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**DEVELOPMENT AND APPLICATION OF A
DECISION AID FOR TACTICAL CONTROL
OF BATTLEFIELD OPERATIONS:**

**Volume I. A CONCEPTUAL STRUCTURE FOR DECISION
SUPPORT IN TACTICAL OPERATIONS SYSTEMS**

by

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20 It was found that more than one decision aid was necessary to impact significantly on an ultimate decision. Therefore, a decision support complex was designed for incorporation into the SIMTOS. The support complex utilized a normative approach and an adaptive approach in regard to estimating the pre-combat tactical situation and in regard to allocating fire resources during combat.

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This is the first of three volumes on "The Development and Application of a Decision Aid for Tactical Control of Battlefield Operations" which comprise the final report for Contract DAHC 19-73-C-0069. Volume 2, "Decision Style Measurement and Decision Support Software Specifications," is a computer printout available on request from the Army Research Institute for the Behavioral and Social Sciences (ARI). Volume 3, "A Preliminary Evaluation of a Decision Support Complex in SIMTOS," is printed separately as ARI Technical Report TR-77-A3. The series received the 1975 award from the American Psychological Association's Division of Military Psychology for outstanding scientific and professional contributions to military psychology.

The entire project is part of a continuing ARI program on simulated tactical operations systems (SIMTOS).

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DEVELOPMENT AND APPLICATION OF A DECISION AID FOR TACTICAL CONTROL OF
BATTLEFIELD OPERATIONS: A CONCEPTUAL STRUCTURE FOR DECISION SUPPORT
IN TACTICAL OPERATIONS SYSTEMS

BRIEF

Requirement:

To develop a methodology which would enable computer systems to help Army field officers to obtain, organize, and analyze tactical data.

Procedure:

Decision-aiding technology and alternative decision procedures were reviewed and critiqued. Emphasis was placed on those decision-aiding principles and concepts which could lead to implementing specific decision aids in a simulated tactical operations system.

Findings:

A single decision-aiding technique is inadequate to realize the best capabilities of the human computer combination. The best approach seems to be a decision support system--that is, a number of decision-aiding techniques of mixed methodologies directed to different levels of the decision-making process and system operation.

A derived taxonomy of decision aids showed two basic types of decision aiding: normative and adaptive. The normative aid is designed to fit the general or "average" decision maker. The adaptive aid is designed to respond to individual differences in decision making (i.e., decision style).

Utilization of Findings:

A decision support system was designed for tactical decision making within the context of a G3 exercise in a simulated tactical operations system (SINTOS). The decision support system emphasized normative aiding to help in estimating the situation in the planning stage, and in allocating resources in the combat stage. The complex addressed adaptive aiding by tailoring the man-computer dialogue to the measured decision-making style of each user.

The decision support system concept and its use in SINTOS will increase the Army's understanding of man-computer interaction in complex tactical decision systems.

ABSTRACT

Volume 1

**A Conceptual Structure for Decision Support
in
Tactical Operations Systems**

A comprehensive review of decision aiding in human/computer environment was conducted to develop principles of decision aiding for the Army Research Institute's simulated tactical operations system (SIMTOS). An analysis of the literature revealed that the integration of a single decision aiding concept into a tactical operations system was inadequate for optimal interactive decision making. A complex of decision aids, integrated into a decision support system, is necessary to optimize the tactical performance of the human/computer decision making unit.

DEVELOPMENT AND APPLICATION OF A DECISION AID
FOR
TACTICAL CONTROL OF BATTLEFIELD OPERATIONS

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DEVELOPMENT AND APPLICATION OF A DECISION AID FOR TACTICAL CONTROL OF BATTLEFIELD OPERATIONS

Section 1 Introduction

1.1.1 Project Overview

The complexity of modern warfare has increased immensely during the last two decades. The development of new technological weaponry, the nature of the political environment, and the changing nature of warfare itself have been reflected in the increased responsibilities of the Army commander and his staff. These personnel must deal with an ever-increasing flow of data, in ever-decreasing amounts of time. Yet as decision time diminishes, the need to generate sound tactical decisions continues to grow. To counter a potential tactical performance decrement associated with this "vicious cycle," military theorists have sought to use the power of advanced interactive computer systems to aid the tactical officer and his staff in processing and interpreting data (Wilson, 1968 and Dmitriev, 1968).

These theorists have correctly assumed that the information processing capabilities of the computer would ameliorate the tactical information processing/operations problem. It soon became apparent, however, that the introduction of the computer into the tactical

environment, while solving some of the old problems, introduced some new problems as well. What was lacking in the early tactical operation system conceptions was a clear understanding of how tactical personnel should and would use these systems (Kirk, 1973). The lack of a clear set of "functional specifications" and the corresponding lack of a clear conception of how humans process information led to some early disappointments when exploratory automated information systems were investigated (Morton, 1973). Some of the confusion concerning the role of the computer in tactical environments remains. While it is deceptively "clear" that computer systems can aid tactical commanders, the interpretation of just how this should be done varies considerably. Furthermore, the objectives of computer aiding remained as "fuzzy" as some of the concepts put forth to deal with human/computer interactions (Hormann, 1971).

A great deal of the relevant scientific literature might be summarized by stating that the objective of introducing computerized systems into the tactical environment is to increase the effectiveness of tactical personnel in obtaining, interpreting, organizing, and acting on information. Summarizing even further, the purpose of tactical operations systems (TOS) was conceived as a means of augmenting the decision making process. Unfortunately, as one set of investigators so aptly observed, while decision making is what tactical personnel do, "there

exists no firm understanding of what those words really mean" (Williams and Hopkins, 1958).

Many models of the decision making process exist (viz., Schrenk, 1969; Henke, Alden, and Levit, 1972); however, none have proven adequate to explain fully decision making behavior. Nevertheless, such models are useful in operationalizing the complex covert and overt behavior that is decision making. Thus, the primary usefulness of such models has been to organize various research approaches and methodologies (Vaughan and Mavor, 1972).

In studies of human/computer interactions, these models have made possible the analysis of aiding concepts according to the stage of the decision process involved. Thus, some aiding concepts are directed at information organization, while others are directed at information aggregation and still others to the assignment of appropriate utilities.

The decision aiding literature, though multifaceted and sometimes confusing, does define a set of issues. While these issues bear on the larger concerns of the psychology of decision making, we are particularly concerned with the light they shed on using automated tactical operations systems to aid Army field officers. Basically, the issues of concern are:

1.1.1 Project Overview

4.

- Given our present knowledge of decision making and particularly tactical decision making, how can tactical operations systems be used to increase tactical performance?
- What is a decision aid and how does it function in the automated tactical information system environment?
- Does the use of decision aiding concepts within the context of automated tactical operations systems lead to any observable improvement in tactical performance?

These are broad and important issues indeed, and the objectives of the present research have been molded to clarify some aspects of each of them.

1.1.2 Objective and Approach

The overall objective of this research was the development of a methodology whereby computer systems can be designed to augment the capabilities of Army field officers in obtaining, interpreting, and organizing tactical data. The approach was to study alternative decision-aiding procedures and to investigate how these procedures affect tactical performance. Within this broad context four research objectives were set:

- To survey the techniques whereby automated systems have been used to augment human capabilities in the tactical environment.

- To select and design appropriate decision-aiding concepts for implementation in a simulated tactical operations system (SIMTOS).
- To develop the software specifications for the decision aids.
- To evaluate, on a preliminary basis, the relative effectiveness of decision-aiding procedures on human information processing and tactical performance.

These four objectives were accomplished in three project phases. The core of Phase 1 was a review and critique of representative decision-aiding concepts relative to their possible usefulness in the SIMTOS environment. To help organize the review, a decision-aiding categorization scheme was developed. Since it was unlikely that an aid suitable for integration into SIMTOS could be found in the literature per se, the review emphasized decision-aiding principles from which specific decision aids could be derived. Alternative aiding principles were analyzed using a quantitative evaluation technique and several decision-aiding concepts were chosen for integration with SIMTOS.

Phase 2 was concerned with the development of software specifications for the decision support system.¹ Such software specifications were

¹ During the first part of this report the terms decision-aiding and decision support will be used interchangeably, as they are in the literature. Section 1.2.3 clarifies the meaning of the two terms. Essentially the argument states that realistic tactical operations systems will include several decision aids integrated into a decision support system.

necessary to translate decision-aiding principles into software appropriate to the SIMTOS environment. Phase 2 also included the construction of a decision style measurement instrument (DSMI), a psychological inventory designed to assess a computer system user's preference for type and format of information. The information yielded by the DSMI is crucial to the concept of adaptive decision-aiding—a concept which is elucidated in detail later in this report.

Phase 3 consisted of a pilot experiment designed to evaluate the effectiveness of the decision support complex in the SIMTOS environment. The evaluation focused on two sets of dependent variables. One set evaluated the effect of the decision support complex in terms of human information processing variables (e.g., search investment); the other set analyzed the complex's effect in terms of tactical performance variables (e.g., depth and speed of enemy penetration).

Overall, the phases were bound together with an attempt to develop and document a methodology for decision support in tactical operations systems.

1.1.3 The SIMTOS Environment

The present study is one of a series of investigations sponsored by the Army Research Institute to study decision making behavior in a

1.1.3 The SIMTOS Environment

7.

Simulated Tactical Operations System (SIMTOS). The SIMTOS scenario is based on an exercise taught at the Command and General Staff College (CGSC), Ft. Leavenworth, Kansas. In the SIMTOS environment, field grade Army officers assume the role of a division operations officer (G-3) responsible for a given tactical assignment. Two versions of the exercise currently exist, a defensive and an offensive scenario. Each of these scenarios is divided into planning and combat phases. In the defensive scenario, the exercise is played from the point of view of an American G-3 whose mission is to plan for (planning phase) and implement (combat phase) the defense of the Hof Gap in Germany. In the offensive scenario, the exercise is played from the point of view of a G-3 in the Combined Arms Army--essentially an "enemy" point of view. The CAA G-3 must plan and implement an offensive mission against the armies defending the Hof Gap.

1.1.4 Organization of the Report

This report of the "Development and Application of a Decision Aid for Tactical Control of Battlefield Operations" is organized according to project phase. Volume 1 (this volume) contains the results of our literature review and the description of the methodology used to choose decision-aiding concepts for integration with SIMTOS. Volume 1

is supplemented by two previously published (September 1973 and April 1974) bibliographic sorts of the decision-aiding literature, and two bound volumes containing readings from the decision-aiding literature.

Volume 2 documents the efforts to develop a decision style measurement instrument (DSMI) for use in describing the implementing the adaptive aiding concept. That volume also contains the two software specification modules for the decision support complex and a guide to the SIMTOS planning data base.

Volume 3 contains the details of a pilot experiment designed to evaluate the effectiveness of the decision support complex in the SIMTOS environment.

1.1.5 Overview of Volume 1

The remainder of Volume 1 is devoted to the documentation of our study of decision-aiding technology. Section 2 of this volume reviews why and how we have chosen to study the process of decision support. The responsiveness of computer technology to military decision making problems is also discussed. Included is a discussion of decision style as the core of a conceptual framework for decision support, and

an in-depth review of selected elements of decision support technology.

Section 3 elucidates our approach to evaluating decision support technology. It contains criteria for SIMTOS decision aid selection, a quantitative evaluation of selected decision-aiding concepts, and the derivation of decision support principles applicable to SIMTOS.

Section 4 concludes with a discussion of recommendations for decision support in SIMTOS.

Section 2 Decision Support in Tactical Information Systems

1.2.1 Approach to Decision Support: Purpose and Method

The processes of decision making and decision-aiding have been under close scrutiny by researchers for a number of years. Since the present work must build on the work of previous investigators, a careful review of the state of decision making and aiding research was conducted. The review was a selective one considering only the scientific literature relative to decision making and aiding in automated information systems. While we did not expect to "find" an existing decision aid appropriate for direct integration into SIMTOS, we expected to derive principles of aiding which could be molded into a series of decision aids appropriate for SIMTOS and with sufficient generality to be applicable to larger scale tactical operations systems.

The raw material for the review consisted of (primarily) post-1960 sources derived from:

- Published research
- Industrial and governmental technical reports (published through the National Technical Information Service)
- Unpublished reports of research in progress and doctoral dissertations (the latter available through University Microfilms, Ann Arbor, Michigan)

From this literature studies were selected for analysis which met the following criteria:

- The study contained a working decision aid technique in an automated information system environment.
- The study contained a model of decision making from which a decision aid could be derived.
- The study contained useful information on tactical decision making.
- The study contained useful information on methodological aspects of decision-aiding in tactical operations systems.

The analysis of this research literature enabled us to develop a list of key words and a literature classification scheme that served as a method of organization for a computerized bibliographic sort.

The list of key words and the literature classification scheme are presented in Tables 1-1 and 1-2.

The classification scheme was designed to meet two criteria:

- The scheme should accurately represent the contents of the scientific literature.
- The scheme should aid the researcher in mastering the literature content.

Pivotal to our study of decision-aiding was the development of the taxonomy of decision aids, Part II of the classification scheme. The

Table 1-1. Key Words from the Decision Aiding-Literature

simulation	man-computer dialog
tactical operations systems	time share
decision aid	computer graphics
man-computer interaction	user requirements
management information systems	decision system
man-computer communication	information retrieval
information systems	interactive displays
computer aided games	human factors
command information processing system	probabilistic information processing
military commanders	strategies
resource allocation	computer based systems
war games	performance aids
computer programs	command and control
job performance aid	on-line
model	military decisions
army operations	information flow
programming	decisions
tactical problem solving	thinking
computer aid	SIMTOS
command decision	TOS
information processing systems	cognitive style
computer assisted instruction	decision style
adaptive	computer user games

Table 1-2. Classification Scheme for the Decision Aiding Literature

- I. Human information processing in man/computer decision making systems
 - A. Human information processing and decision making—general
 - B. Tactical systems
 - C. Management information systems
 - D. Individual differences in information processing

- II. Taxonomy of decision aids
 - A. Task specific
 - B. Process
 - C. Organizational
 - D. Performance
 - E. Adaptive
 - F. Normative (non-adaptive)

- III. Additional data
 - A. Methodological aspects of man/computer experimentation
 - B. General works on the psychology/computer science
 - C. User requirements
 - D. Bibliographies

taxonomy represents part of a conceptual framework for decision support to be discussed in Section 1.2.3 of this report.

From these materials, two bibliographic sorts, each containing approximately 700 titles, were generated during the contract period: One with literature current as of August 31, 1973; another an update, current as of March 29, 1974. Both sorted the literature

- alphabetically by first author,
- alphabetically by author within year of publication,
- alphabetically by key word,
- alphabetically by topic from the classification scheme

and are included as appendices to this report.

Four factors were considered in the analysis of the decision-aiding literature. These were:

- The place of the aid in the decision making.
- The user acceptability of the decision aid.
- The aid in view of the SIMTOS task and mission requirements.
- The aid and its generalizability to larger tactical operations systems.

This analysis of the literature yielded seventeen concepts of aiding for further analysis.² The quantitative evaluation of these concepts

² As a supplement to the Bibliographic Sort of the Decision-Aiding Literature, two volumes containing the research papers describing these seventeen representative concepts were compiled for ARI use.

relative to their applicability to SIMTOS and future tactical operations systems is discussed in Section 3 of this report. Before this evaluation can become meaningful, however, a discussion of human/computer decision making and aiding is appropriate.

1.2.2 Human/Computer Decision Making

Decision Making in the Tactical Environment

Much has been written concerning the nature of human decision making, particularly in the tactical context (e.g., Edwards and Tversky, 1967; Lee, 1971). Decision making models abound, labelling this largely covert process with descriptors such as series, parallel, single stage, multistage, static, dynamic, hierarchical and cascaded (Peterson, 1973). If a single generalization can be made about this literature, it is that we do not fully understand the decision making process (Okrina, 1970; Mack, 1971). And what is understood has been gathered in studies very much more elementary than even the average tactical decision problem (Freedy, Weisbrod, May, Schwartz, and Wettman, 1973).

One lesson to be gleaned from the technical literature is that decision aiding techniques must not be too dependent upon models of human decision making. Decision aiding based on hypothetico-deductive

models of decision making are important and interesting, but at the moment, ineffective in producing large improvements in tactical decision making performance. Part of the problem has been that researchers have treated decision making investigations, and hence decision-aiding efforts, as if they were trying to decipher the covert processes which take place when a decision is made (a sort of explanation by analogy paradigm). Such research is important, but still a long way from capturing the "essence" of the decision making process. Perhaps a more fruitful approach, in an applications sense, to decision making is more empirical-inductive in nature. This conception leads to an alternative view of decision making and aiding which relates more to real world tactical problems than has traditionally been the case.

Before dealing with this alternative decision aiding methodology, however, a brief digression into some of the elements of the tactical decision making problem would be useful.

Kinkade and Kidd (1965) have called decision making "a psychological wastebasket in that the label has been applied to almost every category within psychology from statistics to cognition, perception, thinking and motivation." They attribute most of the confusion inherent in the scientific literature to the global definition of the

concept. Brewin (1964) has even stated that decision making as studied by psychologists, economists, statisticians, and philosophers had added little to the understanding of the tactical decision problem.

The purpose here is not to add to this confusion, but to begin to build a conceptual framework for decision making and aiding in the tactical context. For the purposes of this discussion, decision making is used to label the process by which a commander interfaces with external events, and how he organizes the implications of these events for further action. What should be emphasized about this definition is that decision making starts with the perception of events, which are given meaning by the perceiver and then used in some sort of interaction with the environment. This definition can be further condensed by saying that decision making includes the structuring of information so that it is useful in interacting with the environment. Licklider (1960) has called this process the transformation of data into information.

What makes this definition different is the emphasis on the human process of evoking usable information from environmental stimuli. The other steps in the decision making process, whether they be resource allocation, hypothesis generation, or action selection, build on this primary process. This conception of decision making is

interesting from two points of view: 1) it reflects the current paradigm shift from the human as an overtly behaving entity to an information processing entity, and 2) it provides the context for the study of how human information processing may be augmented by the computer.

This emphasis on information processing as the fundamental building block in decision making is particularly appropriate for the tactical environment. One of the prime functions of the tactician is to use information to allocate available resources in such a way as to maximize the probability of a successful tactical mission. If the role of the tactical operations system is to augment this function, these systems should serve as supplements to the commander's information processing capability. This emphasis on the information processing nature of decision making does not mean that more information should be equated with better decisions. In fact, there is every reason to believe that more information (after a given point) simply leads to more inefficient use of information (Ackoff, 1967). What it does imply is that a fundamental way to supplement the information processing component of decision making in tactical commanders is to design computer information systems that filter, condense, and distill "salient" information so that the decision maker can use his own powers and capabilities to respond meaningfully to his environment.

By emphasizing the information processing component of decision making, we are not demeaning the other components of this process, e.g., action selection. In fact, Section 1.2.3 of this report will outline a conceptual framework that suggests that a decision support complex should consist of a number of decision aids, each directed to a different aspect of the decision making process. The information processing aspect of decision making has been discussed because it has been underdeveloped in the experimental literature. Furthermore, by emphasizing the computer as a tool which makes information more meaningful to the decision maker, the concepts of problem recognition and structure may be clarified. These, as Ward Edwards (1973) has recently stated

...are the most important aspects of decision analysis... not the elicitation of numbers and computational processes. Unfortunately, this process of structuring the problem is least amenable to formal prescription. It seems to be mostly a matter of wisdom, experience, and the ability to tolerate confusion, ambiguity and conflict (p. 8).

We intend to study and conceptualize this "most important aspect of decision analysis" and to devise means where the automated tactical operations system will augment the commander's wisdom and experience --not replace it.

The Responsiveness of Tactical Information Systems

While the last fourteen years have seen much progress in the development of the human/computer interface, Licklider's "man/computer

symbiosis" (1960) has yet to be achieved. Considerable progress has been made in the development of computer hardware and software, less in developing techniques for the optimal integration of human and computer capabilities (Altman, Leavitt, Shannon, and Hovey, 1971). Only recently has the emphasis on the "computer user" begun to accelerate (DeGreene, 1970; Meadow, 1970; Altman, Leavitt, Shannon and Hovey, 1971; and Kirk, 1973). Mayer's 1970 review of the state of the art in military information systems is strongly oriented toward a discussion of computer system parameters as they affect variables of human performance. While she has conceptualized some of the human factors problems inherent in the human/computer environment, she reports very little data (all pre-1965) on the development of computer systems that support the human decision making process. Overlooked were the studies of Baker (1970), Sidorsky and Mara (1968) and Gagliardi and associates (1965), whose purpose was to develop computer systems that support the tactical decision maker, and the methodology of Sackman (1967) which introduced the concept of man/computer dialog. The idea of designing tactical information systems around users rather than hardware first appears authoritatively in the reviews of Vaughan and Mavor (1972) and Henke, Alden, and Levit (1972). (Of course, the seminal idea had been present in the literature since Yntema and Torgerson, 1961.) Vaughan and Mavor point

out "that computer technology has advanced rapidly, while human engineering and systems engineering specialists have failed to shift from a man vs. machine allocation orientation to a man-with-a-computer concept for establishing cognitive work." In discussing problems of tactical operations system design, these authors state:

In a mostly manual information system environment, the staff officer finds himself spending most of the time available for resolving problems in simple search and update activities; essentially collecting the information and organizing it appropriately as a base for resolution. Little time is left for manipulating problem parameters, formulating alternative solutions against contingencies, and the like. Current systems offer him some support in the fact finding and updating operations but not in the problem structure manipulation and solution generation and testing kinds of cognitive functions that are the core of decision making/problem solving activity (p. 268).

Thus, the design approach which focuses on man and considers the computer as a tool (Baker, 1970) and that stresses the development of a "man-computer partnership" (Henke, Alden, and Levit, 1972) was introduced into the research literature from a number of sources within a very short time period.

Vaughan and Mavor go on to analyze the responsiveness of studies of human/computer decision making to the conditions found in tactical environments. They concur with Yntema and Torgerson (1961) that the core challenge of the "coming age of machine aided cognition" is to enable humans to conceptualize complex problems which the unaided

humans would not be capable of understanding. That is, the greatest potential usefulness of the tactical operations system is to distill and condense data into meaningful information. Furthermore, the authors warn against depending on complex multistage theories of decision making for the design of tactical systems since the "empirical processes used by real life decision makers may be surprisingly simple" and probably revolves around their ability to use information in efficient and effective ways to simplify situationally complex problems.

A summary review of the human/computer decision making literature shows that tactical personnel do not use information appropriately in tactical environments. In fact, if that environment includes a computer, e.g., a tactical operations system, the decision making problem increases in complexity. Not only does the tactician have to concern himself with

- tactical and strategic problems,
- operational, and
- personnel and equipment decisions,

but he also has to contend with a class of decisions related to the human/computer interface. Furthermore, since the use of computers expands the decision environment, individual variability in the approach to the decision situation increases (Sackman, 1970). Thus, the efforts to improve tactical decision making with computers have

yielded paradoxical results. Decision makers seem to retain most of their shortcomings and develop new ones based on computer interface concerns (for example, see Hanes and Gebhart, 1966; Schroeder, 1965; or the studies of Vaughan and his associates, 1960, 1964, 1965, and 1966). Tiede and Leake (1971) emphasize this point by concluding that little or no progress has been made in developing tactical operations systems which contribute measurably to combat effectiveness.

The purpose of the present research effort is to develop a methodology whereby a simulated tactical operations system (SIMTOS) can be more completely molded to complement the tactician's information processing and decision making capabilities. The conceptual framework for this task of decision support is discussed in the next section.

1.2.3 A Conceptual Framework for Decision Support

While much of the study and design of information systems in general, and tactical operations systems in particular, can occur without a conceptual structure, we feel one is helpful since a conceptual structure

- organizes and integrates research,
- generates hypotheses for investigation, and
- aids in the understanding of decision support technology.

This section will therefore present a partially completed conceptual structure for decision support systems.

Decision-Aiding Methodologies and the Concept of Decision Support

The development of automated tactical decision aids is derived from study of the decision making process. As such, decision-aiding technology must be understood as part of the larger context of decision making research. Part 1.2.2 of this report stressed that, despite the ubiquity of decision making studies, the nature of the process is still somewhat uncertain. Clearly, it is a complex process during which a problem is recognized, information gathered, alternatives generated and weighted, and an action selected. While the products of decision making (action behaviors) are easily observed, the nature of the decision making process is not. Much (if not all the essential portions) of the decision making process is covert and therefore not directly observable by the experimenter. The covertness of the decision making process has, of course, led to a variety of interpretations concerning its nature. Various decision making models or frameworks (really hypothetical constructs) have been postulated to conceptualize this covert process, and make it possible to study the interrelationships between aspects of decision making behavior.

Examples of such decision making frameworks include a utility model (Mosteller and Noguee, 1951), a Bayesian model (Edwards, 1954), a Decision Process Model (Schrenk, 1969), ACADIA (Sidorsky and Simoneau, 1970) and Decision Style (Henke, Alden, and Levit, 1972).

Most decision aiding methodology is derived from some sort of decision making framework. In fact, the working definition of decision aiding is dependent on the assumptions of the decision making framework from which it is derived. Figure 1-1 represents the universe of decision making frameworks and their derived decision-aiding methodologies.

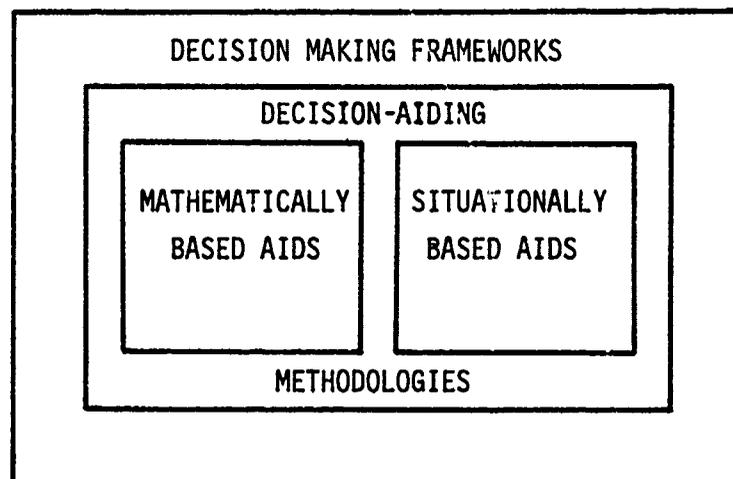


Figure 1-1. The Universe of Decision Making Frameworks and Decision-Aiding Methodologies

Two major methodologies have been developed to aid the decision making process. One is mathematically based; the other situationally based. Both methodologies generate various techniques of aiding as well as specific decision aid types.

In the mathematically based methodologies, decision-aiding is defined as the allocation of decision functions between man and machine (computer) in a way which optimizes the use of their respective strengths (Freedy, Weisbrod, May, Schwartz, and Wettman, 1973). The key to mathematically based aiding is to assist the decision maker to optimize his performance relative to some ideal criterion. Much of the work on mathematically based decision-aiding centers around Probabilistic Information Processing (PIP) (Edwards, 1962, 1964) and systems for Bayesian information processing (see Howell, 1967; Kelly and Peterson, 1971; and Johnson and Halpin, 1972). This decision-aiding approach is derived from a statistical decision theory framework. The aiding technique involves allocating data evaluation to the human and data aggregation to the computer. The basis for this allocation of tasks is that human decision makers are considered well suited to estimating the conditional probabilities of information representing alternative states of the environment, but not very good at aggregating the probabilities into opinion and actions (Edwards, 1964). This aiding technique requires that the human estimate the likelihood ratio of

each data point, and transmit these to the computer which utilizes Bayes' theorem to aggregate the likelihood ratios and make inferences. A substantial number of specific decision aiding systems have been developed using the Bayesian framework. Kelly and Peterson (1971) and Johnson and Halpin (1972) have reported statistically significant improvements in tactical decision performance using these techniques. Such improvements, however, are based on comparing human data with some theoretically (i.e., model) derived criterion, not actual tactical performance.

The problem associated with evaluating decision aids using model based criteria rather than tactical performance is illustrated by another decision-aiding technique based on a utility framework-- JUDGE (Judged Utility Decision Generator) (Miller, Kaplan, and Newman 1967). In the JUDGE situation, a commander was required to consider the relative value of targets, their probability of destruction and available aircraft. In forming a decision policy, human inputs were the utility of destruction of various targets. The JUDGE computer program used these inputs to select a course of action which maximized the expected utility. The relationship between the action recommendation, however, and actual tactical effect of the recommendation is ambiguous. While the application of mathematically based decision-aiding techniques have led to much research, the contribution of

these techniques to tactical information systems is unclear.³ These procedures suffer from problems relating to the structuring of hypotheses, estimation of priors, untangling of source reliability, and robustness (Schum, Southard, and Wombolt, 1969). Furthermore, PIP techniques are not designed for nonstationary, i.e., dynamic, tactical environments (Freedy, Weisbrod, May, Schwartz, and Wettman, 1973), and recently even Edwards (1973; see Section 1.2.2 of this report) has come to question the concentration of probability aggregation, rather than problem structuring, inherent in the mathematically based approaches.

The situational aiding approach is a largely unexplored alternative to the mathematically based methodologies. This approach studies decision making and decision-aiding in specific contexts such as tactical scenarios (hence, the situation designation). The heart of the situational methodology involves the study of the information processing component of the decision making process. Information processing is not defined as a mathematical function, but as the actual procedures used by decision makers. The aim of situational aiding is to enhance the decision maker's conception of the decision situation and to

³ The literature describing mathematically based decision aiding is huge. Readers are referred to Beach (1972) and Edwards (1974) for the current status of this work.

insure that relevant information is condensed and distilled in a way that leads to a more effective analysis and structuring of the problem. Pivotal to the concept of situational aiding is the decision environment or, as Berry (1961) has defined it, "the situational test."

The situational test uses a realistic simulation of a decision making situation to observe the decision making process under plausible yet standardized conditions. Ordinarily, "standardization" might be thought of as a situation where each subject received an identical presentation of the problem and corollary information. The situational test does not provide this type of standardization, but instead provides a standardization of the potential information available. Thus, the situational test provides data on the type of information used to make decisions, what the subject did with the data, how it affected his information processing, and how these variables influenced tactical performance.⁴ Specific techniques exemplifying the situational decision-aiding methodology are rarely found in the decision-aiding literature. The Zeitgeist has clearly favored mathematically based research. A classic example of a situational approach, however, can be found in Berry (1961) and Carr and associates (1970). Berry used a situational test simulating some of the duties of the

⁴ The Army Research Institute's SIMTOS (Simulated Tactical Operations System) is an excellent example of an advanced situation test.

squadron duty officer of a naval air squadron. Subjects were asked to analyze and make decisions concerning three aspects (each a mini-scenario) of his job function. Berry evaluated the adequacy of decision making by analyzing dependent variables such as relevance and quantity of information sought. Berry also analyzed his subjects' style of decision making. Berry considered style as an individual's consistency in approach to a decision or problem situation. The concept of decision style (of which we will have more to say later) allows the investigator to study the "dimensions of variation between subjects." While Berry left the analysis of stylistic aspects of decision making in an undeveloped state, his was, in this respect, a pioneering study.

More recently Carr and his associates (1970) have used a situational aiding technique to study decision making performance in naval duels. In this situation, an automated naval war game was used to study how navigation, tracking and sonar data were processed by naval officers and how that data was transformed into weapons systems orders. After analyzing the tasks involved in the situational context, the investigators implemented a simulation aid aimed at helping the officer assess the relationships between sensor parameters and tactical advantage. The aid allowed the officer to explore the effects of different weapon-response configurations to "sensed" targets. Analysis

of the experimental data showed that the situational methodology yielded important data on command information requirements and that the simulation-aiding technique was a powerful tactical tool.

The distinction between mathematically based and situationally based decision-aiding methodologies has been introduced to help organize the technical area. (In fact, more organizational terminology will be introduced later.) The designer of tactical information systems should realize, however, that the best approach to integrating decision-aiding techniques into tactical systems is eclectic! While debating the theoretical pros and cons of the decision aiding methodologies is "good fun," the requirements of the tactician and his environment demand that the best possible approach be used despite theoretical biases. (Finding the "best approach possible" is, of course, no easy task.) Much of the literature shows that a single decision-aiding technique is inadequate to realize the best capabilities of the human computer dyad. A number of decision-aiding techniques of mixed methodologies directed at different levels of the decision making process and system operation are required. Such a complex of decision aids can be called a decision support system (Meador and Ness, 1973; and Morton, 1973). The role of the decision support system in an automated tactical information system is, in general, to provide a "proper" interface between the tactical decision

maker and his computer system. The variables which require analysis in a decision support system are presented in Table 1-3. The analysis of these variables and their interactions make up the study of decision support systems (Carlisle, 1972).

One further characteristic of the study and design of decision support systems should be mentioned. A decision support system cannot stand alone if it is to be successful. It must be part of a larger system (probably hierarchical) which includes tactical doctrine and procedures, personnel, organization, and communications. In a kernel, decision support systems must be designed with a knowledge of the echelon of command being addressed, and the larger C³ (command, control, and communication) system of which it is a part.

A Proposed Framework

A systematic program of research in decision support includes the study of various levels and combinations of the variables in Table 1-3 to investigate the relationships between these variables and their overall influence on tactical performance (Henke, Alden, and Levit, 1972; Levit, Alden, and Henke, 1973; and Mason and Mitroff, 1973).

This approach to studying decision support emphasizes the conceptual interaction between human and computer. It stresses aiding the human's

Table 1-3. Variables Affecting Decision Support Systems

Independent Variables

- The computer system
- The data base
- The user
- The user-system interface
- The mission
- The context
- Training

Dependent Variables

- The time to complete the mission
- The cost of mission completion
- The quantity and quality of the performance
- The errors completed
- The user's satisfaction
- The utilization of available resources
- The patterns of user and system behavior

information processing capabilities, not simply his job performance in operating I/O and O/I peripherals (Figure 1-2). Further, this approach is concerned with supporting the decision making process, not in developing systems that make decisions! The tactical commander remains the final authority for the decision. (The necessity for this is shown vividly in the work of Hanes and Gebhard, 1966. This concept also plays a key role in the genesis of human/computer dialogs, a topic which will be discussed shortly.)

With this introduction then, let us define the domain of automated tactical operations systems to include: a human of a particular decision style who faces a decision situation in which he needs information which is made available to him through some mode of presentation in a manner consistent with the principles of human/computer dialog (Henke, Alden, and Levit, 1973; and Mason and Mitroff, 1973). Each of these five areas (or variables) provides an opportunity to furnish decision support for tacticians.

Decision Style

Information systems have, at present, been designed for only one type of person, and that person is not the user, but the system designer (Mason and Mitroff, 1973). Only recently have system designers become aware of human variability in decision making and the importance

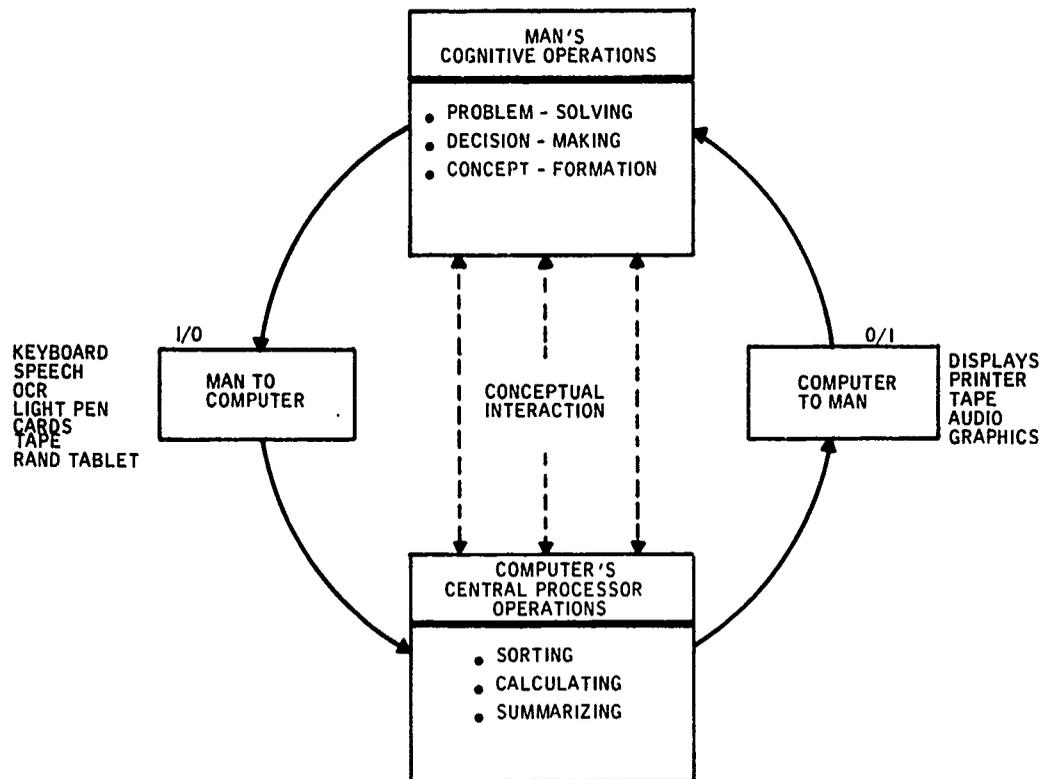


Figure 1-2. The Conceptual Interaction between Human and Computer is Emphasized.

of matching the design of computer systems with the user's cognitive characteristics (Argyris, 1971).

Part of the problem has been in conceptualizing the user's cognitive life. Recent literature has termed personalistic aspects of cognitive behavior "cognitive style" (Tyler, 1965). The concept of cognitive style grew out of the perceptual studies of Witkin and associates in the middle 1950's and early 1960's (Witkin, 1954, 1964 are representative).⁵ Interest in cognitive style has grown dramatically since then, paralleling the paradigm shift from man as a behavior to man as an information processor. In 1972, Henke, Alden and Levit undertook a comprehensive study of the cognitive style literature designed to generate a model for its application in the human/computer decision making. Since human/computer decision making is only one subset of human cognitive behavior, model development was not geared so much toward the conceptualization of cognitive style (the characteristically self-consistent way of cognitive functioning that an individual exhibits across perceptual and intellectual activities), as a subset of cognitive style. Decision style may be defined as the characteristic and self-consistent way an individual uses information i the

⁵ For a comprehensive review of the cognitive style literature, interested readers are referred to Tyler, 1965, and Henke, Alden, and Levit, 1972.

decision making process. Figure 1-3 illustrates the place of decision style in the context of cognitive behavior.

When using the decision style concept in decision support, the researcher faces the problem of the richness of human variability. Are there not as many decision styles as decision makers? In theory, a large number of decision styles exist. However, in practice, it has been found that groups of decision makers cluster around a very few dimensions of style (Pask, 1969, 1970; Pask and Scott, 1971, 1972; Dermer 1972a, b; and Doktor and Hamilton, 1973). To organize and simplify the assessment of decision style, Henke, Alden and Levit (1972) have developed a model of decision style and a methodology of assessment.⁶ The model uses three dimensions to classify eight types of decision styles (Figure 1-4).

Each dimension of decision style corresponds to the variability observed in three aspects of decision maker.

Why resort to decision style as an explanatory concept in human/computer decision making? Decision style provides a mechanism for understanding the nature of individual variability in decision making,

⁶ The model is discussed here; the Decision Style Measurement Instrument is in Volume 2 of this report.

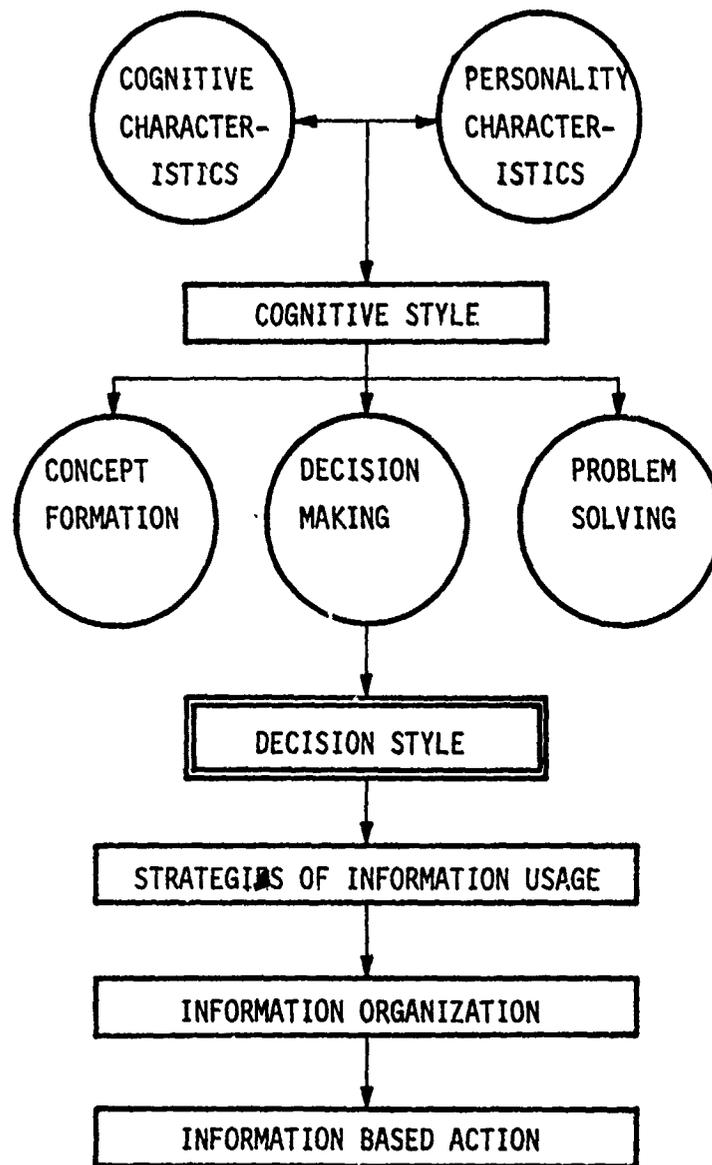


Figure 1-3. Decision Style in the Context of Cognitive Behavior

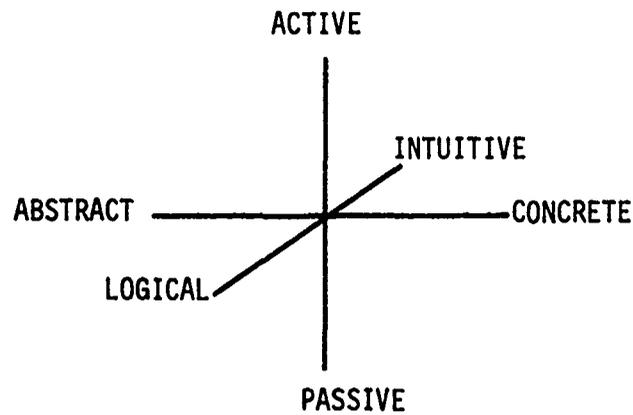


Figure 1-4. Dimensions of Decision Style

Table 1-4. Dimensions of Decision Style

Style Dimension	Style Dimension Typifies	Aspect of Decision Making
Abstract/Concrete	Type of information used	Information acquisition
Logical/Intuitive	Form of information processing	Information assimilation
Active/Passive	Information acquisition/processing activity level	Action selection

and it is this understanding that has shown to be crucial in the design of information systems (Ackoff, 1967; and Mason and Mitroff, 1973).

Systems designed for one type of decision style will cause a performance degradation in a decision maker manifesting a differing decision style (Grindlay and Cumber, 1973). For instance, the design of a decision support complex for a tactical information processing system would differ considerably if it were being designed for a concrete, logical, passive individual (This type is too data bound; he tends to go on collecting data forever because he is afraid to risk a generalization that "goes beyond the available data.") rather than an abstract, intuitive, active individual. (This type may be too "data free" spinning out a decision a second, none of which is based on empirical reality.) The lesson to be learned is that no successful information system can be designed from a data base orientation; it must be designed from a user orientation.

Individuals manifesting pure decision styles are a rare occurrence. The human cognitive structure is too diverse and complicated to be captured by only these styles dimensions. It is the blending and contrasting of the attributes of pure styles that better characterizes any single individual. Nevertheless, as a "caricature,"

decision style may be useful heuristic in designing decision support systems responsive to individual differences in information processing.

Decision Situation, Information and Mode of Presentation

Decision style has been discussed in detail because it plays a central role in the design of a decision support complex for SIMTOS. Other parameters of the conceptual framework, however, are equally important to decision support.

The decision situation is composed of two subcomponents: decision type and organizational context (Meador and Ness, 1973).

An important but somewhat hazy distinction can be made between two decision types, which define two decision situations. These are the so-called programmed and non-programmed decision types (Soelberg, 1967):

Decisions are programmed to the extent that they are repetitive and routine, to the extent that a definitive procedure has been worked out for handling them so that they don't have to be treated "de novo" each time they occur... Decisions are non-programmed to the extent that they are novel, unstructured, and consequential. There is no clear cut-and-dried method of handling the problem because it hasn't arisen before, or because its precise nature and structure are elusive and complex, or because it is so important that it deserves custom-tailored treatment. By non-programmed I mean (that the decision maker) has no specific procedure to deal with situations like the one at hand, but must fall back on whatever general capacity he has for intelligent, adaptive, problem oriented action (p. 19).

Decision situations can be characterized as structured or unstructured to the extent to which programmed or non-programmed decision procedures apply to them (Mason and Mitroff, 1973). In the tactical context, structured or programmed decisions correspond to tactical doctrine. By far, however, the most interesting (and crucial) tactical decisions are unstructured or non-programmed. There is little evidence to show that tacticians need aid in applying tactical doctrine (Powers and DeLuca, 1972). Simultaneously, there exists considerable literature showing that decision makers have considerable difficulty with unstructured decision situations (Mitroff and Betz, 1972). Unstructured decision situations require that the decision maker form a new "appreciation" of the situation (Vickers, 1965). Current automated tactical systems are not responsive to this need. State of the art systems have concentrated on structured problems. No decision system has yet attempted to aid the decision maker expand his "nomothetic net", i.e., give new meaning to information (Schroder, Driver, and Streufert, 1966). Plainly then, great emphasis must be given to designing systems that support the tactician in unstructured decision situations, and more research is necessary to determine the kinds of information that are best suited to this decision type.

Fundamental to any decision situation is the organizational context. An organization's structure and its information system are two sides

of the same coin (Mason and Mitroff, 1973). Anthony (1965) has identified three levels of organizational control:

- Strategic Planning: The process of policy definition
- Management Control: The process of resource allocation
- Operational Control: The process of task completion

In the present study, the organizational context is fixed. The decision maker is a division G-3 qua commander responsible for the planning and defense of the Hof Gap region in Germany. As such, he completes tasks at all of Anthony's levels. His task, however, emphasizes management control (resource allocation). Decision support systems should be designed to be consistent with organization structure, yet little is known about how such systems should be so flexible. In this study, we are being responsive by insuring that the decision support system filters, condenses and distills information appropriate to the G-3 mission. More work will be necessary to determine how tactical information requirements are modified by different echelons of command.

The commodity of the tactical information systems is information. Yet very little is known about what information should be included in a tactical data base. Strub (1973a, 1973b) has conducted an extensive series of investigations studying information requirements in SIMTOS.

He concludes, as have others (Ackoff, 1967) that tacticians rarely use all the data they request or consider necessary. In most decision situations, it may be more fruitful to improve the information processing ability of tacticians so that they may deal more effectively with the information they have rather than adding to the mountain of data already confronting them. It should also be noted that in any unstructured decision situation, decision makers often find it difficult to find a focus for their efforts. One of the most valuable aspects of a decision support system is that it can be used to suggest to decision makers what problems might be usefully considered.

The information contained in the information system's data base must be presented if it is to be useful. Variables affecting mode of presentation include the decision situation, information type, and decision style. Of particular interest in this study is how the presentation of information must vary to accommodate differing decision styles. Table 1-5 illustrates some alternative modes of information presentation for the polarities of each decision style dimension. Research by Morris (1967) and Pask (1971) illustrates that if there is a mismatch between decision style and mode of information presentation, large decrements in cognitive task performance can be expected.

Table 1-5. Hypothetical Information Presentation Correlates of Decision Style

Style Polarity	Information Presentation
Abstract	Symbolic
Concrete	Linguistic
Logical	Structured Data
Intuitive	Global Associative Data
Active	Partial Data Array
Passive	Complete Data Array

Tacticians need information consistent with their information processing characteristics, not information that is determined by system constraints (Henke, Alden, and Levit, 1972). Although this study will not deal with the issue, more information is also needed on how various display software (tabular vs. graphic formats) and hardware (CRT vs. computer synthesized voice) alternatives interact with decision style.⁷

⁷ For instance, there is some evidence to indicate that passive styles would show performance increments if voice output were used instead of CRT displays.

The Human/Computer Dialog

If a decision support system is to be effective in augmenting user capabilities, it must be integrated into a tactical operations system in a manner consistent with optimal human/computer communication. Principles leading to optimal human/computer communications have been designated by several authors as "meaningful human/computer dialog" (Sackman, 1967; Meadow, 1970; Henke, Alden and Levit, 1972; and Martin, 1973). Meaningful dialog goes beyond simple communication links; it extends to the user's feeling of security, trust, and satisfaction in system use. The classic study of Hanes and Gebhard (1966) showed that naval commanders made full use of their information system only after they understood its purpose and the decision logic. Halpin, Thornberry, and Streufert (1973) have conducted an experiment using a "staff" computer which performed both accurately and inaccurately. They found increased system utilization with increased accuracy. They also found that exposure to an initially inaccurate computer system or aid decreased later utilization of an accurate aid. This study points out the importance of the dialog intangibles such as trust.

Other researchers have also emphasized the importance of the elements of human/computer dialog. They have stressed that, unless there is understanding and trust in the system, computers and associated aids

are misused and overall system performance deteriorates. This effect occurs most dramatically as the importance of the decision increases (Myers, Gibb, and McConville, 1963; Schaffer, 1965; and Samet, 1969).

Sackman (1967) was the first to set forth some general principles of human/computer dialog. From several studies of the SAGE system, he postulated the following principles:

- **Real Time Parallelism:** Real time digital events should operate in parallel with, and reflect the pacing of, the separate and distinct real time characteristics of the men, equipment and relevant situational events required to meet system goals. This parallelism should hold throughout the range of system capacity and associated computer operating time. Program design and control should accordingly have a structure that results in a close empirical fit between digital timing and environmental timing as determined by empirical performance effectiveness through system testing.
- **Temporal Anthropomorphism:** The computer system should optimize around the characteristic variabilities of real time human norms for effective system performance rather than try to fit the human into an alien pace that may ostensibly be more convenient from program and equipment considerations.
- **Conversational Principle:** Human performance in man/computer dialog will vary with the similarity of the responding computer system, to the real time exchange characteristic of human conversation...As computer response time and message pattern deviate increasingly from real time parallelism...so will user performance deteriorate...(pp. 442-443).

Since 1967, several others have added to the notion of what constitutes a meaningful human/computer dialog. Henke, Alden, and Levit (1972) have summarized and added to the literature by deriving the following principles:

1. The system should be interactive: communication should be a "give and take" (mixed initiative) between human and machine.
2. The medium of communication between human and computer must be easy to use.
 - Users must not be burdened with difficult programming languages.
 - Rapid communication and feedback is essential.
 - There must be no ambiguities in system use or error interpretation.
3. The system should be responsive to the fact that different individuals analyze and react to the same objective situation differently (i.e., differences in decision style).
 - Data presentation form should be flexible.
 - System should be "regenerative," i.e., flexible enough to adapt to a dynamic environment.
4. The system should be designed so that the user is "comfortable" operating it, i.e., designed with user acceptance in mind.

- Must have user's confidence and trust.
 - Must be easily accessible.
 - Must be adaptive to sporadic activity and on-line creative behavior.
 - Must reinforce the idea of a "human/computer team," rather than the idea that the computer is a competitor.
5. The system must be secure.
- Must be designed so that the user's privacy is respected.
 - Must be protected against accident or deliberate intrusion or destruction.

At the present time, no computer system can meet all of these criteria. They remain as goals or guidelines for system development. The lesson of the human/computer dialog is that decision support systems cannot be hardware and software entities only. They must be responsive to their users if they are to be successful.

1.2.4 Decision Support Technology

Considerable time has been spent developing a conceptual structure for decision support based on five variables: decision style, decision situation, information, mode of presentation, and human/computer dialog. The idea of a decision support system—a complex of decision aids has

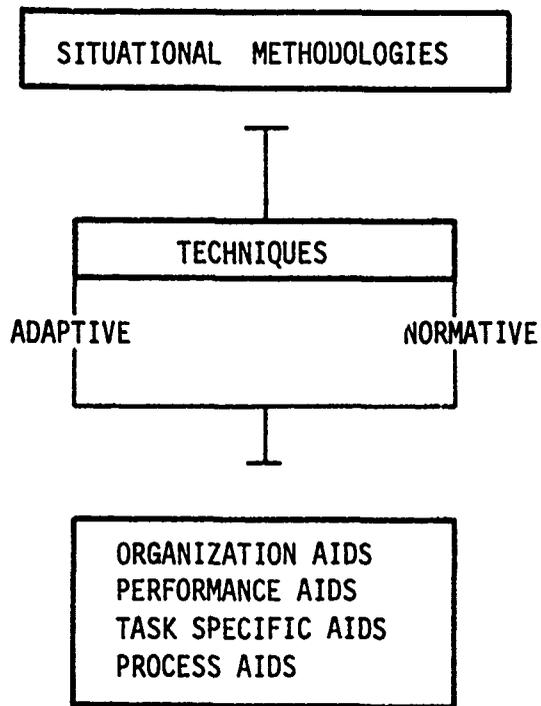
has also been introduced. These aids may be directed and integrated with all of the five variables in the conceptual structure or they can be concentrated on a single variable. The best approach is not determined by any theoretical orientation of aiding, but by what is judged to be best in the situation. Thus, this approach to decision-aiding is called situational.

The development of the situational approach and other decision support work in SIMTOS has its foundation in the research literature. To place the decision support context in better perspective, the highlights of the technology have been identified and reviewed. A taxonomy of decision aids has been developed to lend some organization to this diverse literature. The taxonomy in Table 1-6 should be analyzed in terms of Figure 1-1 (page 25). The taxonomy is meant to clarify different techniques of situational decision aiding.⁸

The domain of situational aiding methodology contains techniques that are adaptive, or responsive to differences in decision style, and normative (non-adaptive), techniques where aids are designed to fit some general user ("the average person"). The adaptive aiding concept is

⁸ The taxonomy of decision aids might also be used to organize the mathematically based methodology. However, other organizational categories (Bayesian, SEU, Gaming) have already been used in that literature (Beach, 1972).

Table 1-6. Taxonomy of Decision Aids



a relatively recent development. Most previous studies of decision aiding have been confined to the normative approach (Henke, Alden, and Levit, 1972).

Within the adaptive and normative techniques, four types of decision-aiding can be identified: organizational, performance, task specific, and process.

Organizational aids help the decision maker structure information in a useful form. The Kepner-Tregoe (K-T) (1965) approach to problem solving and decision making is an example of this type. The K-T approach encourages the decision maker to structure his decision situation and perform a systematic analysis of the information at his disposal. Thus, the K-T approach stresses organization rather than performance. The decision maker can "K-T" and still generate decisions of poor quality (i.e., those with adverse consequences). The advantage of the approach is that a systematic process usually generates "better" decisions than does some haphazard, non-systematic approach.

Performance oriented decision aids help the decision maker to use information in some optimal manner so that decisions will be of better quality when considered in terms of some objective performance criterion. Brewin's (1964) concept of military worth illustrates the performance orientation. Decision makers are aided to maximize the outcome of their decisions on some objective criterion measure.

Vaughan, Virnelson, and Franklin's (1964) classic study explains the philosophy behind the task specific approach.⁹

If an optimal man/computer partnership exists, it can be identified by first defining the component behaviors of tactical decision making as tasks to be allocated and then finding how well unaided but experienced tactical commanders perform individual tasks and combinations of tasks. These performance data could then be used as a basis for diagnosing man's strengths and limitations in decision behavior and for directing efforts to aid him with information processing devices (p. 2).

The development of a decision aid using a task specific approach requires the identification of a particular component of the decision situation that was particularly troublesome for the tactician, and the design of a decision aid to help him with the component. For example, a tactician might be unable to translate data base information into requirements for air support. A task specific decision aid would focus upon this particular task component to help him with the translation.

⁹ This study also pointed out the difficulty in classifying various types of decision aids. The ASW weapon depth selector studied contains elements of task specific, performance and process aids. The methodology for assigning aids to categories is explained in Section 1.2.1. It is not intended to be absolute, only a convenience. Thus, categorization is really a function of the reviewer's judgment of what the aid's designers intended its function to be.

Process oriented decision aids are designed to help the tactician throughout the decision making process. An example of a process aid would be to design a support system which updates information in the same order with the same level of specificity as it was originally requested. Thus, in querying the data base, if a tactician asked for information on intelligence, operations, and fire support, he would receive updated information on these parameters in this order. The underlying assumption of this approach is that a tactical decision maker goes through essentially the same process of analysis for each decision type, regardless of the task specifics.

Highlights of the Technology: The Normative Aids

Seventeen exemplary studies from the decision-aiding literature have been selected for detailed review and evaluation (Table 1-7). The methodology of selection was discussed in Section 1.2.1, and the review is organized using the taxonomy in Table 1-6.

One of the best and most thought provoking of the normative decision-aiding researches is that of Sidorsky and Mara (1968). This study explores the feasibility of using decision aids which provide meaningful answers to tactical questions, rather than simply supplying data on the tactical situation. The experimenters developed two types of decision aids for a decision situation consisting of a submarine ASW

Table 1-7. Summary Table of Exemplary Studies

Normative	Type of Aid	Adaptive
	Organizational	Friedman, 1962
Sidorsky and Mara, 1968 Kelley and Prosin, 1971	Performance	Rigney, Towne, and Bond, 1969
Gagliardi, Hussey, Kaplan, and Matteis, 1964, 1965 Vaughan, Virnelson, and Franklin, 1964 Hanes and Gebhard, 1966 Teitelman, 1966 Miller, Kaplan, and Edwards, 1968	Task Specific	Robertson, Fernald, and Myers, 1970
Shuford, 1965	Process	Grace, 1966 Ferguson and Jones, 1969 Teide and Leake, 1971 Hormann, 1971 Pask and Scott, 1972 Carlisle, 1972

attack. In the Status Display aid, the computer and its associated peripherals were assigned the task of assimilating and processing raw data and supplying a summary display to the tactician. The assumption underlying this aid is that the display of more exact information about the status of various tactical parameters will result in

better decisions by the tactician. A second type of decision aid was also studied in the ASW context. The Response Evaluation Process used the computer to provide information regarding the consequences of a tactical action tentatively selected by the decision maker.

Using these aiding techniques, subjects manipulated four criteria (detection, weapon effectiveness, counter-detection, and vulnerability) to establish the optimal speed and depth of a torpedo attack. Tactical performance using the two aids was compared using a derived "decision effectiveness score." The results showed that decision effectiveness was greater with the Status Display concept than the the Response Evaluation concept. Those results were surprising since the latter technique was judged, a priori, to be a more advanced aiding technique. The study does not, however, deal a death blow to the Response Evaluation concept. Two factors entered into the experiment that could have biased the results in favor of the Status Display aid: training level and problem structuring. The techniques for using and interpreting the Response Evaluation aid were more complex than that of the Status Display. Also, the response evaluation concept assumed a fair degree of sophistication in structuring the tactical situation. Both variables were uncontrolled in the experimental design. Thus, further study is necessary before the Response Evaluation concept is abandoned.

Kelley and Prosin (1971) bring to the decision-aiding literature the concept of "predictive displays." This aiding concept involves the display of actual versus predicted data in a manual control task. The technique aided the subject to detect differences from expected values before they lost manual control of a "trim adjustment" analog. Such an aiding technique might be useful in pointing out the actual versus the expected tactical situation to the decision maker. Kelley and Prosin's technique as such, however, has not been modified to allow the programming of individual experiences.

Gagliardi and associates (1964, 1965) have developed an algorithm decision aid for a submarine missile firing task. The task was to allocate hypothetical missile firing submarines so that a specified number of targets could be covered. Experiments indicated that the subject's processing limitations resulted in a slow and biased search for elements from which to assemble solutions. The aided system delegated the sub-task of finding key elements to an automated process and let the tactician assemble these elements into deployments. The effectiveness of this aiding technique was shown when aided subjects found more uniformly distributed solutions than unaided subjects. While the Gagliardi studies are fascinating, they lack some credibility in the real world tactical environment. The aiding technique depends on an omnipotent computer (i.e., it knows the location of all the targets).

Rarely, if ever, will that be the case in actual combat. However, the studies do point out the dramatic effect human/computer decision making teams could have on tactical performance.

Hanes and Gebhard (1966) have dealt with concepts of automated decision-aiding in a more realistic naval context. These authors were primarily interested in developing decision aids that served a staff function. Automated aids that tactical commanders would use and trust as they now use and trust their human "aids." The decision situation for these experiments was an AAW scenario. A commander used an automated tactical system to deploy his task force against a pre-programmed attack by a hostile enemy force. While the automated system contributed to tactical advantage, Hanes and Gebhard indicate that there are several important caveats in the design of these systems.

- An automated tactical system must be designed to complement the commander's activities--not direct them.
- Temporal aspects of computer responses should match human capabilities.
- The commander should be given system override authority.

What Hanes and Gebhard were specifying were criteria for optimal human/computer dialog, a concept key in our studies of SIMTOS.

Teitelman (1966) developed an interesting computer aiding procedure that will become more important in the near future--techniques of

selective data base manipulation. The objective of "Pilot" (The name designates that it is a pilot system for human/computer symbiosis.) is to give the user flexibility in the structure of his data. Recent work by Alden and associates (1973) hypothesized that different tactical tasks at different echelons of command might be better aided using differential storage structures (arrangement of data in computer memory) which correspond to the data structure (user's conception of the problem) of the user. Another way of stating this proposition is that data arrays within computer memory might be used more effectively if they were designed to complement the user's information processing capabilities (decision style).

The research of Miller, Kaplan and Edwards (1968) was included in this review because it is a good representative of the meeting ground between mathematical and situational methodologies. (Please see footnote 9 on the difficulties of categorization and Section 1.2.3 for an auxiliary explanation of JUDGE.) The JUDGE aid can be considered as a mathematical methodology since it is based on utility theory. On the other hand, it can be considered situational since the concept has been specifically designed for evaluation in a particular Air Force scenario (a situational test)--dispatching close air support missions. While JUDGE was shown to significantly aid performance in its assigned mission, it depends on a high degree of accuracy in

assigning mission priorities. The authors note that tactical commanders do not accurately conceptualize these priorities, but usually overstate the criticality of the situation. When such overstatements are used as JUDGE inputs, performance decrements are observed. The effectiveness of JUDGE as a task specific decision aid, however, should not be underrated. The technique might have been more effective if it were part of a decision support system where a complementary decision aid structured the problem for more accurate priority assignment.

Shuford's (1964) CORTEX aiding technique is an algorithmically based procedure whereby the computer guides the decision maker through a series of steps to define the probabilities associated with various possible states of the world and then helps him define utilities for his mission alternatives. CORTEX has not been evaluated in any decision situation; however, its effectiveness in tactical situations is questionable. Tacticians do not always have the time to go through such extensive evaluative procedures; nor do some of the narrow ranges of probability estimates provided by CORTEX (i.e., $P(\text{action 1}) = 0.45$ vs. $P(\text{action 2} = 0.47)$) make much difference in a complex tactical situation.

The research of Vaughan, Virnelson, and Franklin (1964) is a classic in the decision-aiding literature. The decision situation consisted

selection of torpedo depth in a submarine engagement. The decision aid developed for the submarine commander consisted of display which depicted the degree to which alternative depths satisfied seven criteria for depth selection for a given mission type. No performance data is available on the aiding technique, but this study retains its importance because it introduces the concept of levels of aiding and individual differences in tactical information processing. Vaughan, Virnelson, and Franklin (1964) plainly understood that a decision aid could complement several components of the decision making process or several aspects of tactical mission interpretation. Thus, levels of aidedness, in retrospect, are clearly the harbinger of the decision support system concept. This study was also one of the first to explore individual differences in tactical decision making (on rated importance of the depth selection criteria), an exploration that has culminated with the concept of adaptive decision-aiding.

Highlights of the Technology: The Adaptive Aids

Decision aids were classified as adaptive if the specifications for aid design could be easily rendered in a way responsive to decision style or if the designers intended that individual differences in information processing play a role in aid design.

Friedman's (1962) approach to decision-aiding introduces a recurring theme in the literature--contingency support, or the capability to organize information so that the logical consequences of alternative actions can be assessed. Friedman describes an approach directed toward aiding the weapon resource application task. Tactical officers are given a framework where they could query a data base to detect the location and strength of friendly units within the range of enemy units. In addition, alternative resource allocations could be evaluated in terms of other relevant data, e.g., time to mission completion, etc. Friedman's short paper is theoretical in nature, so no performance data are provided. Ferguson and Jones (1969), however, have tested a similar concept in a business management situation. Using a contingency aiding procedure, the manager of a "job shop" could investigate decision options in a "what would happen if" mode of operation. He could say, "Hold the present shop status fixed while I try various decision alternatives and decide which I like best on the basis of the resulting operations reports." He can thus, in the midst of the decision making process, explore the consequences of alternative actions. The authors concluded that such an aiding procedure yields performance increments. This study also shed some light on the relatively poor performance of Sidorsky and Mara's (1968) Response Evaluation Technique. Ferguson and Jones emphasize that rigorous

training procedures in decision aid use are necessary to overcome the complexity that the introduction of an aid temporarily adds to the decision situation. As Sidorsky and Mara themselves indicate, their subjects were not so rigorously trained. Ferguson and Jones' success with the contingency concept emphasizes the importance of system flexibility. Perhaps the ability of their managers to structure their own information requests added to the system's success. (Subjects in Sidorsky and Mara's studies did not have this capability.)

Rigney, Towne, and Bond (1969) have developed a software oriented (based on LISP statements) aiding technique similar to Teitelmen's "Pilot." In serial action situations, like trouble-shooting electronic equipment, the TASKTEACH statements allow the subject to extract from the data base information geared to support task completion. This information may take the form of:

- Maps of task structure
- Monitor errors
- Monitor progress
- Provide explanation
- Suggest next action
- Provide problem history
- Provide practice

No performance data is available on TASKTEACH. However, the development of software oriented aids implies that the design of flexible data base systems based on user information requirements is a viable aspect of decision aiding technology.

Robertson, Fernald, and Myers (1970) have developed an aiding concept for a business marketing decision situation. The experimental subject's task is to make decisions concerning the price, production, and advertising of a single product line. He plays against two competitors (i.e., a computer program) and is evaluated in terms of his quarterly profit. The decision aid was configured so that it tracked the subject's decisions and the consequences of those decisions across quarters. When sufficient data was gathered, the computer presented the subject with his past decision history when a similar decision arose in the current quarter. This decision history could then be used for guidance in the current situation. The results showed that the use of the aiding technique enabled the subject to outperform his "competitors."

Some decision aiding techniques focus on making computer output more meaningful to users of differing information processing capabilities. Grace (1966) has studied the way performance varies in an information interpretation task as a function of three types of printout format.

A verbal printout format presented information in words, a block data printout format in sets of data, and an eidiform (image) printout in a graphic or maplike format. The authors found that printout format significantly influenced performance. Furthermore, the results of a post-experiment interview indicated considerable subject variability in printout format performance. While Grace did not pursue the variability question, her data gives some supports to the idea that printout format preferences correlate with individual differences in information processing.

A series of experiments by Pask and Scott (1972, 1973) also supports the idea that matching information presentation techniques to information processing characteristics enhance performance variables. Pask and Scott (1973) pursued this line of investigation by studying the differences in performance information presentation techniques have on two types of learners: serialists and holists. A serialist is characterized by "one step at a time learning." He sets himself only one goal and tries to master it before going on to another. The holist sets multiple goals and tries to move toward all of them simultaneously. Pask reports that, when information presentation techniques designed for holists are given to serialists and vice versa, performance decrements were observed.

Aiko Hormann (1971) has been for sometime a prolific contributor to the human/computer decision making literature. In several studies (see Hormann, 1972) she has investigated techniques whereby man-machine synergy can lead to improved performance in problem solving and decision making. Her conceptualization of the "fuzzy set" has allowed the construction of computer systems that can respond to some of the ambiguity in human cognitive processes. Hormann has not concentrated on the development of any particular decision aid, but instead has emphasized multiple techniques (a decision support system) which will maximize human/computer performance. Such techniques include the design of user oriented program languages, alternative generation techniques and on-line simulation.

In an environment very similar to that of SIMTOS (since both are based on proposed Army Tactical Operations Systems), Tiede and Leake (1971) have developed ADVICE II (Analytical Determination of the Value of Information to Combat Effectiveness).

The authors succinctly pose the problem of the use of mathematically based aiding methodologies in tactical contexts.

The computerized decision rules are inevitably very simplistic. They cannot hope to reflect the variety of considerations that enter a commander's decision process. Factors of terrain, weather, progress of flank units, hours remaining to daylight or nightfall, apparent strengths

and dispositions of enemy forces, nuances of available intelligence--these and many other factors enter commanders' decisions. In addition, there are questions of tactics such as when and where to commit the reserve, whether to reinforce a defensive line early or wait and then counterattack, and when and where to apply a main attack effort. These are too complex to be reduced to a few computerized rules. (p. 589).

ADVICE II has, therefore, been designed to be more responsive to actual combat environments, to measure the effectiveness of tactical operations systems as a function of the outcomes of battles, not in any abstract terms.

ADVICE II is really a decision support system, that is, it is composed of a complex of decision-aiding techniques. All the aids, however, are directed toward enabling tactical officers, at the division and brigade echelons, to rapidly sense changes in the tactical situation and to respond with shifts of fire power. ADVICE II emphasizes the use and flow of tactical information to enhance the tacticians's ability to make fire power decisions.

Tiede and Leake provide one of the first opportunities to observe the relationship between the use of a tactical operation system and tactical performance. These authors evaluated tactical effectiveness in terms of a possible combat outcome. Without the help of ADVICE II the tactician often failed to complete his mission. When using

ADVICE II, "the success of the mission was never in doubt." Moreover, tacticians performed better with ADVICE II than with the equivalent number of additional maneuver units. ADVICE II, thus, provides persuasive evidence concerning the benefits of decision support in tactical operations systems.

Carlisle (1973) has designed a type of decision aid which centers on providing information in a manner consistent with a computer user's information processing capabilities. His "protocol analysis" concept uses a computer to trace a user's problem solving strategy, and uses that information to supplement the user's problem solving ability. No performance data is available on the efficacy of the aid; however, the study illustrates the recent tendency to design information systems around the cognitive characteristics of users.

Summary

The seventeen studies discussed in the highlights section were chosen as a representative sample of the decision-aiding literature. These studies present an imposing array of concepts and data. Tables 1-8 and 1-9 are presented to summarize pertinent aspects of the literature. Table 1-8 presents the type of independent variables that were considered by the respective researchers. The variables are those contained in our conceptual framework for decision support. Most of the representative

Table 1-8. Independent Variables in Exemplary Studies of Decision Aiding

Conceptual Framework Exemplary Studies	Decision Style	Decision Situation	Information	Mode of Presentation	Human/Computer Dialog
Sidorsky and Mara, 1968			X	X	
Kelley and Prosin, 1971				X	
Gaghardi, Hussey, Kaplan and Matteis, 1964, 1965			X	X	
Hanes and Gebhard, 1966				X	X
Teitelman, 1966			X		
Miller, Kaplan, and Edwards, 1968			X		
Shuford, 1964			X		
Vaughan, Virnelson, and Franklin, 1964			X	X	
Friedman, 1962			X	X	X
Rigney, Towne, and Bond, 1969			X		
Robertson, Fernold, and Myers, 1970			X		
Grace, 1966			X	X	
Ferguson and Jones, 1969			X		
Fiede and Leake, 1970			X		
Hormann, 1971			X		X
Pask and Scott, 1972	X		X		
Carlisle, 1972	X		X		X

studies are concerned with information and mode of presentation. Properly so, since information is the basic commodity of information systems. Concern over presentation techniques is also prominent in the literature. Much less, if any, attention has been given to designing and evaluating decision aids responsive to individual differences in information processing, or to testing different aiding concepts across types of decision situations. Human/computer dialog questions (usually oriented toward user acceptance and satisfaction) have been much discussed, but not systematically studied. Hopefully, the conceptual framework discussed in Section 1.2.3 will serve as an organizing medium for research so that these variables and their interactions can be systematically studied. The framework for decision support might also serve to place situational aiding methodologies at the same level of prominence as mathematically based ones, and to emphasize the concept of decision support in tactical operations systems.

Human/computer dialog is both a variable for experimentation (in our conceptual framework) and a potential set of specifications for tactical operations system design.¹⁰ Table 1-9 summarizes the responsiveness of the representative studies to human/computer dialog criteria.

¹⁰ Sections 1.3.2 and 1.3.3 will evaluate the representative studies on yet another set of criteria, more specific to the SIMTOS context.

Table 1-9. Human/Computer Dialog in Exemplary Studies

Principles of Human/ Computer Dialog Exemplary Studies *	Princ. 1 "Inter- active"	Princ. 2 "Ease of Use"	Princ. 3 "Flexi- bility"	Princ. 4 "User Accept."	Princ. 5 "Security"
Sidorsky and Mara, 1968	X	X			
Kelley and Prosin, 1971		X			
Gagliardi, Hussey, Kaplan and Matteis, 1964, 1965		X			
Hanes and Gabhard, 1966	X	X		X	X
Teitelman, 1966	X				
Miller, Kaplan, and Edwards, 1968	X				
Shuford, 1964	X				
Vaughan, Virnelson, and Franklin, 1964		X			
Friedman, 1962	X	X			
Rigney, Towne, and Bond, 1969	X				
Robertson, Fernald, and Myers, 1970	X	X		X	
Grace, 1966	X	X	X		
Ferguson and Jones 1969	X				
Tiede and Leake, 1970	X			X	
Hormann, 1971	X	X		X	
Pask and Scott, 1972	X	X	X	X	
Carlisle, 1972	X	X	X	X	

* Please see Section 1.2.3 for a discussion of human/computer dialog principles.

Almost all of the studies dealt with interactive systems, but none made full use of the mixed initiative communication potential. Machine initiated communication is still a rarity and is a fertile area for investigation. (The need for machine initiated communication with passive decision styles is evident.) Many of the studies give considerable discussion to ease of use, but proceeded to design systems that require the user to master complex procedures or to evaluate and quantify complex dynamic situations. In these circumstances, decision aided confusion often results. User orientation is becoming a by-word with many sources attributing considerable importance to this criterion (particularly in tactical contexts). System security and Flexibility have received little attention, but have been mentioned increasingly in the literature as important variables.

Section 3 Decision Support in SIMTOS

1.3.1 Approach to Decision Aid Evaluation

The review of decision support technology and the associated development of a conceptual framework for decision support was not conducted in a vacuum. Its purpose has been to prepare for the further development of these concepts within an actual simulated tactical operations system (SIMTOS). To assess what decision support technology could contribute to SIMTOS, an evaluation approach based on three factors has been formulated. These factors are:

- Analytic generation of criteria for decision-aiding in SIMTOS.
- Quantitative evaluation of representative decision aids by a panel of project personnel familiar with SIMTOS.
- Derivation of principles of aiding that could be applied in the SIMTOS environment.

Each of these topics is discussed in this section.

1.3.2 The Development of Criteria

Section 1.2.3 of this report provides some of the raw materials for the development of a set of criteria for decision support in tactical operations systems. Other raw material has been provided by the many

studies cited in the review of decision support technology. The following list of criteria, then, is both a summary of our conceptual thinking and a reflection of a considerable number of empirical studies.

A decision support system must:

- Give the tactician greater "awareness and control" over his command environment.
- Be acceptable to the user.
- Strive to improve accuracy and performance.
- Impel the tactician into action.
- Prepare the tactician for contingencies.

A decision support system should:

- Enable the tactician to interpret each action as part of a "bigger picture".
- Help the tactician focus on crucial aspects of his task.
- Help the tactician generate new relationships among his data.
- Facilitate the selective retrieval of information.
- Be responsive to individual differences in information processing.

While it is unlikely (and unnecessary) that any particular decision aid could meet all these criteria, the complex of aids composing a decision support system should be designed to do so.

Table 1-10 evaluates the exemplary studies of decision-aiding on these analytically derived criteria. None of the decision-aiding techniques meet all the criteria. Most of the aiding procedures, however, meet at least five of the criteria. Therefore, it seems reasonable that a complex of decision aids comprising a decision support system could be designed to satisfy all the stated requirements.

In order to "tailor make" a decision support system for SIMTOS, the task of criteria development was iterated so that criteria specific to SIMTOS environment could be generated. To the raw materials mentioned above (conceptual analysis and empirical studies), the iteration considered the scope and mission of the Army Research Institutes' SIMTOS, the Command and General Staff College exercise on which it is based, and the tasks and procedures used by a division G-3 (operations officer) as outlined by Army Staff Manuals (particularly FM101-5).

The new set of "combined" criteria consisted of four major criteria and 20 specifications.

Criterion 1: The decision support system must give the tactician greater control over his environment and thus improve the accuracy and effectiveness of information processing and job performance within the SIMTOS context.

Table 1-10. Exemplary Studies Evaluated by Analytically Derived Criteria

Criteria for Decision Support Systems	Normative										Adaptive						
	Sidorsky and Mara, 1968	Kelley and Prosin, 1971	Gargliardi and Associates, 1964	Hanes and Gebhard, 1966	Tetelman, 1966	Miller and Associates, 1968	Shurford, 1964	Vaughan and Associates, 1964	Friedman, 1962	Rigney and Associates, 1969	Robertson and Associates, 1970	Grace, 1966	Ferguson and Jones, 1969	Tiede and Leake, 1970	Hormann, 1971	Pask and Scott, 1973	Carlisle, 1972
1. Awareness and Control	X			X	X			X	X		X	X	X	X	X		
2. User Acceptance				X						X				X	X	X	
3. Accuracy and Performance	X	X	X	X		X	X	X	X	X	X	X	X	X		X	
4. Impel to Action		X	X	X			X	X	X								
5. Prepare for Contingencies	X								X				X				
6. Interpret "Bigger" Picture										X			X	X			
7. Focus on Task	X	X	X	X	X		X	X	X			X	X				
8. Generate New Relationships	X		X		X				X	X		X		X			X
9. Facilitate Information Retrieval			X	X	X		X	X	X				X	X	X	X	X
10. Responsiveness to Individual Differences										X					X	X	X

Characteristics and Specifications

- Can be integrated with SIMTOS.
- Prepares for contingencies.
- Facilitates selective evaluation of information.
- Facilitates the restructuring of data.
- Allocates tasks between human and computer.
- Impels action.
- Reduces decision making parameters (time, etc.).
- Reduces the discrepancy between expectancies and the real world.

Criterion 2: The decision support system should enable the G-3 to explore and evaluate multiple courses of action within tactical and operational constraints.

Characteristics and Specifications

- ~Helps G-3 "scope" his task.
- Generates new relationships/test ideas/gives feedback.
- Encourages the practical application of common sense (the "feel" of the situation, command intuition, hunch, etc.).

Criterion 3: The decision support system promotes user acceptance and confidence by conforming to the principles of human/computer dialog.

Characteristics and Specifications

- System is interactive.
- Easy to use.
- Flexible (to accommodate individual differences).
- Aid "rationale" clear.
- Emphasizes user acceptance.
- User privacy and system security.

Criterion 4: The decision support system will be developed in the SIMTOS context, but should be generalizable to other (larger scale) tactical operations systems.

Characteristics and Specifications

- Responsive to SIMTOS task.
- Representative of decision support in general.
- Applicability of design principles to other systems.

These criteria were used in a quantitative evaluation of the exemplary decision-aiding literature (Section 1.3.3). This quantitative procedure complements the more qualitative analysis of Sections 1.2.4 and 1.3.2 (Table 1-10).

Summary

Lest the reader becomes lost in specifications and criteria, Figure 1-5 outlines the logical development of the criteria for decision support in SIMTOS.

1.3.3 Quantitative Evaluation

The Problem Evaluation Process (PEP) procedure, developed at Honeywell, represents a quantitative technique for ranking alternatives based on the application of complex criteria. This technique was used to derive a quantitative estimate of how a select group (Honeywell and ARI personnel) of knowledgeable judges ($N = 7$) would rank the principles of decision-aiding found in the exemplary studies.

In the PEP technique, decision support criteria were first rated a priori relative to each other. The highest value or weight was assigned to the criterion considered the most important and lower values were assigned to the remaining criteria in proportion to their importance. The PEP weights for the derived criteria were as follows:

Criterion 1:	Give the tactician greater control over his environment.	PEP Weight = 0.4
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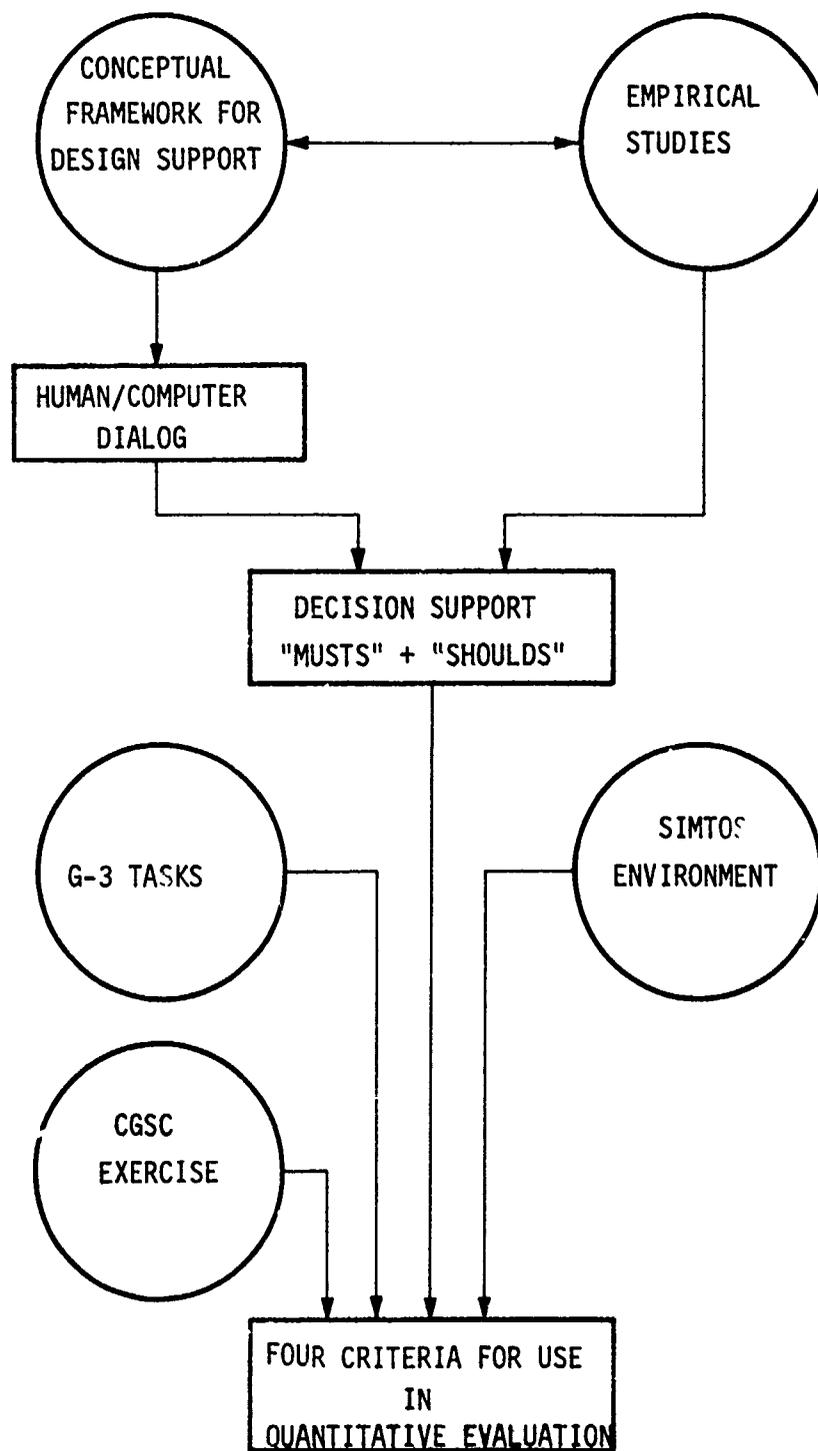


Figure 1-5. Genesis of Decision Support Criteria

1.3.3 Quantitative Evaluation

81.

Criterion 2:	Enable the G-3 to explore multiple alternatives	PEP Weight = 0.3
Criterion 3:	User Acceptance/Human-Computer Dialog	PEP Weight = 0.2
Criterion 4:	Generalizability	PEP Weight = 0.1

The task of the PEP evaluators was to assign a "relevance number" to each exemplary study with respect to each exemplary study with respect to each criterion (a requirement of the analysis was that criteria weights and relevance numbers each sum to 1.0). The product of the criteria weights and relevance numbers were used to determine the average PEP values for seven evaluators. These values represent the evaluators "preference" for decision-aiding techniques found in the representative studies. The PEP values appear in Table 1-11.

Although the PEP analysis suffered from some methodological problems (particularly the sum to 1 requirement and the independent rating of aids) and while the data was characterized by a large variance, the analysis did serve to put preferences for decision aids into perspective. PEP showed that evaluator preference was rather universally distributed across all the representative studies (PEP value range equals .0068). While the data indicates some minor preferences for performance oriented aids (rather than information processing aids),

Table 1-11. PEP Values (Evaluator Preference) for Decision-Aiding Techniques Found in Exemplary Studies

Investigators	Aid Type	PEP Value
Kelley and Prosin, 1971	Normative	.0300
Gagliardi, Hussey, Kaplan, and Matteis, 1964, 1965	Normative	.0283
Friedman, 1962	Adaptive	.0279
Shuford, 1964	Normative	.0277
Carlisle, 1972	Adaptive	.0273
Ferguson and Jones, 1969	Adaptive	.0268
Teitelman, 1966	Normative	.0268
Hormann, 1971	Adaptive	.0264
Sidorsky and Mara, 1968	Normative	.0263
Miller, Kaplan, and Edwards, 1968	Normative	.0261
Rigney, Towne, and Bond, 1969	Adaptive	.0261
Grace, 1966	Adaptive	.0159
Vaughan, Virnelson and Franklin, 1964	Normative	.0253
Pask and Scott, 1972	Adaptive	.0246
Hanes and Gebhard, 1966	Normative	.0245
Tiede and Leake, 1970	Adaptive	.0244
Robertson, Fernald, and Myers, 1970	Adaptive	.0232

no particular aid or aid type (normative or adaptive) was dramatically preferred over another. This finding gives some credence to the decision support idea which states that no one type of decision aid is appropriate for tactical systems. A complex of aids or the "right" mix is necessary for effective tactical decision support.

1.3.4 Derivation of Aiding Principles for Decision Support

When we began our study of decision aiding technology, we did not expect to "find" an aid or aids suitable for direct integration with SIMTOS. What we sought were principles of aiding that could be tailored to fit the SIMTOS environment. From our analyses, qualitative and quantitative, we have derived one major aiding principle and three leitmotifs. The major principle is that of the decision support system. (This concept was introduced and discussed in Section 1.2.2). The decision support principle states:

In order to maximize the effectiveness of human decision making in human/computer environments, the system designer must implement a variety of decision aids (a complex) in a mix appropriate to the aspects of decision making crucial to a particular decision situation and in a manner consistent with meaningful human/computer dialog.

The principle emphasizes that no single decision aid will maximize the effectiveness of human decision making. A complex or hierarchy of

aids is necessary. Aids should be directed at each component of the decision making process across tasks, but should be tailor made for the decision situation (problem and organizational context) within tasks. That is, the aiding principles composing a decision support system might be similar to the extent that the decision making process is similar across individuals, but in their particulars they must be molded to fit a particular decision context. For example, though there is a similarity in the ways that a division commander and a company commander make tactical decisions, aids designed for both should reflect the difference in echelon of command.

While there are similarities in the human decision making process, there are important individual differences (decision style) associated with decision making. Therefore, the principle implies that the appropriate decision aid mix must include aids directed at both similarities (normative aids) and differences (adaptive aids) in the decision making process. Finally, any aid used must be designed to meet the criteria of meaningful human/computer dialog.

What is the appropriate decision aid mix? While, as the principle states, it is situation specific, certain leitmotifs appear in the literature. These are:

- Estimate of the situation aiding.
- Resource allocation aiding.
- Contingency planning aiding.

The aids designed for a particular decision situation will be molded reflections of these leitmotifs. A decision support system should include aids from all three categories.

Estimate of the situation aiding provides the decision maker with a core of relevant information to structure and interpret the problem in a decision situation. Since information requirements seem to be highly individualistic, "estimate" aids might be adaptive in nature.

Resource allocation aiding provides the decision maker with the information and communicative authority to disperse resources in some systematic and optimal manner for a particular task or tasks.

Contingency planning aiding provides the decision maker with the capability to play "what if" and to thereby assess the consequences of alternative actions.

Table 1-12 illustrates the presence of these aiding themes in the exemplary studies from the literature review. How these concepts will be applied to SIMTOS will be discussed in the next section.

Table 1-12. Aiding Themes in Exemplary Studies

Exemplary Study	"Estimate" Aiding	"Allocation" Aiding	"Contingency" Aiding
Sidorsky and Mara, 1968	X		X
Kelley and Prosin, 1971	X		
Gagliardi, Hussey, Kaplan, and Matteis, 1964, 1965	X	X	
Hanes and Gebhard, 1966	X	X	
Teitelman, 1966	X		
Miller, Kaplan, and Edwards, 1968		X	
Shuford, 1964	X		
Vaughan, Virnelson, and Franklin, 1964	X		
Friedman, 1962	X		X
Rigney, Towne, and Bond, 1969	X		
Robertson, Gernald, and Myers, 1970	X	X	
Grace, 1966	X		
Ferguson and Jones, 1969			X
Tiede and Leake, 1970	X	X	
Hormann, 1971	X	X	
Pask and Scott, 1972	X		
Carlisle, 1972	X	X	

Section 4 Recommendations for Decision Support in SIMTOS

1.4.1 A Proposed Decision Support System

We propose a decision support system for SIMTOS based on the three concepts of aiding discussed in the last section: estimate, allocation, and contingency aiding. Tables 1-13 and 1-14 illustrate that such a tripartite aiding scheme will satisfy both the general criteria for decision support systems, and those criteria more specific to the SIMTOS environment.

Estimate Aiding

This aiding concept provides the SIMTOS user with an estimate of the situation designed to give timely and accurate information on the tactical situation confronting him. This information would be available in the planning phase as a separate briefing resource, and in the combat phase as a structured list of standard requests for information (SRI). The presentation of this information will allow the user to remain in constant touch with the status of his data and the tactical environment it represents.

Since individual differences in information requirements are large, the estimate aid will be the test bed for the adaptive aiding concept.

Table 1-13. Evaluation of a Proposed Decision Support Complex on General Criteria

Aid Criteria	Awareness and Control	User Acceptance	Accuracy and Performance	Impel Action	Prepare for Contingencies	Interpret Bigger Picture	Focus on Task	Find New Relationships	Facilitate Information Retrieval	Individual Differences
Decision Aids										
Estimate	X	X				X	X	X	X	X
Allocation	X	X	X	X						
Contingency	X	X	X	X	X		X	X		

Table 1-14. Evaluation of a Proposed Decision Support System on SIMIOS Criteria

Criteria*	Criterion 1 Control	Criterion 2 Alternative Actions	Criterion 3 User Acceptance	Criterion 4 Generalizability
Aids				
Estimate	X		X	X
Allocation	X		X	X
Contingency	X	X	X	X

* Please see Section 1.3.2 for a discussion of the criteria.

Estimate briefings will be structured according to decision style in the planning phase. Decision style will be measured off-line by a specially developed instrument which is discussed in Volume 2 of this report.

Resource Allocation Aiding

This aiding concept, designed for the combat phase of SIMTOS, would optimize weapon usage by helping the user select the weapon or unit to be used in a tactical operation. By indicating the coordinate of an enemy unit, the user would call a display indicating the weapons, friendly units and number of basic loads available to attack that enemy unit. Should he desire to order an attack on the enemy unit, he can do so directly through the aiding procedure, without recourse to other aspects of the data base. The allocation aid is closely linked with the estimate aid to provide the means for quick detection and response in the tactical environment.

Contingency Aiding

This aiding concept would allow the SIMTOS user to explore the consequences of various tactical operations before actually conducting them in real time. The aid would provide the tactician with a method for running "a mini-simulation" of a particular tactical operation.

For example, it would allow the tactician to evaluate the effectiveness of an air strike in terms of resources expended and anticipated own force and enemy losses. Contingency aiding would be particularly useful in the combat phase.

Synthesis

In the discussion of a conceptual framework for decision support (Section 1.2.3) and once again when discussing the derivation of aiding principles (Section 1.3.4) the importance of the concept of decision support system--a complex of decision aids each directed at a different aspect of the decision making process-- was emphasized. The proposed decision support system outlined above is responsive to this concept. Each aid is designed to complement one aspect of the three stage decision making model outlined in Section 1.2.3.

The proposed system is also composed of both adaptive (estimate) and normative (allocation/contingency) aids.

While decision support system design should be largely independent of conceptual decision making frameworks, the material presented in Table 1-15 has some explanatory value. It helps to link the conceptual framework with the empirically derived decision aiding leitmotifs. (The concept of decision style in estimate aiding also serves this function.)

It also allows the designer to conceptualize which aspects of decision making are more crucial to a particular task (one aspect of the decision support principle, Section 1.3.4) or decision situation, and to design support systems accordingly.

Table 1-15. Responsiveness of the Proposed Decision Support System with a Model of Decision Making

Decision Making Stage	Responsive Aid
Information Acquisition and Organization	Estimate
Information Processing	Contingency
Action Selection	Allocation

1.4.2 First Implementation

The design of decision support systems should be an important component in the overall design of tactical operations systems. Where this is not possible, the decision support systems must be retrofitted in an already existing system (as in SIMTOS), the integration of the support system should be done in phases with a careful assessment of the results of each phase. Often the integration of new software and hardware can

1.4.2 First Implementation

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severely disrupt the logic of an existing system, resulting in a decrement in overall system performance rather than the desired improvement. For this reason, Honeywell and ARI project personnel decided to concentrate on the development of the estimate and resource allocation aiding concepts in the initial study of decision support in SIMTOS; and to leave the development of the contingency concept to a later program. While this approach reduces the power of the proposed decision support system, it provides the ability to evaluate the contribution of each aiding component to the total decision support system.

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