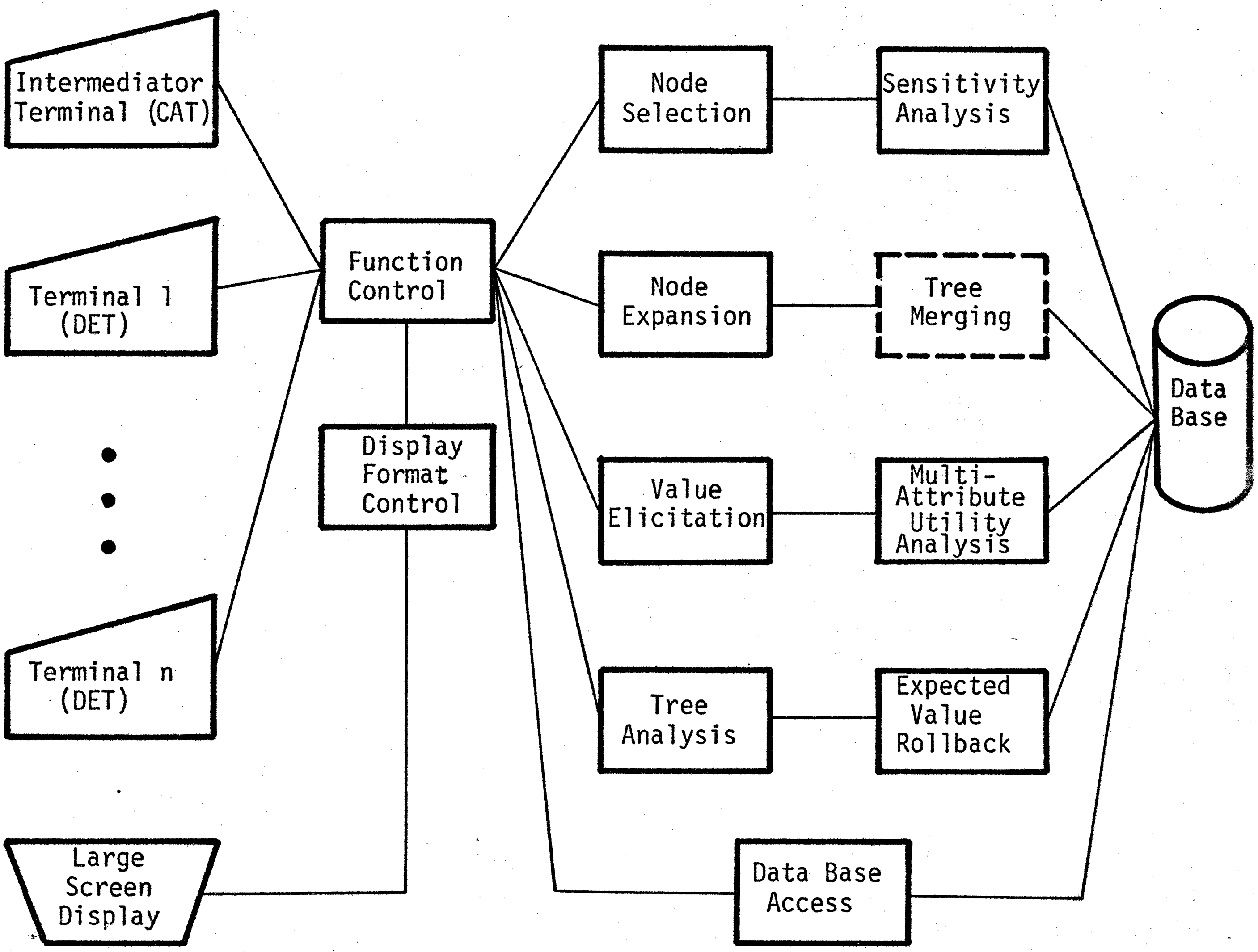


FIGURE 3-3
ORGANIZATION OF GROUP DECISION AIDING SYSTEM

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task. The intermediator will have a capability to request the display of data in varying formats to accommodate the member's requests.

3.2 System Software

3.2.1 Operating System.

The following software systems are proposed for the implementation of the group decision tree elicitation algorithms:

(1) UNIX operating system
(2) LISP programming language

A version of LISP is available for the UNIX operating system and requires a relatively small amount of storage (about 4K). LISP is ideal for implementing the group decision aiding system for the following reasons: (1) suitability, (2) utilization of existing programs, and (3) transferability. LISP is well suited for tree generation and manipulation because of its "list-processing" data structure. The existing tree elicitation program, written by Dr. Leal, is already written in LISP and may be used almost directly. Finally, the LISP system can be transferred along with the program source code if necessary.

3.2.2 Program Modules.

The group decision-aiding system requires program modules for each of the four process steps as described in Section 3.1. These modules and their constituent routines include:

(1) Discussion Control

   (a) A sensitivity analysis module for isolating the most critical parts of the tree.

   (b) A criticality comparison module for determining differences between two suggested topics of discussion.

(2) Tree Elicitation

(a) An elicitation module for directing discussion to the generation of decision alternatives or event outcomes.

(b) A response interpretation algorithm using keyword search for text comparison.

(c) A tree manipulation program for maintaining the correct structure for the group decision tree.

(3) Value Elicitation

(a) A utility scale elicitation package for the definition of individual relative utility scales. (One time use.)

(b) A probability calibration package for adjusting for bias in predicting probabilities. (One time use.)

(c) A utility and probability elicitation module for determining the required information for proper tree analysis at each stage.

(d) A multi-attribute utility analysis module for conflict resolution of estimated values.

(4) Tree Analysis

(a) An expected value rollback algorithm for determining the currently most desirable alternative from the group tree.

(b) A multi-attribute utility analysis module for conflict resolution of estimated values.

(5) Service Routines - the following service modules are required for system use.

(a) Display control
(b) Function control (supervisor)
(c) Data access routines

3.3 System Hardware

3.3.1 Components. Major components of the aiding system hardware are as follows:

(1) Computer System
(2) Individual Input/Display Terminals
(3) Group Feedback Display

The equipment proposed for each is described separately below.

3.3.2 Computer System. The group aiding programs will be supported on a PDP/11 minicomputer. The computer system, which is currently under order by Perceptronics, includes a main frame, disks and controllers, printer, DEC graphics terminal, and DEC scopes. The capabilities of this system are more than adequate for the proposed application. In addition, the PDP/11 has become virtually a standard in the ARPA and general military communities, thus transferability of the aiding programs will be excellent.

3.3.3 Individual Terminals. Group member interaction with the aiding program will normally be through a DEC Scope VT52 Video Terminal or equivalent. The VT52 video display terminal displays 24 lines of upper and lower case text at selectable speeds to 960 characters per second, and permits user input through a standard keyboard and auxiliary numerical keypad. The terminal, illustrated in Figure 3-4, is a compact unit reflecting good human factors

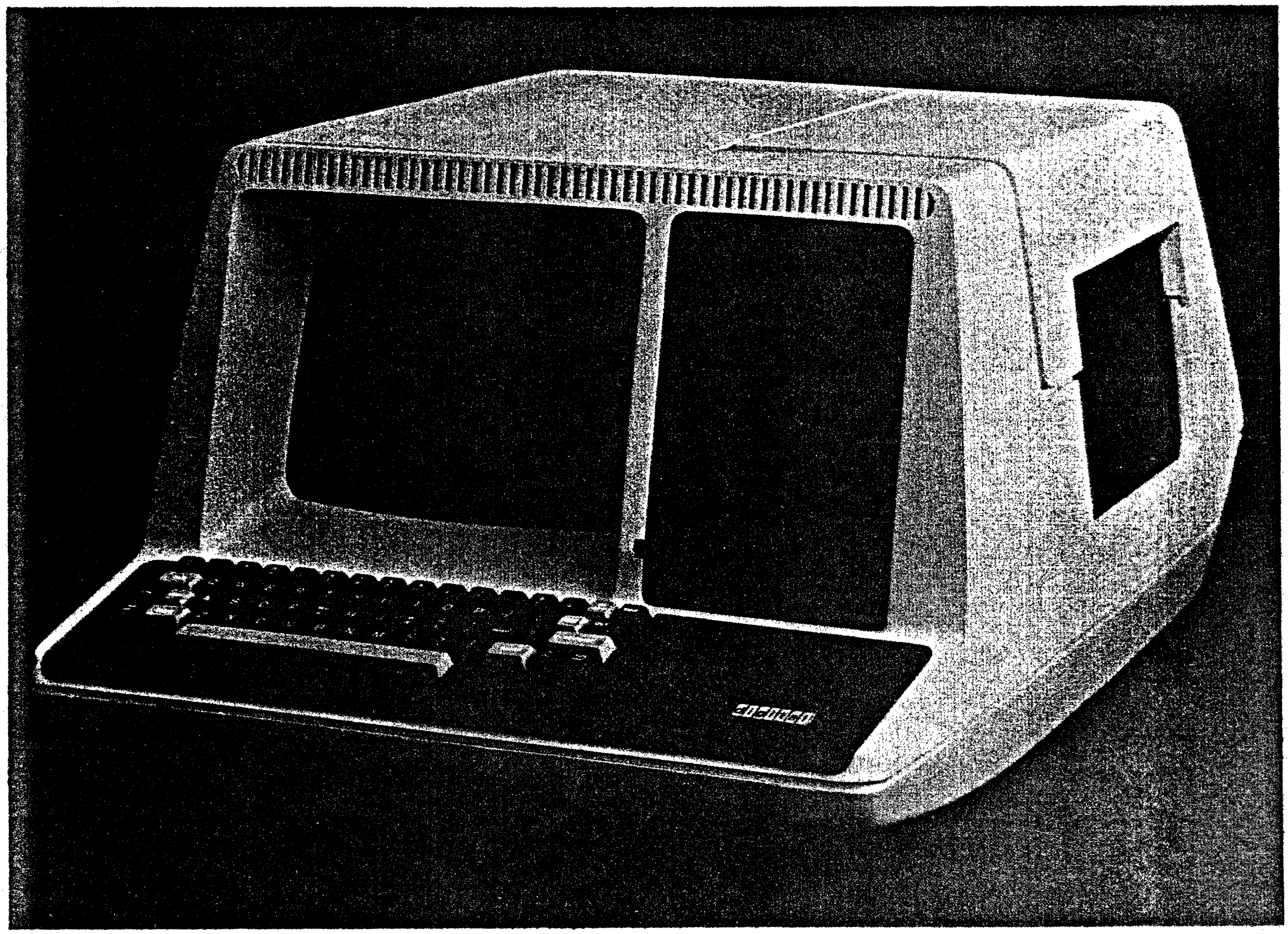

FIGURE 3-4
DEC VT52 VIDEO TERMINAL

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design, and is well suited to the proposed application. In certain experimental situations, as discussed below, the group members' terminals may be replaced by numerical and special-function keypads. It is anticipated, however, that the intermediator will always operate from a terminal.

3.3.4 Group Feedback Display. It is planned to provide a centralized large-screen color display for feedback of information needed by the group as a whole. The display system, shown schematically in Figure 3-5, is composed of three components:

(1) DEC PDP/11 Minicomputer
(2) DEC VT30 Display Controller
(3) Advent 750 Video Projector LSD

The PDP/11 Minicomputer has already been described. The other two units are described separately below. Use of color in the display system adds little to the cost, since standard 525-line video is employed throughout, but it adds considerably to the graphic impact and flexibility of the feedback displays, allowing color-coding of critical display contents, and separation of individual responses.

Large Screen Display. Presentation of the feedback display will be done through the Advent Model 750 Videobeam Color Television Projector. Figure 3-6 presents the major components and specifications of the Advent Model 1000A professional unit. The Model 750, just out on the market, is a consumer version of this unit, with a smaller projector case, slightly smaller screen (60" x 45"), and essentially the same TV specifications. It is designed to sell for $2500 rather than for $4000, the cost of the Model 1000A. Both units offer high quality, full-color video, projected on a bright screen intended specifically for group viewing. Both units can be driven from conventional color video signal sources.

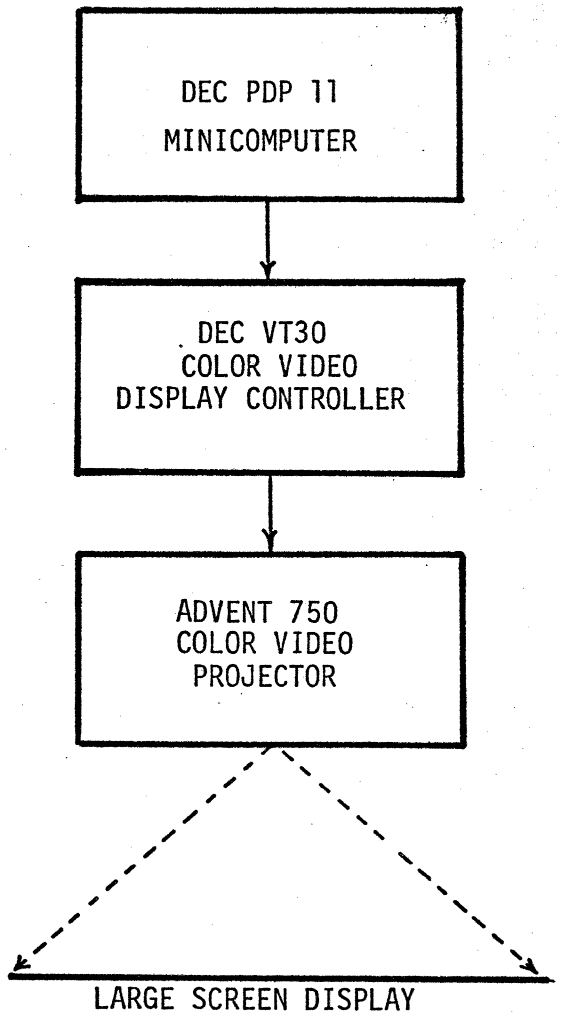
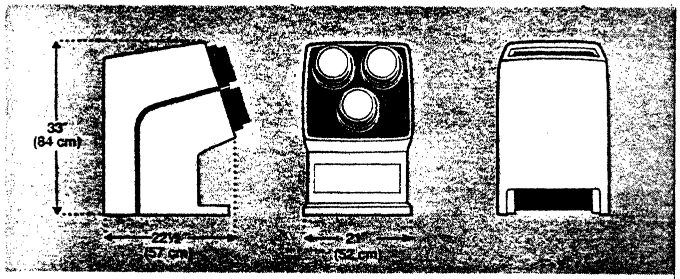
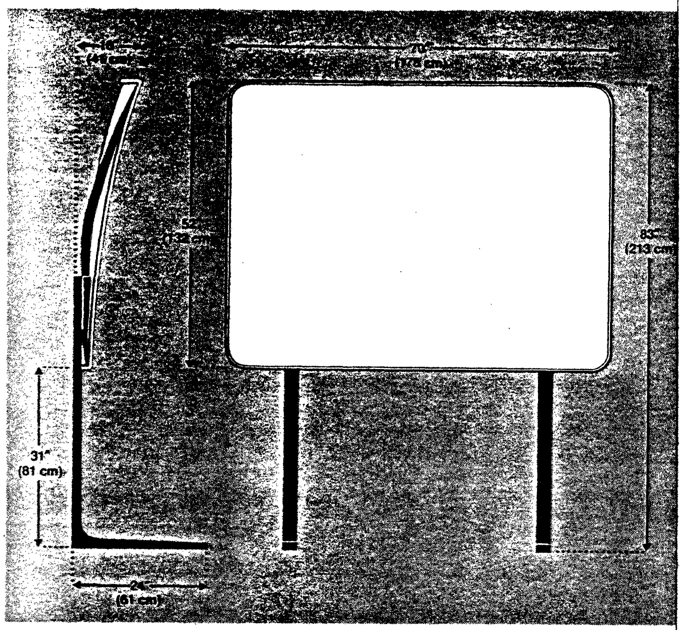


FIGURE 3-5
GROUP FEEDBACK DISPLAY SYSTEM

SPECIFICATIONS



THE VIDEOBEAM RECEIVER-PROJECTOR.



THE VIDEOBEAM SCREEN.

Picture Size
4¼ ft. h. x 5⅔ ft. w. (132 cm h. x 178 cm w.); 7-foot diagonal (2.2 m); 24.5 sq. ft. (2.3 sq. m). Not variable.

Brightness
More than 20 foot-lamberts (above the brightness range recommended for motion picture theaters by the Society of Motion Picture and Television Engineers).

Audience Size
With screen and projector sitting on the floor as illustrated, approximately 50 viewers can be accommodated, depending on room size and configuration. By raising both screen and projector according to instructions supplied on request, coverage can be increased to 200 or more viewers.

Screen to Projector Lens Distance
100" ± 1" (254 cm ± 2.5 cm). Not variable.

Projection Tubes
Each of the three Advent-developed and manufactured LightGuide projection tubes* incorporates a wide-angle Schmidt projection system. A spherical mirror sealed inside the tube collects the light emitted from a phosphor-coated aluminum target and projects it to the screen through a molded acrylic aspheric lens bonded to the tube.

Optical speed	*f*.7
Mirror size	6" (15.2 cm)
Target size	3.3" diagonal (8.4 cm)
Anode voltage	30 KV
Beam current	200 microamperes maximum per tube
Deflection	28 degrees per tube
Focus	Primary permanent magnet with secondary electromagnet for incremental focus adjustment by user

Resolution
Determined by NTSC video bandwidth; not limited by electron optics, projection lens system, or segmentation of raster into color dots or stripes.

Signal Standard
VideoBeam television operates from regular American NTSC broadcasts and external video sources; 525 scanning lines interlaced 2:1 with 60 Hz field rate and 30 Hz frame rate; picture aspect ratio 4:3. (Sets for use with other signal standards are available outside the U.S.; contact Advent for further information.)

FIGURE 3-6
ADVENT 1000A SPECIFICATIONS

Display Controller. The proposed video signal source is the DEC Model VT30 display controller. This unit was recently developed by DEC's Computer Special Systems (CSS) group, working from an earlier version available only in Europe. It attaches directly to the PDP/11 bus, and generates the video signals necessary to produce 8-color alphanumerics and graphics.

Figure 3-7 is a block diagram of the controller unit. For graphics purposes, the Monitor screen is divided into 2304 squares arranged in 36 rows of 64 characters each. Each square consists of an 8 x 8 dot matrix. In order to display graphic information, the squares are filled with the required characters. The Display System allows the user to define its own set of special characters. Up to 64 characters, specified as particular bit patterns within an 8 x 8 matrix frame, can be defined dynamically, by loading a Read/Write Memory within the Controller. Dynamically means that any character can be changed at any time under program control. In addition to the 64 user-defined characters, the 64 upper case ASCII characters are also available as standard 5 x 7 matrix from a ROM Character Generator.

Figure 3-8 illustrates the Controller's graphics capability. As seen, this unit is excellent for the display of decision trees, graphics, bar charts, situation maps, and related alphanumeric information. The controller is priced at $7500. This is low compared to the cost of equivalent color graphics controllers available from such firms as Video Disk, Ramtek, etc. According to the CSS group, relevant graphics software is available in the DEC library, and they themselves will assist early users to develop special graphics routines.

3.3.5 Group Aiding Facility. Figure 3-9 shows the planned configuration of the large-screen group display and individual interactive terminals in an existing room of Perceptronics' Woodland Hills facility. The Advent Model 750 projector, which is only 26" high, will fit under a standard

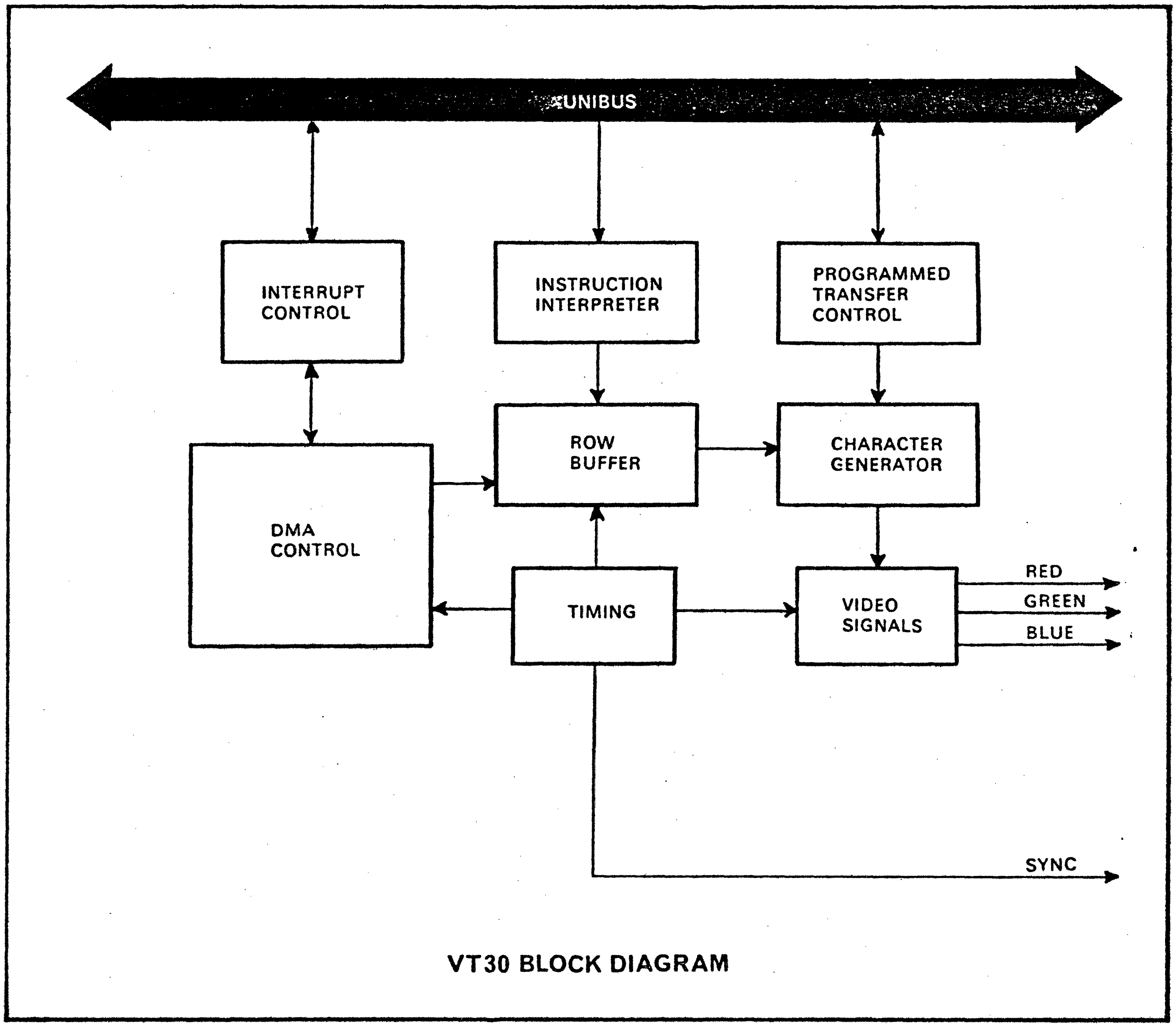
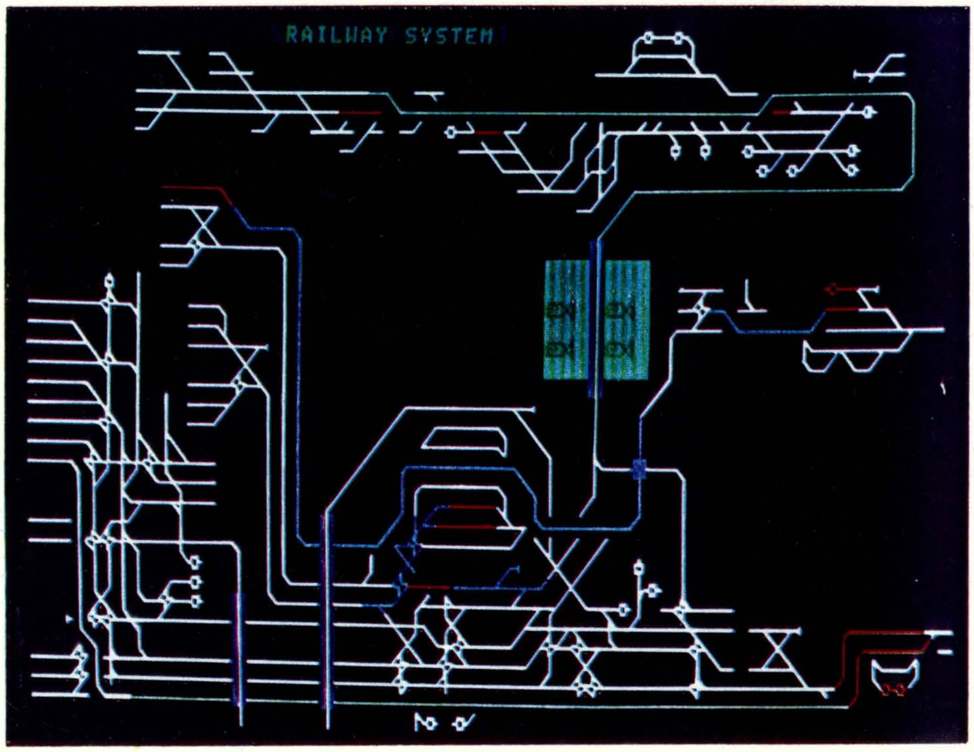


FIGURE 3-7
VT30 BLOCK DIAGRAM



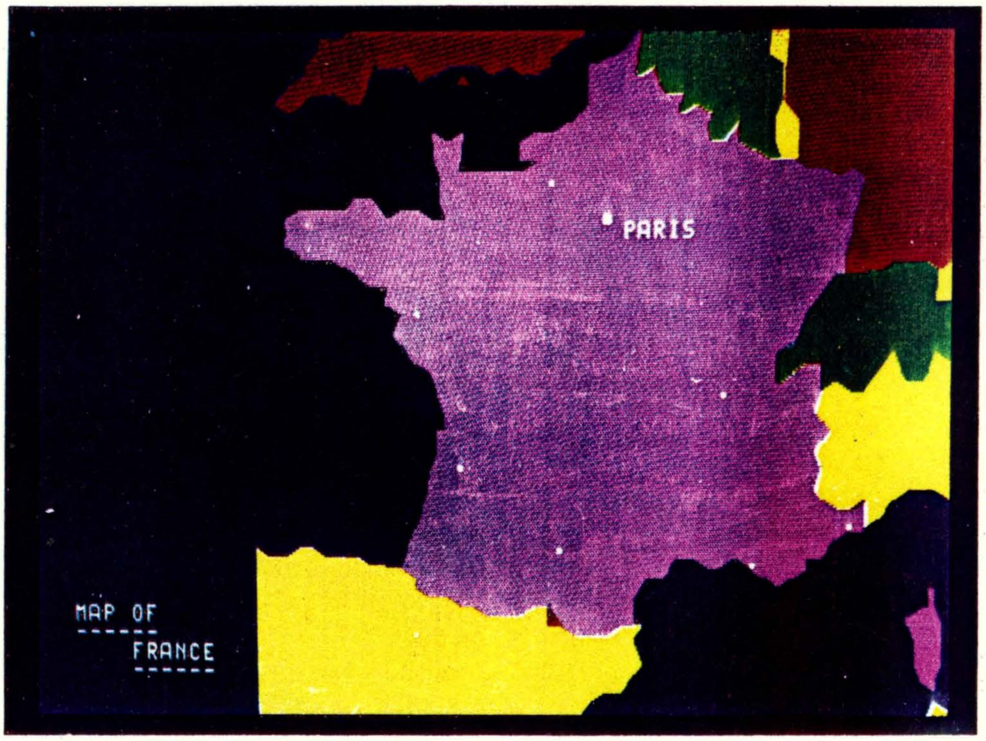


FIGURE 3-8
VT30 EXAMPLE DISPLAYS

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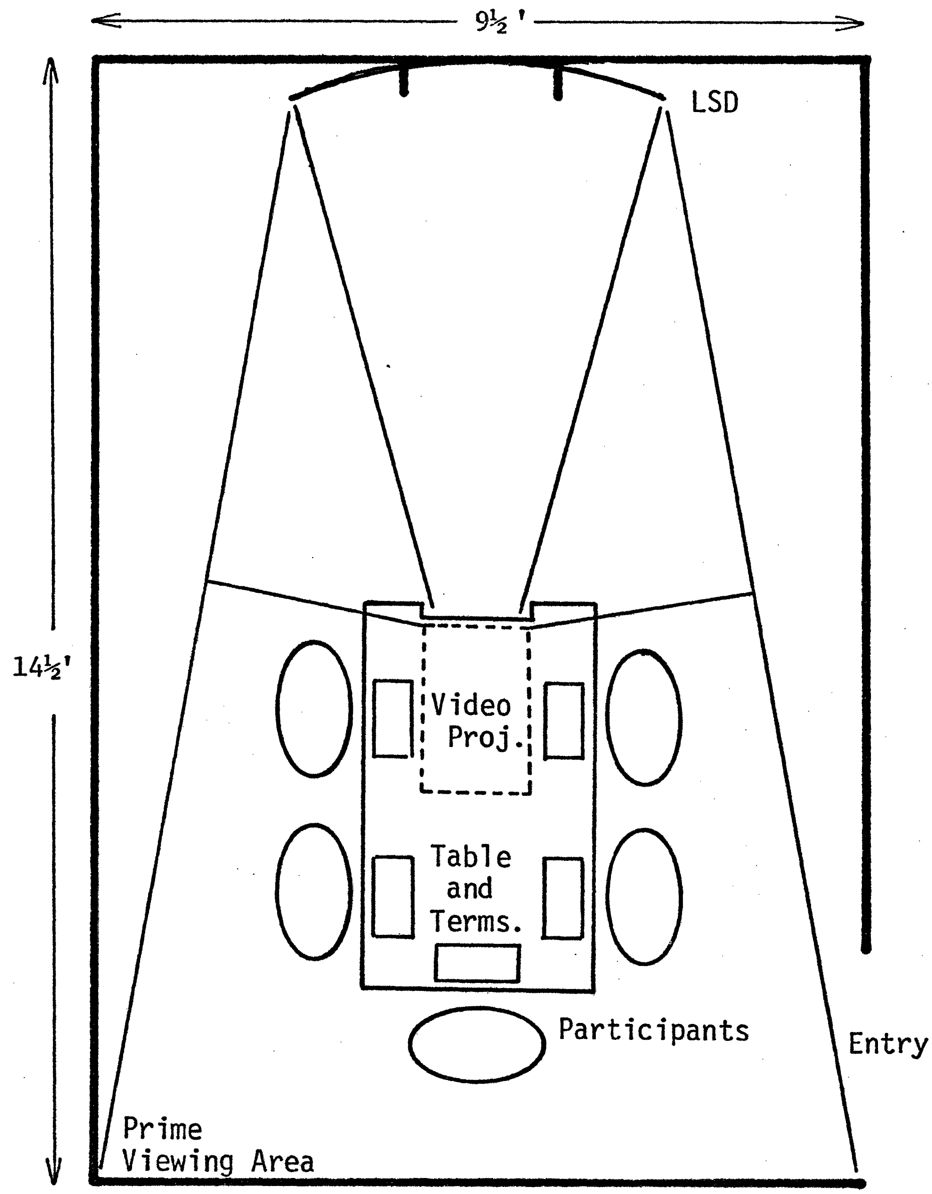

FIGURE 3-9
PROPOSED PERCEPTRONICS
GROUP DECISION AIDING SYSTEM LAYOUT

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conference table. Group members, including the intermediator, will be seated around the table in front of their terminals, and will be located in the display's prime viewing area. Sufficient space is still available for experimental observers. Alternatively, if it appears desirable to remove observers from the immediate discussion area, a view-window can be cut in the back wall, and the observers located (behind glass or one-way mirrors) in the adjacent room.

3.4 System Evaluation

3.4.1 Major Aiding Factors. A number of aiding factors can be expected to impact the type of interaction that the group has with the aiding system, and its decision making performance. These factors include:

(1) Tree Elicitation Mode. Two major elicitation modes have been identified. In one, the tree is elicited from the group as a whole. In the other, complete individual trees are merged by group action. Elicitation from groups could: (1) minimize points of conflict, (2) use sensitivity analysis to explore only branches important to the group as a whole; (3) simplify system implementation, including programming and presentation. On the other hand, elicitation from individuals might (1) produce more unique decision alternatives, (2) allow more flexibility in personnel scheduling, and (3) allow the group to identify general areas of agreement beforehand and therefore focus on only major problem areas during interaction. Preliminary analysis suggests that group elicitation is most advantageous but because of the potential benefits, a more detailed comparison with individual elicitation seems warranted.

(2) Intermediator's Role. The notion of a so-called "intermediator" to intercede between the members of the decision making group

and the decision aiding program has been very well received when presented to command level personnel. An attractive feature is that it could relieve the actual decision makers of almost all responsibility for learning "hands-on" operation of the aiding system. At the same time, it places a relatively heavy load on the intermediator himself. Thus, one might ask whether he is in fact essential; what is the tradeoff between his functions and those of the group members; and correspondingly, what should be the format of the interactive programs with which each is in contact.

(3) Interactive Configuration. As an adjunct to the above, one can conceive of a broad spectrum of input/display mechanisms for the intermediator and the decision makers. At one extreme, the intermediator would have full interactive capabilities with the program, while the decision makers would have only numerical entry pads, or even simpler switches or potentiometers for entering utility and probability values. At the other extreme, everyone would have computer terminals able to interrogate the program independently, and could follow up points of personal interest even during the course of group interaction. Clearly, it would be impossible to implement all variations in this area, but some attempt to match requirements to the characteristics of actual decision making groups, at several command levels, appears worthwhile.

(4) Presentation Formats. Careful human factors analysis and design will be necessary to optimize the presentation of the key feedback factors to the group. In particular, the intragroup conflicts arising during tree elicitation must be clearly represented. Moreover, representation of conflict should be done in a manner which points toward its resolution. It is anticipated that

development of display formats will proceed in an evolutionary manner, with initial choices modified following actual group experience. Fortunately, the display of program data, while highly critical, is usually more easily modified than are the more basic program functions.

(5) Decision Problem Area. The type of decision problem addressed by the group can be expected to affect its interaction with the aiding system. Since the system is directed toward elicitation of trees and resolution of tree-related conflict, one would anticipate its greatest benefits in aiding decisions for which there are a good number of options, the scenarios are relatively complex, and the outcome values are largely judgmental. To test this hypothesis, it would be of interest to examine computerized group aiding for representative command-level decisions which differ on one or more of these dimensions. For example, a meaningful comparison could be made between two decision types of equal complexity, one of which has outcomes whose monetary values are directly known, the other of which has outcomes measurable only in relative utility terms.

(6) Group Composition. The make-up of the decision making group itself should also have a strong influence on aiding system performance. A major factor may be previous familiarity with computer aiding per se. Perceptronics has found in other studies that careful indoctrination into the goals and function of a decision aiding system significantly improves system performance. Whether a group is like-thinking or highly divided regarding the general approach to a decision problem would also affect how it uses the computer-aiding capabilities. Level of command, and the associated decision

styles involved, will further color the group-computer dialogue. Group size should not be as significant a factor under aiding conditions as it is normally, because the computer essentially handles all individual inputs simultaneously, and larger groups may actually come more rapidly to a consensus. Exploration of these factors could be done economically by allowing varied groups, of reasonably small size, to encounter the same types of problems under controlled conditions of system indoctrination.

3.4.2 Methodology. Perceptronics plans to conduct empirical tests of the group aiding system in accord with the following methodology.

Facility. One room of Perceptronics' new office area will be designated the group decision facility, and will be configured as illustrated in Figure 3-9. This facility will be used for subject briefings, for system explanation, and for actual test sessions.

Subjects. It is planned to work initially with decision-making groups of three to five members. Group subjects will be selected to be as representative as possible of personnel who would interact with such systems in a military setting. Although it will be difficult at this program stage to obtain active-duty, senior-level military personnel, Perceptronics has had good success in the past using reserve officers from local Naval units. It is also planned to use university graduate students for comparison purposes. But initially, the test groups will be kept as homogeneous as possible.

Procedure. Section 1.2.3 has outlined the reasons for our choice of counter-terrorist activities as the initial problem area for group decision making. Several suitable problem scenarios in this area will be developed early in the first-year program, and supporting documentation will be produced. Subject decision making groups will first be familiarized with the general area of decision trees and decision analysis. They will then receive a demonstration of the aiding system, given by an intermediator, and will be led through one or more brief sample problems. This will occupy one or two meetings. During the actual test session, they will be introduced to the problem scenario, given the supporting documentation, allowed to study it briefly as individuals, and then convened as a group for a problem-solving meeting scheduled for about two hours.

Performance comparison between aided and unaided decision making groups raises both theoretical and practical problems. Foremost is the question of how the aided group would approach the decision problem. If the group is allowed to proceed in a completely unstructured manner, problem formulation and group dynamics would differ completely from the aided case. For example, emergence of strong group leader, who dominates discussion, might radically shorten solution time at the expense of analytical breadth and depth. On the other hand, if the unaided group is asked to attempt a "manual" decision analysis, then a trained analyst would have to be assigned to it, and the lengthy procedures of interview, utility measurement, etc. would have to be carried out for each control case. While this holds some interest as a means of establishing a state-of-the-art performance baseline, it would seem a misuse of program resources to attempt enough manual analyses to yield a statistically significant comparison. Accordingly, we plan at present not to conduct a formal test of cases; but if it proves feasible, we will conduct one or more manual analyses to obtain a rough comparison standard.

Measures. Experimental data will be gathered during the test sessions for the purpose of analyzing the group interactions, characterizing the group's decision performance, and assessing the acceptance of the various aiding functions. Selection and formal definition of measures will be done in an early program stage. Those under consideration include:

(1) Problem Solving Protocols. Closed-circuit TV recording can be used to provide a detailed audio-visual record of interactive processors during problem solution. Since the group display will be video-based, an effects generator could be used to split the videotape between the current display and the groups response to it. Perceptronics presently has a TV camera/recorder/monitor system suitable for this purpose.

(2) Decision Time. Overall and elemental decision times will be directly available from the computer program, and can be printed out as a summary report following the test session.

(3) Decision Performance. Since the groups' decision will not actually be implemented, soundness of choice will be the main performance criterion. Number of alternatives raised and considered will be available from computer and video records. Data on the extent to which the group acts in accord with its own values (achieves maximum expected utility) will be available from the sensitivity analysis portions of the program. In addition, comparisons can be made between utilities and decisions of the test groups and those of recognized experts in the problem area.

(4) Participation. This factor has been identified as important in the preliminary effectiveness analysis. Computer-directed participation of each member will be recorded by the interactive program. Associated verbal participation will be available from the video recording.

(5) Subjective Response. Group debriefing, selected individual interviews, and individual questionnaires will be used to determine the attitude of the test subjects toward the

computerized aiding system. Of particular importance will be questions regarding: problem clarification, individual inclusion, depth of analysis, role of intermediator, types of interaction, methods on conflicts resolution, and confidence in eventual solution.

4. PROGRAM SCHEDULES

4.1 Overview

The general objectives of the proposed R&D program were stated in Chapter 1. Subsequent chapters outlined research accomplished to date and discussed in some detail the planned technical approach. This chapter deals with the means by which the proposed program will be carried out.

4.2 Two-Year Plan

A two-year R&D schedule is proposed with the following division of major program goals:

(1) First Year -- Model development, prototype system implementation, system concept demonstration, pilot experimental evaluation performance measure analysis, system description and evaluation report.

(2) Second Year -- System expansion and modification as required. Full scale experimental evaluation, using additional decision problem areas. Preparation of software in transportable form. Development of guidelines for future military application. Final report.

4.3 Proposed First-Year Program

A four-phase effort is proposed for the twelve month period. The phases are:

(1) Planning and Design Specification
(2) System Development and Integration
(3) Experimental Evaluation Studies
(4) Analysis and Reports

The following presents the main features of each program phase.

4.3.1 Planning and Design Specification. During this phase Perceptronics will:

(1) Specify and develop problem scenarios for group decision making.

(2) Develop algorithms for value conflict identification and resolution using multi-attribute utility analysis, establish procedures for tree merging and formation of group decision trees, and adapt the existing tree elicitation and sensitivity analysis programs to the context of group decision making.

(3) Develop and specify the required display programs and formats for presenting information to the group and establish a methodology for representing the areas of conflict. Define procedures for group computer interactions.

(4) Design system software, specify all required programs and subprograms, data files, and interactive functions.

4.3.2 System Development and Integration. During this phase, Perceptronics will:

(1) Design the computer subprograms for: (a) tree elicitation, (b) utility and probability elicitation, (c) tree sensitivity analysis, group tree formation, and expected value rollback, (d) group/individual interactive protocols, and (e) display control functions and data access.

(2) Code all software, integrate complete system on the PDP-11 hardware.

4.3.3 Experimental Evaluation Studies. During this phase Perceptronics will:

(1) Perform evaluation test to verify the various operational features of the system and modify as required.

(2) Design and conduct a set of evaluation experiments using representative decision making groups to examine the effect of group aiding on group behavior and decision performance in the area of counter-terrorist activities.

(3) Use the decision aiding system to elicit decision trees from representative individual subjects for comparison with the group product.

(4) Perform analysis of the problems involved in merging complete individual trees, incorporating both theoretical considerations and the results of the group individual comparisons.

4.3.4 Analysis and Report. During this phase Perceptronics will:

(1) Analyze the group and individual experimental data and document the experimental results.

(2) Prepare a year-end technical report including a description of the system concept, specification of system programs, experimental method and results, preliminary conclusions, planned future research, and recommendation regarding the application of the group decision aiding to military operations.

4.4 Milestone Chart

Table 4-1 is a Milestone Chart showing the planned task schedule for the initial twelve month period.

4.5 Personnel Schedule

Table 4-2 is a personnel schedule in which the hours budgeted for the project staff is distributed over the main program phases. The proposed personnel level is approximately 2.5 people-equivalents over the 12-month period.

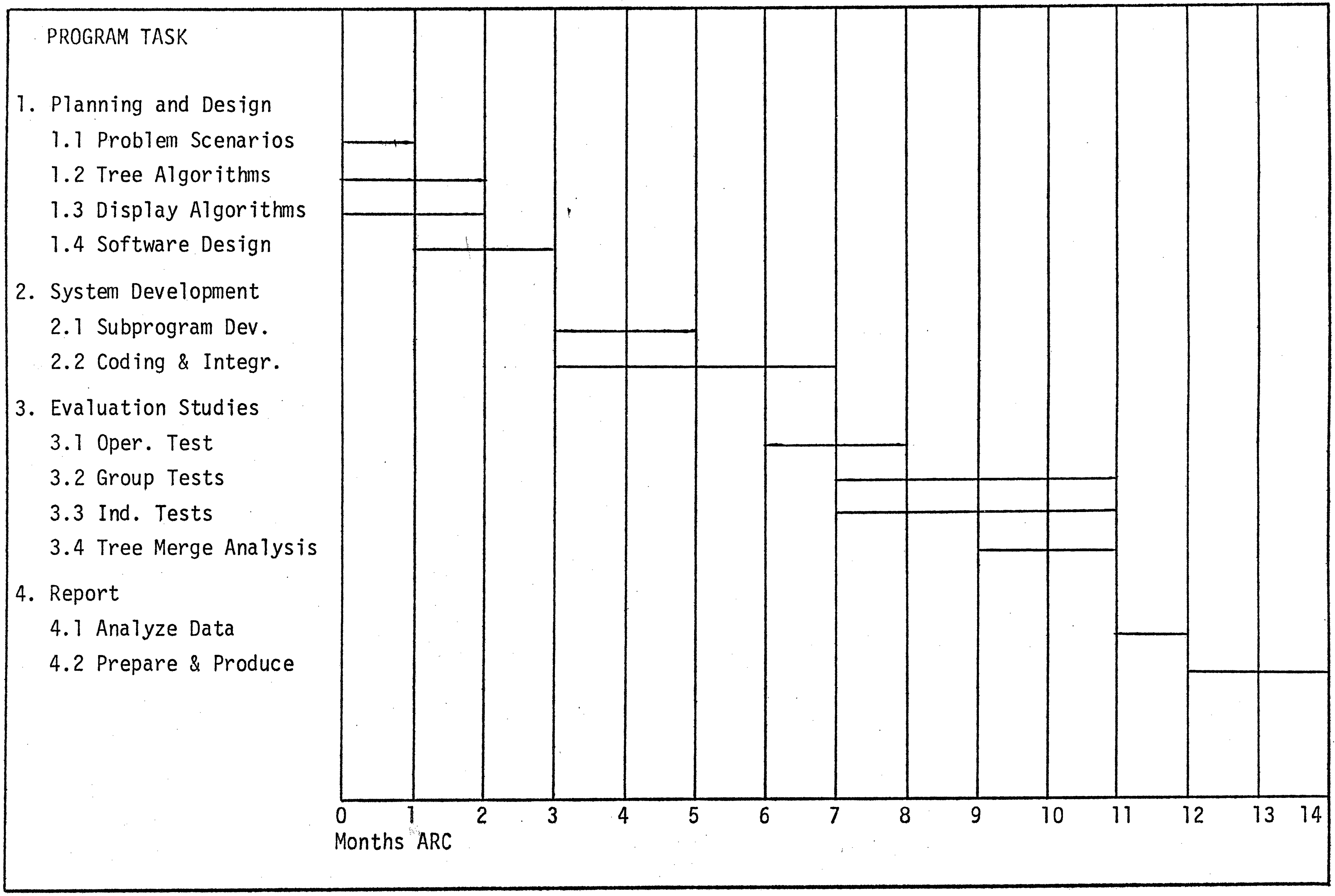

TABLE 4-1. PROGRAM MILESTONES

TABLE 4-2. PERSONNEL SCHEDULE

	System Design	Prototype Development	Eval. Studies	Analysis & Report	Total
Senior Scientist	250	200	200	150	800
Engineering Psychologist	150	150	250	200	750
Senior Engineering Analyst	250	150	150	50	600
Programmer	250	1000	250		1,500
Research Assistant			400	100	500
Consultants	150	50	50	50	300
					4,450

5. MANAGEMENT AND QUALIFICATIONS

5.1 Corporate Background

Perceptronics is a California corporation, incorporated in Los Angeles on April 14, 1969. The company is directed by applied scientists: Dr. Gershon Weltman, President, and Dr. Amos Freedy, Vice President. Their goal is to apply advanced concepts in informational, behavioral, and computer sciences to the solution of real-world problems. The company supplies R&D studies and specialized hardware/software systems to customers in industrial, defense, and space applications.

Perceptronics specializes in three related technical areas. One is decision making, which includes the use of adaptive and artificial intelligence computer techniques for automation, aiding, and training of complex decision processes. The second is advanced automation, or robotics, in which computer technology is used to provide autonomous machine operation as well as new display/control techniques. The third is human factors engineering, which includes human factors analysis and design, training, organizational effectiveness, and biomedical systems.

In addition to its main facility in Woodland Hills, California, Perceptronics maintains branches in two other locations. The Decision Research Branch, Eugene, Oregon, focuses on basic and applied problems in the psychology of judgment and decision making. Perceptronics Israel Ltd., Tel Aviv, Israel, provides human factors and software services to the IDF and other local agencies.

Perceptronics' staff includes senior personnel in the areas of engineering, applied science, and psychology. They, and the other talented project people, have had broad experience in both laboratory research and in the design and installation of working systems, as well as in the presentation of results to scientific and technical audiences through journals, reports, and professional meetings. Perceptronics staff members have together contributed several hundred technical and scientific publications in their special areas of work.

5.2 Project Organization and Personnel

Perceptronics project management is designed to perform three main functions: (1) insure top-level scientific and technical direction, (2) provide day-to-day activity review, (3) take full advantage of skilled company personnel. Table 5-1 is an organization chart showing the corporate division by major technical group. Each project is assigned to a technical group. The main elements of project organization is as follows:

Program Director. The Program Director is responsible for overall administrative control and direction. He supervises the proposal effort and the budget planning and insures compliance with major contractual requirements. Dr. Freedy or Dr. Weltman generally performs this function.

Group Director. The Group Director coordinates projects within a given technical area, coordinating personnel assignments, scheduling of facilities, etc., and helping to maintain consistent scientific and technical quality.

Principal Investigator or Program Manager. The Principal Investigator (Program Manager) is responsible for the scientific (technical) progress of the project and for executing the details of the research and/or development plan. He supervises directly the project team and support personnel.

Project Teams. Perceptronics project teams are made up from the research and technical staff on the basis of optimum contribution to the project goals. Teams generally contain three to five members. These usually include a technologist, engineering psychologist, computer analyst, one or more programmers, a research aide, and technical support.

Contracts and Accounting. Contractual details are handled by the Director of Administrative Services. Billing and cost feedback are provided by the Business Manager using a full-time bookkeeper and the corporate accountant. The objective is to maintain tight control of contract budgets and obligations without overly burdening the project's scientific and technical people.

Resumes. Resumes for key project personnel are provided in Appendix A.

5.3 Facilities

Plant. Perceptronics occupies about six thousand square feet in a modern air-conditioned building in the Warner Ranch Industrial Park, Woodland Hills (the San Fernando Valley portion of Los Angeles). The well-lit office area provides comfortable desk space for the administrative, scientific, and engineering personnel, along with conference and library facilities. There are separate enclosed areas for the computer facility and interactive display systems, and for electronic test and assembly. These areas have sufficient room for operation of robotic and manipulator devices.

The Perceptronics' facility in Eugene, Oregon, occupies approximately thirty-five hundred square feet of office space in a modern building situated close to the University of Oregon, whose library, computing, and other facilities it regularly draws upon. The facility has space for subject experimentation and for operation of a small computer.

Computer Facility. Perceptronics maintains an inhouse computing facility built around two Interdata Model 70 minicomputers with 24K of 16-bit memory capacity. The third-generation, high-speed (1 usec) machines combine substantial computing power with small size and low operating costs. The Interdata Model 70 utilizes Assembler and Fortran IV programming languages. Computer system accessories include the following:

IDIgraf Graphics Display Terminal
ADDS Consul 580 CRT Terminal
Interactive 3-D Display Terminal
Centronics 306 Printer
Pertec Dual Disk Drive
+I/O Modular Interface

The Perceptronics' facility is ideal for experimentation with interactive man-machine systems and for control of remote manipulators and other devices. For large-scale off-line data processing, Perceptronics maintains an active account with the PRC computer center, a short distance from Perceptronics' plant.

5.4 Previous Contract Experience

A number of previous and ongoing corporate projects are summarized on the following pages to demonstrate Perceptronics' breadth of contract experience. Perceptronics has shown its ability to adhere to firm schedules of achievement and cost on all of its previous programs.

1. ADAPTIVE DECISION MODELING

1-01 Man/Machine Interactions in Computer-Aided Decision Making and Control

This study program was undertaken for the Office of Naval Research to establish human factors criteria for computer aided decision making and control. The program focuses on optimization of the man-machine interface -- what information to give the human operator, and how to best allocate system functions between man and intelligent machine.

Contract: N00014-72-C-0093
Price: $210,037 — Type: Cost plus Fixed Fee
Period of Performance: 15 November 1971 -- 15 November 1975

1-02 Adaptive Manipulation Program

Working with Jet Propulsion Laboratory for NASA, Perceptronics developed and installed an adaptive computer program to guide a remote manipulator in sample collection on a lunar or planetary surface. The program learned sample-collection strategies from a human operator, and enabled the remote manipulator to improve performance time under control time delays.

Contract No. NAS-7-100
Price: $16,000 — Type: Fixed Price Subcontract
Period of Performance: 1 March 1972 -- 1 July 1972

1-03 Adaptive Computer Aiding in Dynamic Decision Processes

Perceptronics was awarded an ARPA funded and ONR managed contract to study adaptive computer aiding systems for human operators in dynamic decision processes (i.e., intelligence data gathering tasks). The work involves the development and evaluation of adaptive methods to facilitate and improve human decision making, as well as unique display formats.

Contract No. N00014-73-C-0286
Price: $378,600 — Type: Cost plus Fixed Fee
Period of Performance: 1 March 1973 -- 28 February 1976

1-04 Adaptive Decision Aiding in Computer Assisted Instruction

This is a research contract with the Army Institute of Behavior and Social Science to investigate the application of adaptive decision aiding systems to computer assisted instruction. The Perceptronics approach involves the on-line modeling of a student's value structure in order to permit instruction in higher cognitive and judgmental tasks.

Contract No. DAH C19-75-C-0013
Price: $156,397 — Type: Cost plus Fixed Fee
Period of Performance: 2 January 1973 -- 31 December 1975

1-05 Adaptive Engagement Logic and Control Study

Perceptronics under subcontract to TRW Systems Group was tasked to select techniques and design algorithms for the application of adaptive decision making and artificial intelligence to on-line ballistic missile defense. Initial application of problem solving programs proved highly successful, in simulation tests. The study was funded by the U.S. Army Ballistic Missile Defense Advanced Technology Center, and is classified SECRET.

Contract No. DASG60-76-C-0037
Price: 93,224 — Type: Fixed Price Subcontract
Period of Performance: 1 April 1975 -- 30 May 1977

1-06 Ultrasonic Signal Processing

NASA's George C. Marshall Space Flight Center contracted with Perceptronics for the development of signal processing algorithms for ultrasonic detection of coal seam interfaces. Pattern recognition and other computer techniques are used to increase the amount of information available from returning ultrasonic signals.

Contract No: NAS8-31782
Price: $28,960 — Type: Firm Fixed Price
Period of Performance: 18 December 1975 -- 18 July 1976

1-07 Adaptive Distribution of C3 Information

This program is sponsored by the Advanced Research Projects Agency (ARPA). Its purpose is to utilize the type of on-line adaptive models developed by Perceptronics for the effective and timely distribution of information in systems for command, control and communication (C3). Because information overload is a critical factor in modern computer-based C3 systems, adaptive distribution should have a major effect on system effectiveness.

Contract No. MDA903-76-C-0241
Price: $56,516 Type: Cost plus Fixed Fee
Period of Performance: 1 March - 30 September 1976

1-08 Decision Aiding in Anti-Submarine Warfare

This program represents the initial application to a real-world decision making situation of adaptive decision aiding techniques previously developed by Perceptronics (see 1-03). Sponsored by the Office of Naval Research, the program focuses on the decision environment of the Navy's P-3 ASW aircraft. Its goal is to analyze the decision tasks involved, develop and evaluate specific aiding techniques, in simulated conditions, and provide computer software which can be tested in the aircarft itself.

Contract No. (In process)
Price: $65,820 Type: Cost plus Fixed Fee
Period of Performance: 15 April - 15 December 1976

2. HUMAN FACTORS AND BIOMEDICAL

2-01 Patient Monitoring Equipment Manual System

Perceptronics performed a Human Factors analysis of instructional needs for operating patient monitoring equipment. The work was performed under a service contract to Spacelabs, Inc., Chatsworth, Ca. Specifications for operating and troubleshooting manuals were made. These were characterized by modular organization of the manual text and by compatible nomenclature and graphics. A complete set of manuals was developed and produced. They are currently in use.

Contract No. Spacelabs, Inc. P.O. 20800
Price: $16,000 Type: Fixed Price
Period of Performance: 1 July 1970 -- 31 October 1970

2-02 ECG Analysis Program

Under subcontract to Computer Applications, Inc., Perceptronics designed a computer program which analyzed ECG signals telemetered from subjects during air rescue operations. The program was installed for NEL at El Centro Navy Base as part of the Biomedical Data Analysis and Reduction System.

Contract No. N00123-70-C-0145
Price: $9,750 Type: Fixed Price Subcontract
Period of Performance 27 July 1970 -- 1 January 1971

2-03 Physiological Data Analysis Program

Perceptronics developed and installed a biomedical program for the on-line acquisition and analysis of physiological data from an exercising infantryman for the U.S. Army Combat Effectiveness Test Facility, Camp Pickett, Virginia. The biomedical program performs safety alarm generation and data storage, and generates a post-run summary report. Under an extension to this contract Perceptronics provided human factors and bioengineering support to Spacelabs, Inc. in the development of a radiosonde method for measuring temperature in an exercising infantryman. The "radio-pill" was successfully tested in an alternate deep body temperature/sensing technique.

Contract No. DAA605-70-C-0884
Price: $20,538 Type: Fixed Price Subcontract
Period of Performance: 22 July 1970 -- 14 October 1971

2-04 Physiological Telemetry System

Perceptronics developed and successfully installed an on-line computer system for physiological data acquisition from an exercising infantryman. The system is used by the U.S. Army Human Engineering Laboratory at Aberdeen Proving Grounds. The system monitors three vital physiological indices: heart rate, body temperature and skin temperature. Monitoring is by means of radio telemetry. The computer generates on-line safety alarm indication as well as test data summary reports, combining physiological and timing measures.

Contract No. DAAD05-72-C-0238
Price: $33,320 Type: Fixed Price Subcontract
Period of Performance: 1 May 1972 -- 15 October 1972

2-05 Automated Graphics Testing

Perceptronics developed a procedure which utilizes human factors principles for testing commercial graphics design. Part of this work involved the development of SAGE, a computerized system for Automated Graphics Evaluation. A minicomputer operates in a real time mode, controlling and evaluating a visual test which gives the graphics designer timely data on the relative discriminability of complex symbols. An Interdata Model/70 minicomputer was used for graphics display and data acquisition. The work was performed under subcontract for the Dillingham Corporation of Hawaii.

Contract No. Helgesson Design P.O.
Price: $12,000 Type: Fixed Price Subcontract
Period of Performance: 1 December 1971 -- 30 March 1972

2-06 Human Factors Field Instrumentation Package Development

Perceptronics, under contract to the U.S. Army TECOM HQ, Aberdeen Proving Ground, developed a Human Factors Instrumentation Package for use in equipment test and evaluation at the various TECOM field activities. Neatly packed into two compact field cases are a complete set of instruments for environmental and performance measures. In addition to the selected measurement equipment, the package includes specialized operating and maintenance manuals, and a complete training course.

Contract No. DAAD05-73-C-0793
Price: $84,813 Type: Cost plus Fixed Fee
Period of Performance: 20 June 1973 -- 1 April 1974

2-07 Human Factors Field Instrumentation Package Delivery

As a follow-on to the above R&D contract, Perceptronics was chosen to supply four (4) full Instrumentation Packages to selected TECOM Test activities. The packages include several equipment items manufactured by Perceptronics, and continues to be ordered by Government agencies.

Contract No. DAAD05-74-C-0367
Price: $99,975 — Type: Fixed Price Procurement
Period of Performance: 21 June 1974 -- 28 August 1974

2-08 Nurses Information Station

Perceptronics provided the design specifications for a computer-oriented Nurse Information System under a service contract to Spacelabs, Inc., Chatsworth, Calif. The system uses advanced minicomputer technology to handle record keeping and patient data acquisition at a hospital nursing station. Individual stations can be linked to form a complete hospital information system.

Contract No. Spacelabs P.O. 31755
Price: $8,000 — Type: Fixed Price
Period of Performance: 1 May 1973 -- 1 August 1973

2-09 TV Requirements for Space Shuttle Manipulator

Perceptronics under subcontract to RCA Astro-Electronics Division was tasked to perform human factors analyses and establish simulation requirements in a NASA-sponsored study of TV requirements for space shuttle manipulator control.

Contract No. NAS 9-14266
Price: $32,500 — Type: Fixed Price Subcontract
Period of Performance: 1 July 1974 -- 2 July 1975

2-10 Guide to Human Factors Testing

The Army's Human Engineering Laboratory (HEL), Aberdeen Proving Ground, Md., contracted with Perceptronics to produce a guide for obtaining and analyzing human performance data in a material development project. The purpose of the program is to explain and demonstrate the use of Data Item 1334 to future contractors and project managers. It involves the performance of two carefully conducted human factors tests, one on a system in its early development phase, the other on two systems in a post-prototype phase.

Contract No. DAAD05-76-C-0734
Price: $50,000 — Type: Cost Plus Fixed Fee
Period of Performance: 17 November 1975 -- 31 July 1976

3. ADVANCED AUTOMATION

3-01 Space Station and Shuttle Manipulator Design

Perceptronics, working with MBAssociates for NASA, was responsible for the computer systems design of the space station and space shuttle manipulator. On the same project the company developed and installed on an Interdata Model 4 minicomputer a unique Trajectory Following Control Program (TFC) for generating slow and smooth trajectories with large space manipulators. The system was demonstrated with the MBA-NAT manipulator arm.

3-02 Advanced Underwater Manipulation

This is a research and development contract to design, fabricate, and evaluate a computer system for improved control and display in underwater manipulation. The work is based on a proprietary computer imaging technique. Its objective is to examine new solutions to the problem of controlling manipulators under limited viewing, including zero visibility.

Contract No. Cannot be disclosed
Price: $396,418 Type: Cost plus Fixed Fee
Period of Performance: 1 February 1973 -- 31 June 1975

3-03 Manipulator Control System

Perceptronics designed, fabricated and installed a computer-oriented manipulator control system for the Guidance Technology Group of the Jet Propulsion Laboratory, Pasadena. The stand-alone control package consists of an Interdata 70 minicomputer, a Perceptronics +I/O Modular Interface, and supporting software. It permits generalized computer control of remote mechanisms in advanced R&D projects.

Contract No. CS-611109
Price: $24,650 Type: Fixed Price Procurement
Period of Performance: 11 September 1974 -- 11 February 1975

3-04 +I/O Modular Interface

Perceptronics has developed a high-speed Modular Interface to connect minicomputers to a wide variety of outside processes and devices. The programmable unit handles analog and digital signals, and provides for both input and output transfers. Each Interface unit is configured to meet exact user needs. Customers for the device have included TRW Systems, U.C.L.A., Purdue University and JPL. Uses have ranged from speech processing to manipulator control.

Contract No. (Various)	
Price: $5,500 (Average)	Type: Fixed Price Procurement
Period of Performance:	90 day delivery

3-05 Stimulus Programming System

The Southern California Research Institute, Encino, contracted with Perceptronics to supply an advanced system for presenting controlled visual stimuli and recording subject responses in studies of industrial pollutant effects. The portable system is built around the Perceptronics +I/O Modular Interface, configured to operate in a tape program controlled stand-alone mode. See Figures 4-2, 4-3, and 4-4.

Contract No. 75-110b	
Price: $27,000	Type: Fixed Price Procurement
Period of Performance:	24 March 1975 -- 1 September 1975

3-06 Image Enhancement System

Perceptronics has been tasked to develop and deliver three systems for enhancement of real-time video images from an advanced medical thermographic scanner. The enhancement system will incorporate a mini-computer, and will perform contrast enhancement and edge enhancement routines to improve the diagnostic capability of the scanner. The contract is with Paragon Medical Research, Inc. of Encino, California.

Contract No. 2014	
Price: $130,000	Type: Fixed Price Procurement
Period of Performance:	22 April 1976 - 22 January 1977

6. STATEMENT OF WORK

6.1 General

Perceptronics, Inc. proposes to provide the personnel, facilities, materials and services necessary to conduct a 12-month level of effort research program directed toward the development of a group decision aiding system.

6.2 Program Tasks

The program will be organized into four phases. The essential features of each phase are outlined in the following paragraphs.

Phase 1 - System Planning Design Specifications

(1) Select and design group decision test scenario
(2) Develop group decision aiding algorithms
(3) Specify and design interactive group input display programs
(4) Establish overall system software design specifications.

Phase II - System Prototype Development in Integration

(1) Design system subprograms
(2) Code all subprograms and system software
(3) Integrate all system programs, test and debug on a PDP-11 system computer

Phase III - Experimental Evaluation Studies

(1) Perform evaluation studies and operational system tests
(2) Design and conduct experimental evaluation studies involving both groups and individual subjects.

Phase IV - Analysis and Report

(1) Analyze all experimental data.
(2) Prepare year-end final report

7. REFERENCES

Bauer, V., Gebert, A., and Meise, J. Urban Systems Studies, Part I Evaluation in Urban Planning. Report, Batelle Institute, Science & Human Affairs Program (Batelle, Frankfurt).

Dalkey, N. and Helmer, O. An Experimental Application of the Delphi Method to the Use of Experts. Management Science, April 1963, Vol. 9(3):458-467.

Dawes, M. A Case Study of Graduate Admissions: Application of Three Principles of Human Decision Making. University of Oregon and Oregon Research Institute (Eugene, Oregon) American Psychologist, 1971, 26:180-188.

Fischer, G.W. Multi-Dimensional Value Assessment for Decision Making. Engineering Psychology Lab., University of Michigan, Tech. Report 037230-2-T, 1972.

Freedy, A., Davis, K.B., Steeb, R., Samet, M.G. and Gardiner, P.C. Adaptive Computer Aiding in Dynamic Decision Processes: Methodology, Evaluation, and Application. Perceptronics, Inc. (Woodland Hills, CA) Final Technical Report PFTR-1016-76-8/30, Contract N00014-73-C-0286/NR 196-128, ARPA Order No. 2347, Code 455, Office of Naval Research, August 1976.

Gardiner, P.C. The Application of Decision Technology in Monte Carlo Simulation to Multiple Objective Public Policy Decision Making: A Case Study in California Coastal Zone Management. Unpublished Ph.D. dissertation, Center for Urban Affairs, University of California, 1974.

Gardiner, P.C. & Edwards, W. Public Values: Multi-Attribute Utility Management for Social Decision Making. In Schwartz & Kaplan (Eds.), Human Judgment & Decision Processes: Formal and Mathematical Approaches, New York: Academic Press, Inc. 1975.

Gardiner, P. and Ford, A. Which Policy Run is Best and Who Says So?" SSRI Technical Report, In Press, 1976.

Goldberg, L.R. Man Versus Model of Man: A Rationale, Plus Some Evidence, for a Method of Improving on Clinical Judgments. Psychological Bulletin, 1970, 73:422-432.

Hays, M.L., O'Connor, M.F. and Peterson, C.R. An Application on Multi-Attribute Utility Theory: Design-to-Cost Evaluation of the U.S. Navy's Electronic Warfare System. Decisions and Designs, Inc. (McLean, Virginia), Technical Report DT/TR75-3, Contracts N00014-75-C-0426, N00039-75-C-0084, N00024-73-C-1060, ARPA, Code 455, Office of Naval Research, October 1975.

Huber, G.P. Multi-Attribute Utility Models: A Review of Field and Field-Like Studies. University of Wisconsin (Madison, Wisc.) Management Science, June 1974, Vol. 20, No. 10.

Keeney, R.L. Utility Functions for Multi-Dimensional Consequences. Management Science, January 1972, Vol. 18(5):276-287.

Leal, A. An Interactive Program for Conversational Elicitation of Decision Structures. Ph.D. Thesis to UCLA School of Engineering, Report No. UCLA-ENG-REP-7666, June 1976.

Leal, A. and Pearl, J. A Computer System for Conversational Elicitation of Problem Structures. UCLA Engineering Report UCLA-ENG-7665, Contract GJ-42732, National Science Foundation, June 1976.

Leal, A. and Pearl, J. An Interactive Program for Conversational Elicitation of Decision Structures. IEEE Special Issue on Decision Making, In Press, 1977.

May, D.M., Crooks, W.H., Purcell, D.D., Luccacini, L.F., Freedy, A., and Weltman, G. Application of Adaptive Decision Aiding Systems to Computer Aided Instruction. Perceptronics, Inc. (Woodland Hills, CA) Technical Report PATR-1019-74-12, December 1974.

Miller, L.W., Kaplan, R.J., and Edwards, W. JUDGE: A Value-Judgment-Based Tactical Command System. Organizational Behavior and Human Performance, 1967, 2:329-374.

Miller, L.W., Kaplan, R.J., and Edwards, W. JUDGE: A Laboratory Evaluation. Organizational Behavior and Human Performance, 1969, 4:97-111.

Newman, J.R. Assessing the Reliability and Validity of Multi-Attribute Utility Procedures: An Application of the Theory of Generalizability. SSRI Res. Report 75-7, Univ. of Southern California (Los Angeles), 1975.

Nickerson, R.S. and Feehrer, C.E. Decision Making and Training: A Review of Theoretical and Empirical Studies of Decision Making and Their Implications for the Training of Decision Makers. Bolt, Beranek, and Newman (Cambridge, Mass.) Tech. Report NAVTRAEQUIPCEN 73-C-0128-1, July 1975.

Nilsson, N. Problem Solving Methods in Artificial Intelligence. New York: McGraw Hill, 1971.

Pizano, C. Feedback Technology, The Key to Homogeneous Participation in Group Discussion. Mechanical Engineering Department, Massachusetts Inst. of Technology (Cambridge, Mass.) S.B. thesis, May 1974.

Raiffa, H. Preferences for Multiattributed Alternatives. Rand Corporation (Santa Monica, CA) Memorandum RM-5868-DOT/RC, April 1969.

Sheridan, T.B. Community Dialog Technology. Proceedings of the IEEE Special Issue on Social Systems Engineering, March 1975, Vol. 63(3):463-475.

Sheridan, T.B. and Sicherman, A. Estimation of A Group's Multi-Attribute Utility Function in Real Time by Anonymous Voting. IEEE Special Issue on Decision Making, to be published March 1977.

APPENDIX A -- RESUMES

PERCEPTRONICS

RESUME - GERSHON WELTMAN

TITLE

President

PROFESSIONAL SPECIALTY

Human Factors Engineering

PERSONAL

Born: August 7, 1936
Married: Two Children
Security Clearance: Secret

EDUCATION

1958	B.S.	U.C.L.A., Engineering
1960	M.S.	U.C.L.A., Engineering (Biotechnology)
1962	Ph.D.	U.C.L.A., Engineering (Biotechnology)
1962-3	Fellowship	Weizman Institute of Science, Israel

BACKGROUND AND EXPERIENCE

Dr. Weltman acts as chief scientist at Perceptronics, Inc. In addition, he contributes human factors and bioengineering aspects of system design and development. For the past sixteen years, Dr. Weltman has participated in research projects covering a broad area of biotechnical interest, including manual and automatic control, physiological instrumentation, human performance in man-machine systems, and human performance underwater (with particular reference to the effects of psychological stress). Prior to participating in the formation of Perceptronics, Dr. Weltman was a member of the engineering faculty at the University of California, Los Angeles. He also served as a consultant to industry in the fields of bio-instrumentation for space and commercial applications. At Perceptronics, Dr. Weltman has headed a number of research and development projects in the areas of display optimization, man/machine interaction, robotics, and physiological monitoring. He has contributed over 30 papers to scientific and professional journals.

PERCEPTRONICS

RESUME - AMOS FREEDY

TITLE

Vice President

PROFESSIONAL SPECIALTY

Computer Systems, Control Systems and Biotechnology

PERSONAL

Born: October 11, 1937
Married: Two Children
Security Clearance: Secret

EDUCATION

1965	B.S.	U.C.L.A., Engineering
1967	M.S.	U.C.L.A., Engineering (Control Systems and Biotechnology)
1969	Ph.D.	U.C.L.A., Engineering (Electronics Systems, Control Systems, and Biotechnology)

BACKGROUND AND EXPERIENCE

Dr. Freedy is a senior scientist at Perceptronics, Inc., and is responsible for system analysis, design and development. For the past six years, Dr. Freedy has been actively participating in the broad area of computer decisions and control, in the particular the applications of learning and artificial intelligence techniques to man-machine systems. Dr. Freedy is the developer of the Autonomous Control Subsystem (ACS) an interactive computer learning system that has been used for remote manipulator control and operator decision aiding in continuous command and control. Dr. Freedy has also worked in bioengineering where his work included design of physiological data acquisition systems, myoelectrical servo controls, and development of control systems for artificial arms. Dr. Freedy has also served as consultant to industry in the design of physiological instrumentation and development of models of biological processes. Dr. Freedy has been a principal investigator in numerous projects including computer data acquisition and control. Dr. Freedy has published with his colleagues over 15 papers in scientific and professional journals.

RESUME - SARAH A. S. GOLDBERG

TITLE

Director of Administrative Services

PROFESSIONAL SPECIALTY

Administrative Management and Clinical Psychology

PERSONAL

Born: August 26, 1951
Citizenship: USA
Security Clearance: Secret

EDUCATION

1973	B.A.	U.C.L.A., Psychology
1971	Certificate of Psychological Services	L.A.C.C., Psychology

BACKGROUND AND EXPERIENCE

As Director of Administrative Services for Perceptronics, Ms. Goldberg's principal responsibility is to supervise the administrative functions of the office. These include contract administration, personnel management, secretarial and support services, purchasing of supplies and equipment, and production of all corporate documentation. In addition, Ms. Goldberg acts as Security Supervisor. Her duties make her one of the main points of interaction between Perceptronics and the outside world, as well as between Perceptronics management and employees. Her professional specialization in clinical psychology often facilitates solution of the problems involved.

PERCEPTRONICS

RESUME - JUDEA PEARL

TITLE

Consultant

PROFESSIONAL SPECIALTY

Decision Analysis, Problem Solving Systems, Artificial Intelligence

PERSONAL

Born: September 4, 1936
Married: Three Children

EDUCATION

1960	B.Sc.	Technion, Israel, Electronics
1961	M.Sc.	Newark College of Engineering, N.J., Electronics
1965	M.Sc.	Rutgers University, New Brunswick, N.J., Physics
1965	Ph.D.	Polytechnic Institute of Brooklyn, N.Y., Electronics

BACKGROUND AND EXPERIENCE

Dr. Pearl acts as consultant in decision aiding and problem solving systems at Perceptronics, Inc. For the past six years, he has been a Professor in the Engineering Systems Department at UCLA and has done research in the areas of decision analysis, problem solving systems, pattern recognition, heuristic learning, inferential question-answering systems, information theory, storage and computational economy, probability assessment, and the theory of representation. Prior to working at UCLA, Dr. Pearl did pioneering research in superconducting material for RCA in Princeton, N.J. for which he received the RCA Laboratories Achievement Award (1963). He has experience with a multitude of professional and academic disciplines. At Perceptronics, Dr. Pearl consults in the areas of group decision making, decision tree elicitation, multi-attribute utility assessment, and probability assessment.

RESUME - ANTONIO LEAL

TITLE

Director of Adaptive Systems

PROFESSIONAL SPECIALTY

Artificial Intelligence and Computer-Aided Decision Making

PERSONAL

Born: December 9, 1942
Married: Three Children
Security Clearance: Secret

EDUCATION

1965	B.A.	University of Illinois, Mathematics
1966	M.S.	University of Illinois, Mathematics
1976	Ph.D.	University of California at Los Angeles, Computer-Aided Decision Making

BACKGROUND AND EXPERIENCE

Dr. Leal acts as Director of Adaptive and Problem Solving Systems at Perceptronics, Inc. He supervises projects involving the application of heuristic techniques to decision-making and strategy selection in Ballistic Missile Defense, the application of planning networks to robot problem solving tasks, and the use of decision aiding in anti-submarine warfare. For the past six years, Dr. Leal has done research and development at System Development Corporation, Santa Monica, California, in the areas of Computer Language Design, Robot Problem Solving Systems, Natural Language Processing, Data Base Management Systems, Query Language Design, Computer-Aided Decision Making, Man/Machine Interactive Planning Systems, and research into cognitive processes and learning. Prior to working at SDC, Dr. Leal was Project Manager at Computer Sciences Corporation in Washington, D.C., where he designed and developed Air-Defense Simulation Models and worked on Hospital Information Processing Systems. Dr. Leal has experience with a multitude of programming languages and software systems. He is currently a member of ACM and MENSA.

PERCEPTRONICS

RESUME - WILLIAM H. CROOKS

TITLE

Senior Scientist

PROFESSIONAL SPECIALTY

Engineering Psychology, Training and Instructional Systems, Experimental Design and Analysis

PERSONAL

Born: January 21, 1944
Single
Security Clearance: Secret

EDUCATION

1966	B.S.	Oregon State University, Social Science
1970	M.S.	University of Illinois, Urbana-Champaign, Psychology
1973	Ph.D.	University of Illinois, Urbana-Champaign, Major: Experimental Psychology Minor: Computer Science

BACKGROUND AND EXPERIENCE

Dr. Crooks is a staff scientist at Perceptronics, Inc. His primary responsibility is experimental design and analysis for evaluation of human performance in advanced man/machine systems. The research topics include computer-assisted instruction, computer-aided decision making, and display system evaluation. Dr. Crooks is a graduate of the Aviation Research Laboratory, University of Illinois. While at the Laboratory he conducted research in automated adaptive training and developed a number of specialized computer programs for experimental control and data analysis. Prior to joining Perceptronics, Dr. Crooks was an applications engineer for a research equipment manufacturer. He is an accomplished programmer with several computer languages and is a licensed private pilot. Dr. Crooks is a member of the Human Factors Society.