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SPECIFICATION OF ADAPTIVE AIDING SYSTEMS

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Designers' decision making in specifying adaptive aiding systems is considered. A study of design decisions in specifying aiding for a fighter aircraft mission scenario is discussed. The requisite background knowledge required for the design of aiding systems and inherent complexity of situations to which adaptive aiding is applicable is quite broad. Considering these facts, the initial analysis of aiding designer's decision processes focused on identification and validation of solutions currently used in the design process. Results indicate a high degree of consistency on the part of individual designers. However, there were substantial variations among designers in terms of both decisions made and information used to make the decisions. The implications of these results for development of design tools, as well as the types of research studies whose results would be valued by designers, are considered.

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INTRODUCTION

Development of mechanisms to aid operators of complex systems has a long and rich history (Rouse, 1991). A wide variety of approaches has been developed for aiding operators in problem formulation/structuring, probability estimation and updating, selection among alternatives, and task execution and monitoring. In recent years, aiding has evolved to include decision support systems and intelligent systems.

Unfortunately, despite the availability of a growing number of "proof of concept" studies, most aiding systems have been unsuccessful. They have been developed, but not fielded. Not infrequently, they have been fielded, but not used (Klein, 1989).

It can be argued that this unfortunate result is due to unacceptable rigidity in the design of aiding systems and/or inflexibility in the aiding or automation philosophy underlying such systems (Rouse, 1988). A typical approach to aiding/automation is to computerize everything that can possibly be computerized, and make whatever is left over for humans as easy as possible. The realization that this approach often does not work has led to the concept of adaptive aiding systems, whereby the nature of the aiding, as well as whether or not the aiding is used, are modified or adapted to changing characteristics of tasks and/or operators' needs.

The adaptive aiding concept attempts to address several concepts in the complex task domain. For example, the complex task environments for which adaptive aiding systems are suited often have multiple operational elements which compete for the same (limited) operator and system resources. The nature of these environments also requires a distinction between discrete selection and continuous control tasks. Further, there are often dynamic task execution priorities for which the operator is responsible for maintaining. All of these factors must be taken into account when designing an operator aiding system.

Over the past two decades, substantial conceptual development and a variety of experimental efforts have proven the value of the adaptive aiding concept – see Rouse (1988) for a review of this work. These efforts have culminated in an initial high level framework for designing adaptive aids. The initial answers to these questions suggest a preliminary set of design principles to guide design decisions (Rouse, 1988, 1991).

This design framework is structured in terms of a set of six questions:

- What is adapted to?
- Who does the adapting?
- When does adaptation occur?
- What methods of adaptation apply?
- How is adaptation done?
- What is the nature of communication?

The framework also includes alternative answers to these questions and is discussed below.

A primary difficulty with these questions and alternative answers is a lack of data upon which to base choices among alternatives. The set of design principles currently available are helpful, but by no means sufficient to cover the problem domain suggested by the six design questions. So the primary problem is we have a suitably defined problem domain, but we do not have a good sense of viable solutions within that domain.

Initially, it might appear that the obvious solution to this problem is collection of the requisite data to "fill in" the needed set of principles. Unfortunately, the experimental effort necessary to provide this data is at least impractical, and possibly unimaginable. The complexity of the situations where adaptive aiding is of particular value make the set of potentially relevant data much too large to imagine collecting it.

An alternative approach to this problem is adopted in this study. The emphasis of this work is to define the data engineers use in specifying requirements for adaptive decision aids. In other words, rather than attempt to compile data, as well as the resulting principles, to cover all possible answers to the design questions, the focus at this time should be on elaborating and validating solutions the designers are employing currently to determine what features of the de facto adaptive aid design process are contributing to their success. Further, the definition of prospective design principles and guidelines should pay particular attention to the data designers rely on in making their design decisions.

In this paper, we report the results of pursuing this approach. An experimental investigation was performed involving designers whose task was to produce specifications for adaptive aiding within aircraft mission scenarios. Statistical methods were used to identify relationships among a variety of decision making attributes and designers' specification decisions.

BACKGROUND

This section organizes many of the results and ideas discussed earlier. In addition, several adaptive aiding notions are discussed that have yet to receive serious study. A primary goal of this section is to illustrate the breadth of possibilities when designing adaptive aids. In this way it is hoped that one might possibly counteract the previously mentioned tendency to pursue design of intelligent support systems in an ad hoc manner.

We have found that the conceptual design of an adaptive aid can be approached systematically by pursuing answers to a specific set of design questions or issues. While it is not possible to provide generic, context-free answers to these questions, it is possible to outline the range of alternative answers and suggest principles of adaptation and interaction that may assist designers in choosing among these alternatives.

Design Issues

In developing a framework for research on adaptive aiding several years ago (Rouse and Rouse, 1983), a structured set of design issues emerged. A subset of these issues is quite similar to the framework proposed recently by Lehner and his colleagues (1987). The overall set of issues is discussed in this section.

What is adapted to?

In general, adaptation to the user and/or task is possible. In addition, an aid can adapt to a class of users (or tasks), a particular user (or task), or a particular user (or task) at a specific point in time. In other words, adaptation can be relative to a class as a whole, a member of a class, or the state of a particular member.

An interesting aspect of answering this question concerns whether the emphasis should be on adapting *to* the user or adapting *of* the user. Although it is often the case that users' needs and preferences should be accommodated, there are also situations in which overall performance can be enhanced by providing users with new skills and knowledge. Current interests and developments in embedded training and intelligent tutoring systems are providing a strong basis for pursuing the notion of adapting the user as well as the aid. Lehner and his co-workers (1987) and Noah and Halpin (1986) have advocated embedded training as a potential component of an adaptive aiding system.

Who does the adapting?

If viewed very narrowly, this question has only one possible answer -- the aid adapts. However, from a broader perspective the agent of adaptation can be the system designer, users, or the aid. It can reasonably be argued that a system designer always adapts a system to a class of users and tasks. Beyond such "static" adaptation, users often configure a system for themselves by, for example, adjusting the seat and mirrors, choosing autopilot modes, or requesting particular report formats. The aid is the appropriate agent of adaptation if design adaptations need to be refined and/or changed and if users are unlikely to perceive the need or be able to execute these adaptations.

When does adaptation occur?

It may be possible to adapt off-line prior to operation. Alternatively, adaptation can occur on-line in anticipation of changing demands. Finally, adaptation can occur on-line in response to changes. Clearly the "what," "who," and "when" questions interact in the sense that not all possible combinations of answers are feasible. For example, it is difficult to imagine a designer being the agent of on-line adaptation to the time-varying state of a particular user.

What methods of adaptation apply?

There are three general methods for aiding a user: (1) an aid can make a task easier, (2) an aid can perform part of a task, and (3) an aid can completely perform a task. These three methods can be termed *transformation*, *partitioning*, and *allocation*, respectively (Rouse and Rouse, 1983). As examples, many display enhancement techniques (e.g., filtering and smoothing) represent transformations. Display highlighting (e.g., for cautions, alarms, and warnings) is an example of partitioning. Autopilots represent aiding via allocation.

Although the distinctions among these three methods of adaptation are certainly not crisp, it is a reasonably straightforward matter to decide which method applies if one focuses on the implications for the role of users. With transformation, users still perform the task in question. With partitioning, users are still "in the loop" but are not the sole agents of action. With allocation, the computer is the only active agent for the task that has been allocated.

How is adaptation done?

This question does *not* concern how the aid performs a portion or all of a task. Rather, the issues is the basis for determining the need for transformation, partitioning, or allocation. There are basically two approaches to making this determination. One approach is *measurement*, directly in terms of performance decrements or changes of demands or indirectly in terms of, for example, leading indicators of performance. In the study conducted by Morris, Rouse, and Frey (1985), it was found that the average time to detect a target once it came into view, began increasing about 20 seconds prior to any targets being missed. This detection latency served as a leading indicator of the primary measure of detection accuracy.

The other approach is *modeling*, whereby predictions of intentions, resource availability, and performance can be used to trigger adaptation. This approach basically provides the agent of adaptation with "expectations" the violation of which results in at least more targeted monitoring and eventually some degree of adaptation. Approaches based on mathematical models of human decision making (Reevesman and

Greenstein, 1986), and Geddes's model for intent inferencing (Geddes, 1990) are good examples of models that are used in this way.

It is important to emphasize that depending on the agent of adaptation (e.g., user as opposed to aid), measurement and modeling have to be handled differently. If the user is to make the necessary measurements, the requisite information must be available and displayed appropriately. Further, if the user is to have the necessary "mental models," it is likely that specialized training will have to be developed (and perhaps embedded) as well as associated displays for supporting the use of these models. In contrast, if the aid is the agent of adaptation, measurement and modeling must focus on instrumentation and processing issues rather than displays and training.

<u>What is the nature of communication?</u>

The basic issue here concerns whether communications *about adaptation* should be explicit or implicit. Explicit communication between user and aid concerning the activities, awareness, and intentions of each party has the advantage of being minimally ambiguous but can impose substantial overhead. The cost of this overhead can potentially exceed the benefits of aiding.

In contrast, implicit communication, via measurements and/or models, can greatly lessen this overhead but suffers from greater uncertainty and ambiguity regarding the actions and intentions of each party. Revesman and Greenstein's work (1986) clearly illustrates the trade-off in choosing between explicit and implicit communication. The trade-off hinges on the uncertainty associated with model-based implicit communication. If a model can provide perfect predictions of the user's intentions and actions, there is no need to communicate explicitly, and thus the cost of explicit communication can be avoided. However, as uncertainty grows, predictions will more frequently be wrong, and as a result, tasks will slip through the cracks or receive redundant efforts. To avoid these possibilities, increased explicit communication is needed to check or calibrate a model's predictions. If the level of uncertainty associated with a model's predictions becomes too great, totally explicit communications become the best policy.

Principles of Adaptation

The current data base of empirical studies of adaptive aiding is much too meager to codify a *principia adaptivia* (Rouse, 1988). However, sufficient R&D experience has been gained to be able to outline the general nature of the requisite principles and suggest, at least tentatively, specific design principles.

Two types of principles are needed: (1) principles of adaptation and (2) principles of interaction. Principles of adaptation concern when and how adaptive aiding applies, as well as the underlying mechanisms of adaptation. The experimental results discussed earlier, as well as some recent recommendations by other researchers, suggest the following *incomplete* set of principles:

- The need for aiding can depend on the interaction of impending and recently completed task demands (Morris and Rouse, 1986) -- task allocation decisions should not be based solely on the demands of the task in question.
- The availability of aiding and who does the adapting can affect performance when the aid is *not* in use (Morris and Rouse, 1986) -- total system performance may be enhanced by keeping the user in charge of allocation decisions.
- When using measurements as a basis for adaptation, temporal patterns of user and system behavior can provide leading indicators of needs for aiding (Morris, Rouse, and Frey, 1985; Morris, Rouse, Ward, and Frey, 1984) -- it may be possible to use secondary indices as proxy measures of the indices of primary concern.
- When using models as a basis for adaptation, the degree of task structure will dictate the accuracy with which inferences of activities, awareness, and intentions can be made (Rouse, Geddes, and Curry, 1986, 1987) -- tasks with substantial levels of user discretion may limit the potential of model-based adaptation.

To the extent possible, incorporate within the aid models that allow predictions of the *relative* abilities of users and the aid to perform the task in particular situations (Lehner et al., 1987; Morris and Rouse, 1986) -- substantial variations of *relative* abilities of users and aids provide the central impetus for adaptation.

Although the foregoing principles are qualitative, they help to answer some of the design questions posed earlier. For example, answering the question of who does the adapting can be seen to depend on task structure, likely task sequences, and the extent to which appropriate measurement and modeling methods are available and computationally viable.

Principles of Interaction

These principles relate to the characteristics of adaptive aiding that foster (or hinder) humans' acceptance and utilization of these aids. Principles of interaction also concern the extent to which users must understand the functioning of adaptive aiding in order to utilize the aiding appropriately and determine whether or not it is functioning properly. Finally, of course, these principles relate to the somewhat traditional human factors issues of the displays and controls associated explicitly with adaptive aiding. Based on the experimental results summarized earlier and various researchers' recommendations, the following *incomplete* set of principles is suggested:

- Users can perceive themselves as performing better than they actually do and may want an aid to be better than they are (Morris and Rouse, 1986) -- as a result, an aid may have to be much better than users in order to be accepted.

- Ensure that user-initiated adaptation is possible and appropriately supported, even if aid-initiated adaptation is the norm (Lehner et al., 1987; Noah and Halpin, 1986) -- ensure that users feel they are in charge even if they have delegated authority to the aid.

- Provide means to avoid user confusion in reaction to aid-initiated adaptation (Lehner, et al., 1987) and methods for the user to preempt adaptation (Chu and Rouse, 1979) -- make it very clear whether human or computer is supposed to perform a particular task at a specific time and provide means for changing this allocation.

- It appears that aid-initiated "off-loading" of the user and user-initiated recapturing of tasks is a viable means of avoiding "hot potato" trading of task responsibilities (Rouse, Geddes, and Curry, 1986, 1987) -- this asymmetry may help to ensure that users will feel in charge of the overall system.
- There is a trade-off between the predictive abilities (i.e., in terms of uncertainty reduction) of models of human performance and intent and the way in which the explicit versus implicit communication issue is resolved (Revesman and Greenstein, 1986) -- the cost of explicit communication (e.g., workload and time required) should be compared with the cost of adaptation errors (i.e., misses and false alarms).
- The extent to which users can be appropriate agents of adaptation may depend on their models of the functioning of the aid and themselves (Lehner, et al., 1987; Morris and Rouse, 1986; Morris, Rouse, and Ward, 1985) -- adaptation *of* the user (e.g., via embedded training) is a viable approach for providing such models.
- A variety of specific human factors principles for design of complex information systems appear to apply to the design of the displays and controls associated with adaptive aiding -- see the list provided by Noah and Halpin (1986).

The design questions discussed in this section, as well as the tentative and incomplete list of principles of adaptation and interaction, illustrate the maturity of the concept of adaptive aiding. A variety of researchers have invested substantial efforts in the area, and as a result, the concept has moved substantially beyond the ad hoc status of much decision-aiding technology. Nevertheless, there is a surprising paucity of data upon which to base firm conclusions. Much of what has been outlined and suggested in this section merits efforts aimed at replication and generalization of results and interpretations.

Aiding Scenarios

Using the framework discussed in the previous section as a starting point, we began to investigate designers' decision making processes. In order to replicate the design environment as closely as possible, we provided the designers with typical aiding design context: the target system functional scenario. Functional scenarios are often a major source of information for top-level designers, and are used by designers to determine how specific aiding functions will be realized in the target system.

The task to be addressed utilized a mission scenario for a 2000+ fighter aircraft involved in a beyond-visual-range attack engagement. This seven-page scenario was decomposed into 42 scenario events, each characterized as shown in Figure 1. The four elements of the event descriptions are shown in Figure 1 and described below.

sa: Information seeking

|CROWN provides as much targeting information as possible as the two forces close to about 150 miles. This information is transmitted to the Blue Flight's aircraft fire control systems via secure link where it appears on each aircraft's tactical situation display.

6.0 Intercept
6.33 Correlate external data with on-board data/information
6.42 Perform target acquisition
6.43 Perform target ID
6.44 Assess raid
6.45 Determine target assignments
6.46 Determine preliminary targeting

6.15 Maintain formation/mutual support

Figure 1. Scenario Event Example

First, the general user-system task is shown. In this case, the task was judged to be situation assessment ((SA): information seeking). Events were characterized in this manner using Rouse's task taxonomy. This taxonomy (Figure 2) has been found to be useful in a variety of efforts involving design of aiding systems for command and control, nuclear power, manufacturing, and design information systems (Rouse, 1986, 1991). For the purposes of this study, only the main four categories were employed:

- Execution and monitoring,
- Situation assessment: information seeking,
- Situation assessment: explanation, and
- Planning and commitment.

Execution and Monitoring
1. Implementation of Plan
2. Observation of Consequences
3. Evaluation of Deviations from Expectations
4. Selection Between Acceptance and Rejection

Situation Assessment: Information Seeking
5. Generation/Identification of Alternative Information Sources
6. Evaluation of Alternative Information Sources
7. Selection Among Alternative Information Sources

Situation Assessment: Explanation
8. Generation of Alternative Explanations
9. Evaluation of Alternative Explanations
10. Selection Among Alternative Explanations

Planning and Commitment
11. Generation of Alternative Courses of Action
12. Evaluation of Alternative Courses of Action
13. Selection Among Alternative Courses of Action

Figure 2. Taxonomy of User-System Tasks

Each of the 42 scenario events were classified by two independent analysts into one of these categories. The small percentage of disagreements were resolved by discussing the elements of the event in question and reaching a consensus on its classification.

The second element of Figure 1 is a prose description of the event. This information provides context, as well as mission-related links to the rest of the scenario. This context is critical to designers being able to relate to the design task that they were being asked to do.

The third element, shown within a single box, describes the foreground tasks for which aiding might be specified. This information is characterized using Cohen's taxonomy for advanced aircraft operations (Cohen, 1990). This characterization assured that all designers were given the same task requirements.

The fourth and final element of Figure 1, shown within a double box, describes the background tasks that must be performed despite the emergence of new foreground demands. The distinction between foreground and background tasks provides designers with the possibility of aiding new demands and/or ongoing demands. This distinction is important because new demands can be satisfied by either aiding these demands, or by aiding other tasks, thereby freeing the operator to address the new demands.

The complete description of all 42 scenario events, as well as the decomposition process used to classify and characterize events, is provided in Appendix A. The appendix also describes in much more detail, the experiment, data analysis, and results presented in the remainder of this paper.

Specification of Aiding

For each of the 42 scenario events, designers were asked to respond to the multiple choice questions shown in Figure 3. For the "motivation" category, designers were asked to rank order the four alternatives from most important reason for aiding to least important.

Motivation for Specifying Adaptive Aiding

- Estimated performance degradation without aiding
- Projected workload in the scenario event
- Tactical significance of scenario event
- Projected implementation practicality

Tasks to be Aided

- Foreground
- Background

Type of Adaptive Aiding

- Allocation
- Partitioning
- Transformation
- None

Method of Aid Invocation

- Unacceptable system performance
- Number of concurrent operator tasks
- Operator resource allocation estimate
- Nature of task (Fitts' list reference)
- Other (e.g., operator requests aiding)

Operator-Aid Communication Requirements

- Procedural
- Product
- Process

Figure 3. Specification Categories

Designers could respond to the "tasks to be aided" category by specifying neither, either, or both foreground and background tasks. As noted earlier, the choice here concerns aiding new demands or aiding existing demands to enable reallocation of attention to new demands. If designers specified both foreground and background tasks, then two specification sheets were filled out for the event, one for foreground and one for background tasks.

The "type of adaptive aiding" category in Figure 3 included four possible responses -- three types of aiding and a fourth choice of no aiding at all. These three types of aiding are those postulated in the adaptive aiding design framework (Rouse, 1988).

For allocation, the aiding system assigns task execution activities to itself. Operator coordination of task performance is not necessary. While the operator must be notified of allocation recommendations/decisions, once the aid is activated, it carries execution to completion unless operator decides to resume task performance.

With partitioning, operator and aid "share" task execution. In most cases, the aid will indicate what it can do (e.g., target designation) while the operator retains remaining portions of tasks (e.g., target identification). Aspects of the task (sub-tasks) are shifted between agents. Partitioning of tasks requires that operator and aid share information to coordinate task performance.

Transformation involves modifying a (possibly increasingly) difficult task to mitigate task demands. For example, an operator engaged in a demanding flight control task in conjunction with a difficult situation assessment task (e.g., due to subsystem failure) might be aided by transforming flight control displays to allow a simpler mode of tracking. Conceptually, the requirements for performing the task are changed by the aiding, but the pilot remains involved with the task.

The "method of aid invocation" category in Figure 3 relates to the intervention "threshold" used to activate aiding. The alternative responses in this category are reasonably self explanatory, with the possible exception of the reference to Fitts' list. This refers to the classic "men are better at/machines are better at" lists that Fitts originated (Fitts, 1951). Several alternative lists of this type are currently available.

The final category in Figure 3, "operator-aid communication requirements," refers to the types of information that operator and aid can share. The three types of information include:

- Procedural information - A primary type of aid status information. Refers to information pertaining to when to use the aid, or for determining intervention thresholds (Morris, Rouse, and Ward, 1985).
- Process information - A primary type of aid status information. Refers to functional information about the aid; information about the process by which the aid accomplishes its tasks. This information may allow the operator to determine the applicability of the aid to the current situation (Morris, Rouse, and Ward, 1985).
- Product information - A primary type of aid status information. Refers to information about normal aiding system output that allows the operator to determine whether the system is functioning properly (Morris, Rouse, and Ward, 1985).

Subjects were asked to respond to this category by rating (0-10) the relative amount of information needed of each type. These three types of information were chosen based on an analysis of information requirements for adaptive aiding (Morris, Rouse, & Ward, 1985). The results of this analysis indicated that human interaction with adaptive aiding systems is likely to be substantially affected by the extent to which procedural, product, and process information is available.

Decision Making Attributes

In addition to specifying adaptive aiding using the categories in Figure 3, subjects were asked to rate (0-10) the twelve attributes listed in Figure 4. The purpose of these ratings was to assess the characteristics of the aiding situation that appeared to relate to specification decisions. Attribute ratings were performed for each scenario event subsequent to completion of the aiding specification sheet for that event. Subjects were asked to rate the importance of each attribute to the eventual success of the specified aid (0 = not at all, 10 = critical).

The twelve attributes in Figure 4 were defined as follows:

1. *Anticipated Aiding Intervention Criterion* - One of the principle design questions that the designer must face is whether or not to aid the operator. Success of the aiding system will greatly depend on what criterion is used in answering: "Under what circumstances should the aid intervene?" There are several criteria upon which aid intervention can be based (e.g., unacceptable operator performance, number of concurrent tasks, operator errors). The criterion must be considered in the context of aiding. Within this context, the designer must also consider the anticipated knowledge representation of the supporting architecture.

2. *Tradeoffs between cost of communication with the operator about error vs. aiding* - In specifying aiding to assist the operator, for example, when he commits critical (i.e., life threatening) errors, the designer should consider several factors (e.g., time pressure, severity of error, intervention criterion, etc.) in deciding whether to communicate with the operator about an error or immediately activate aiding to compensate for the error.

3. *Anticipated difficulty of implementing the aid* - Deciding whether or not to aid the operator is often influenced by how difficult the implementation of such a system may be. Additionally, the type of aiding and interaction with the operator will be affected by this consideration. This attribute should be considered in terms of the level of aid functionality and level of technology embedded in the aiding system.

4. *Anticipated reliability of aid behavior in normal vs. novel situations* - An aiding system is only as effective as designed. In this context, reliability is defined as the expected, repeatable performance of the aid, not mean time between failures of the aid. The behavioral science definition for reliability is used here instead of the engineering definition. We are more concerned with the expected vs. actual behavior of the aid in novel error situations. In other words, can the operator rely on the aid's functionality in novel situations?

5. *Necessary types and level of detail of operator-aid communication* - In order to facilitate e'fective coordination between the aid and the operator, the aid must communicate useful information to the operator. The operator can receive information about what the aid is doing (procedural), what the aid's outputs are (product), or how the aid is executing the task (process). The designer should consider what information requirements the operator will have about the aid and the necessary detail of that information.

1.	Anticipated aiding intervention criterion
2.	Tradeoffs between costs of communicating with operator about error vs. aiding
3.	Anticipated difficulty of implementing the aid
4.	Anticipated reliability of aid behavior in normal vs. novel situations
5.	Necessary types and level of detail of operator-aid communication
6.	Overall risk (from design perspective) of aiding this event
7.	Anticipated ease of aiding introduction and removal
8.	Suspected user attitude towards aiding
9.	Essential information requirements for effective aiding
10.	Necessary level of aid tailorability
11.	Availability of technology to support aiding implementation
12.	Number and applicability of interface/aiding models available

Figure 4. Decision Making Attributes

6. *Overall risk (from design perspective) of aiding an event* - The overall risk rating is of paramount importance to the specification of an adaptive aiding system. Risk is defined as what the designer is willing to trade off for potentially high functionality. For example, specifying an aid that will intervene in critical error situations and save the operator's life, albeit through unpredictable behavior, may be worth the interaction risk.

7. *Anticipated ease of aiding introduction and removal* - The designer must consider the ease with which aiding can be introduced into the task environment. For example, will the operator perceive a lack of "cognitive unity" when a task transformation is introduced? It is also important that the negative cognitive and perceptual effects of removal of adaptive aiding be minimized. In this case, the designer must consider the costs of removal of aiding vs. the benefits of allowing the aid to execute a task to completion.

8. *Suspected user attitude towards aiding* - Some types of aiding are more acceptable to a user population than others. If the designer is specifying a risky adaptive aiding system from the *operator's* point of view, for example, the designer should consider whether the operator

will want to use it. The operator must be (or become) comfortable with an aiding system before he will use it.

9. *Essential information requirements for effective aiding* - The information requirements, necessary to facilitate the aiding process, are important considerations in specifying aiding. Information requirements for the operator about the aid, as well as information for the aid about the operator, will determine how and what will be aided in the system.

10. *Necessary level of aid tailorability* - How much of the aid's behavior can (and should) be tailored based on individual differences and/or population differences? This attribute affects aiding intervention thresholds (e.g., "What is the *value* that determines unacceptable performance for this operator?", etc.). In addition, this could pertain to the level of communication between the operator and aid within a particular task context).

11. *Available technology to support aiding implementation* - Even though we are analyzing scenarios for future aircraft, the designer must consider what role technology push and/or pull will play in implementing some adaptive aiding systems. Consider the range to be from none (all technology must be developed to support this design) to all technology available now "off-the-shelf."

12. *Number and applicability of interface/aiding models available* - Tools, task models, simulations, etc. allow the designer to gain insight into the process that he wishes to aid. In addition, embeddable models may facilitate better interaction and aid functionality. When specifying the aiding system, consider the number of available models, their applicability, and anticipated success of using such models.

The above definitions were provided to subjects prior to beginning the aiding specification process and were available for reference throughout the experiment.

The analysis whereby the above attributes were identified is presented in Appendix B of this report. Basically, this analysis process involved reviewing a wide range of attributes used by previous researchers and practitioners. The union of all sets of attributes was taken to form an initial set. Attributes were then clustered in terms of common orientation and purpose. Redundant attributes within clusters were then pruned and a consistent set of definitions chosen.

Method

Five subjects participated in this experiment. Three worked as individuals and two worked as a team. The team included an adaptive aiding system designer and a former U.S. Air Force pilot. The reason for the team was to enable participation in this experiment of an individual with substantial operational experience.

The four adaptive aiding analysts were all very familiar with the concept of adaptive aiding and the design framework discussed earlier. Experience with adaptive aiding ranged from 1 to 15 years, with an average of 7 years.

Procedure

Each subject, or team, performed independently in separate rooms. The experiment was completed in one day, averaging 5.5 hours per subject or team.

There were three segments to the experiment, run in serial order:

1. *Familiarization with Context* - In the first segment, subjects were asked to read the textual, narrative mission scenario. Subjects were requested to take note of significant mission events, since the mission decomposition was not provided in the familiarization run. Note taking was encouraged to facilitate understanding of the event sequences in the text.
2. *Specification of Adaptive Aiding* - Once subjects had read the scenario and understood the context, the specification process was begun. Subjects were given a segmented copy of the scenario just read. Each of the 42 segments were similar in format to Figure 1. Subjects were asked to specify adaptive aiding using specification sheets that followed the format in Figure 3.
3. *Rating Decision Making Attributes* - Using the decision making attributes listed in Figure 4, subjects rated the importance of these attributes to the types of aiding specified for each scenario event.

In summary, subjects familiarized themselves with the context at the outset, and then produced 42 sets of specifications and ratings, one set per scenario event.

RESULTS

Basic Summary Statistics

Subjects' specifications over all 42 scenario events were compiled and summary statistics calculated. The summary specification statistics are depicted in Figure 5. This segment of the analysis focuses on the most frequent responses by each subject. The response categories of primary interest were (abbreviation in parentheses):

- Motivation for aiding (Motive),
- Tasks to be aided (Tasks),
- Type of aiding (Type),
- Method of aid invocation (Invocation), and
- Communication requirements (Communication).

Results showed that two of the subjects (1 and 2) based their adaptive aiding specifications primarily on operator-related factors (i.e., workload increase as a result of task demands, performance degradation due to increased task demands, and explicit user request for aiding), while subjects 3 and 4 considered primarily task-related factors (i.e., implementation practicality of aiding, tactical significance of aiding, allocation of task execution based on the nature of the tasks to be conducted). These results suggest that subjects 1 and 2 were "human activity centered," while subjects 3 and 4 were "task requirements centered." In other words, the former were more concerned with the operator's requirements necessary for satisfying the task objectives, while the latter were more apt to consider the nature of the task to be completed according to mission requirements.

Subject	Motivation	Tasks	Type	Invocation	Communication
1	Projected Workload 31% (13/42) Perform. Degradation 26% (11/42)	Foreground 76% (32/42) Background 19% (8/42)	Allocation 62% (26/42) Partitioning 31% (13/42) Transformation 2% (1/42) None 5% (2/42)	Projected Resources 36% (15/42) User Requested 21% (9/42)	Procedural 6.1 Product 8.4 Process 2.8
2	Perform. Degradation 34% (14/42) Projected Workload 12% (5/42)	Foreground 36% (15/42) Background 21% (9/42)	Allocation 29% (12/42) Partitioning 26% (11/42) Transformation 2% (1/42) None 43% (18/42)	Unacceptable Perform. 30% (13/42) User Requested 21% (9/42)	Procedural 6.0 Product 7.8 Process 2.0
3	Impl. Practicality 38% (16/42) Perform. Degradation 36% (15/42)	Foreground 83% (35/42) Background 7% (3/42)	Allocation 33% (14/42) Partitioning 40% (17/42) Transformation 12% (5/42) None 14% (6/42)	Fitt's Lists 57% (24/42) User Preauthorization 21% (9/42)	Procedural 9.1 Product 10.0 Process 8.0
4	Tactical Significance 36% (15/42) Impl. Practicality 21% (9/42)	Foreground 69% (29/42) Background 0% (0/42)	Allocation 45% (19/42) Partitioning 29% (12/42) Transformation 0% (0/42) None 26% (11/42)	Fitt's Lists 43% (18/42) Projected Resources 14% (6/42)	Procedural 1.2 Product 8.8 Process 1.4

Note: Since no aiding (i.e., "none") is a choice, some of the numbers may not sum to 42.

Figure 5. Summary of Subjects' Responses

It is interesting to note that the dichotomy of human activity centered vs. task requirements centered does not hold if the type of aiding chosen is considered. As shown in Figure 5, subjects 1 and 2 bracket subjects 3 and 4 in terms of type of aiding chosen, e.g., subject 1 chose "none" the least (5%) while subject 2 chose "none" the most (43%). Thus, the dichotomy relates more to why aiding is specified rather than what aiding is specified. This difference is further discussed in later consideration of variations in designers' belief structures or aiding philosophies.

The communication column in Figure 5 also illustrates interesting contrasts. The average ratings for all subjects were high for product information, i.e., what the aid's outputs are. All but one subject (no. 3) gave low average ratings to process information, i.e., how the aid functions. For procedural information, i.e., what the aid is doing, subjects 1 and 2 both gave moderate average ratings, while subjects 3 and 4 were at opposite extremes. Thus, in the communication category, subjects 1 and 2 were, again, very similar in all three average ratings. However, subjects 3 and 4 were only similar for one of three average ratings.

Discriminant Analyses

Discriminant analyses were performed to determine the extent to which the type of adaptive aiding specified was related to responses in the other specification categories in Figure 3. This approach was taken because subjects' choices were from categories rather than continuous response variables.

A discriminant model was constructed for each subject, or team, using the four response categories for type of aiding as the dependent variable. There were six independent variables, including the responses to the motive, tasks, and invocation categories and the ratings of requirements for procedural, product, and process information. Canonical coefficients for the resulting discriminant functions were computed, which enabled ranking coefficients, in terms of absolute values, to determine relative influence.

The results are shown in Figure 6. As indicated by the boxed coefficients in this figure, subjects 1 and 2 are very similar in terms of the factors that are primarily associated with their specification decisions. Subjects 3 and 4 also have a high degree of similarity. These results are consistent with the notions that subjects 1 and 2 were human activity centered, while subjects 3 and 4 were task requirements centered. More specifically, subjects 1 and 2 were similar (as were subjects 3 and 4) in terms of the variables they took into account to make decisions. However, as noted in the discussion of Figure 5, these pairs of subjects did not necessarily reach similar decisions for type of aiding.

Figure 7 indicates the goodness of fit of the discriminant models. Percentage agreement of predicted choices of types of aiding and actual choices was 60%, 81%, 74% and 83% for subjects 1-4, respectively. The average was 75%, which for this type of study is generally viewed to be a good fit.

Clearly, the discriminant models match the allocation decisions better than those for partitioning and transformation. Similarly, the models match partitioning decisions better than those for transformation. These differences are probably due to allocation being a rather crisp decision compared to partitioning and transformation. For example, transformation can include many concepts for modifying a task while allocation includes just one concept -- automation.

	Allocation	Partitioning	Transformation
Subject 1	tasks (1.018) prod (1.015) proced (0.314) R^2 0.886	invoc (0.867) process (0.747) proced (-0.614) product (-0.369) R^2 0.348	motive (0.742) tasks (0.441) proced (-0.401) invoc (-0.383) R^2 0.308
Subject 2	tasks (2.780) proced (-1.228) prod (1.010) process (0.867) invoc (0.556) R^2 0.998	invoc (-0.960) proced (-0.718) tasks (0.551) motive (0.396) R^2 0.874	motive (-1.016) proced (-0.871) tasks (0.657) R^2 0.238
Subject 3	tasks (0.568) invoc (0.527) R^2 0.910	motive (1.103) tasks (-0.762) product (0.395) proced (0.315) R^2 0.661	proced (0.767) invoc (0.588) tasks (-0.546) process (0.534) motive (-0.335) R^2 0.463
Subject 4	tasks (0.730) invoc (0.585) R^2 0.974	proceed (0.798) tasks (-0.563) motive (0.544) process (0.506) R^2 0.594	product (-0.914) invoc (0.569) tasks (0.554) motive (-0.520) R^2 0.0

Note: coefficients <\|.3\| excluded

Figure 6. Discriminant Coefficients and R^2 by Subject

Predicted

Subject 1

		Alloc.	Part.	Trans.	None	TOTAL
Actual	Alloc.	14	10	2	0	26
	Part.	4	8	1	0	13
	Trans.	0	0	1	0	1
	None	0	0	0	2	2
	TOTAL	18	18	4	2	42

Subject 2

		Alloc.	Part.	Trans.	None	TOTAL
Actual	Alloc.	10	2	0	0	12
	Part.	0	5	6	0	11
	Trans.	0	0	1	0	1
	None	0	0	0	18	18
	TOTAL	10	7	7	18	42

Subject 3

		Alloc.	Part.	Trans.	None	TOTAL
Actual	Alloc.	12	2	0	0	14
	Part.	3	10	4	0	17
	Trans.	1	1	3	0	5
	None	0	0	0	6	6
	TOTAL	16	13	7	6	42

Subject 4

		Alloc.	Part.	Trans.	None	TOTAL
Actual	Alloc.	15	4	0	0	19
	Part.	3	9	0	0	12
	Trans.	0	0	0	0	0
	None	0	0	0	11	11
	TOTAL	18	13	0	11	42

Figure 7. Actual vs. Predicted Values - by Aiding Type

Decision Making Attributes

Subjects' ratings of decision making attributes were analyzed in the following way. A mean rating for each attribute was obtained across events for each subject. To assure that attribute ratings were not correlated, the set of ratings for each subject were analyzed via Mann-Whitney pairwise comparisons. All pairwise comparisons for independence proved significant, rejecting the null hypothesis that the ratings were from the same population. The mean ratings were then normalized to facilitate comparison across subjects. The normalized ratings were rank ordered to determine the most influential attributes across specifications.

The top 6 attributes of each subject were selected for comparison. After the sixth attribute, ratings tended to vary more widely. The resulting highly ranked attributes are shown in Figure 8. The rankings across subjects, the right column, were compiled by ordering weighted sums of individual subject's rankings. Due to the limited size of the subject population, no attempt was made to statistically compare rank orderings.

ATTRIBUTE RANKING	SUBJECT				
	1	2	3	4	ALL
1	7	4	11	8	4,11
2	4	3	9	1	
3	11	11	4	11	7
4	8	5	7	4	8
5	1,5	2	5,3,6	7	1
6		1		9	3,9

Figure 8. Decision Attribute Rankings by Subject

Comparing the rankings of subjects 1 and 2 with those of subjects 3 and 4, attributes addressing the anticipated reliability of the aiding and availability of technology to support aiding were the top two concerns for both groups. However, the two subject groups differed on the attribute rankings after the top two attributes. From this perspective, the attribute rankings suggest that there was not as distinct a grouping effect as was earlier indicated.

For example, attributes addressing the ease of introduction of aiding (i.e., how aiding is invoked), possible difficulty of implementing the aiding, operator-aid communication issues, and anticipated user attitude towards aiding (i.e., attributes 7, 3, 5, and 8) completed the ordering for the first group.

The remaining attributes for the second group did not reflect the first group's. For the second group, decision attributes pertaining to user attitude, information requirements, user interaction criterion, and ease of introduction of aiding (i.e., attributes 8, 9, 1, and 7) completed the second group's ordering.

Thus, the two groups were similar except subjects 1 and 2 emphasized implementation difficulty and operator-aid communication while subjects 3 and 4 focused on information requirements and desired aiding intervention criterion. Clearly, the two groups are not as discriminable as they were in earlier analyses. This is likely due to the fact that the types of aiding chosen, and hence the attributes of most importance, did not follow this dichotomy of groups.

Given the number of subjects involved in the study, it is difficult to conclude more than the distinction mentioned in the previous paragraph. This segment of the study shows that the concerns of the designer corresponds closely with the type of aiding desired. A few research questions arise out of this initial decision analysis. Specifically, were the proper decision attributes posed to the designers? Possibly the attributes associated with this process are tacit knowledge for designers, and would therefore be difficult to characterize. Further, are there distinctions between attributes valued based not only on type of aiding chosen, but also on the requisite knowledge brought to the design process by individual designers? A summarization of all results (including the discriminant analysis and the decision attribute analysis) and a possible interpretation of these results are posed in the Discussion section of this paper.

Design Rule Elicitation

In order to gain further insight into subjects' decision making, each subject was debriefed upon completion of the experiment. During this debriefing, subjects were queried about possible design rules that may have surfaced in the course of the specification experiment. At least four "If-Then" design rules were elicited from each subject, some with interesting implications for generating aiding specifications. The topics addressed ranged from the use of specific aiding types under certain conditions to how the nature of operator-aid communication varies with the mission timeline. The complete set of design rules can be found in Appendix C.

Most of the rules were of a general nature (e.g., IF pre-occupying events occur, THEN aid background tasks according to change in performance). Additionally, most of the rules (e.g., IF pre-occupying events occur, THEN aid background tasks according to changes in performance) appeared to apply to the designer's particular approach to aiding design, not to a particular design philosophy. Or stated more clearly, the rules may reflect fundamental principles of aid-operator interaction, and not context dependent implementation rules.

The rules not only provide insight into a subject's design orientation and specification strategy, but may also provide a basis for eventual development of a specification knowledge base to assist designers in specifying adaptive aiding systems. These rules were also used in a post-hoc analysis of belief systems possibly used by subjects during the experiment. The belief systems are discussed in the following section.

DISCUSSION

The data indicate that subjects were highly consistent in their specification decisions. This was particularly for allocation and partitioning, but less so for transformation. There were also substantial differences among individuals, although this was not as pronounced in the analysis of decision making attributes.

Designers' information needs for making specification decisions are demonstrated by the results in Figures 6 and 8 and associated discussions. Designers are clearly interested in information about:

- Relationships among tasks and appropriate types of aiding (Fig. 6),
- Appropriate invocation criteria for different types of aiding (Fig. 6),
- Appropriate motivations for different types of aiding (Fig. 6),
- Anticipated reliability of aid behavior in normal vs. novel situations (Fig. 8), and
- Availability of technology to support aiding implementation (Fig. 8).

Designers appear to be much less interested in information about:

- Tradeoffs between costs of communicating vs. aiding,
- Necessary level of aid tailorability, and
- Number and applicability of interface/aiding models available.

These conclusions would appear to have important implications for the types of research studies whose results designers would value. In particular, from Figure 6 it can be concluded that designers are likely to value data that compare types of aiding and appropriate invocation criteria as a function of types of tasks and the motivation for aiding (e.g., likely performance decrements vs. possibly excessive workload). Further, based on Figure 8 we can conclude that they are concerned that approaches to aiding be sufficiently robust to be supportive in a range of situations and that supporting technology be tested and practical. From this perspective, designers are not likely to value research results that simply show that performance is better with aiding than without it -- they would like to know the specific ranges of conditions where a particular type of aiding is valuable.

These conclusions have important implications for designing adaptive aiding systems and supporting the design process. The summary statistics, results of the discriminant analyses, and the rank orderings of attribute ratings show what information designers choose to use in specifying aiding. These results also show what information they do not use. Clearly, a design support environment should provide what is needed and wanted, and not burden the design process with additional information.

It is also apparent that designers want specific, concrete information that enables decision making. General principles are only useful to the extent that they can be readily translated into context-specific decisions. Thus, for example, "look before you leap" is an acceptable general principle, but "look for a 50% increase in response latency before you automatically invoke aiding" is a more useful design guideline.

As a means of integrating all of the results presented in this paper, the interpretations compiled in Figure 9 are offered. These interpretations represent a qualitative integration of all of the statistical results presented earlier, as well as designers' rules discussed in detail in Appendix C. We speculate that these differences in beliefs underlie the individual differences identified in the results. Further, the fact that subjects do not neatly fit in just one row (i.e., one belief type) of Figure 9 may explain why differences among groups did not consistently emerge. For example, the agreement of subjects 1 and 2 on <u>why</u> aiding is needed, but their disagreement on <u>what</u> aiding is needed may, at least in part, be explained by the interpretations in Figure 9. However, at this point, we offer only the speculation that designers' beliefs or aiding philosophy (explicit or otherwise) is likely to affect their design choices (i.e., specifications) as well as the information that they choose to employ in making these choices.

	Belief Type	Type of Aiding		
		Allocation (A)	Partitioning (P)	Transformation (T)
Task Requirements Centered	I	Let aid execute well-defined task. (S1, S3, S4)	Aid what tasks pilot cannot attend to in complex task. (S2, S4)	Transform difficult manual task. (S3, S4)
Human Activity Centered	II	Only allocate task when operator cannot attend to it. (S2)	Leave ill-defined parts of complex task to human, aid all else. (S1, S3)	Transform difficult situation assessment or planning task. (S1, S2)

Note: Parentheses indicate subjects.

Figure 9. Alternative Belief Structures Influencing Specification Strategies

This speculation quite naturally raises another research issue -- what belief system is appropriate? More specifically, how should designers think about aiding decisions? While the "correct" answer to this question is not clear, it is clear that the answer is likely to affect the types of information sought and, consequently, the types of aiding chosen.

CONCLUSION

An investigation into designers' decision making processes involved in specifying adaptive aiding systems was conducted. A small population of aiding system designers was asked to analyze a scenario involving an advanced tactical aircraft concept for possible adaptive aiding application. Two analyses of the resulting data were conducted which involved identification of most frequent responses for specification categories and also a ranking of the most highly influential decision attributes used during the specification process.

Results indicated a high degree of specification consistency for individual designers, but a great deal of variation among designers. Upon further analysis, it appeared that consideration of the individual's design philosophy (human-activity or task-requirements centered) provided a unifying structure for interpreting all of the data.

Although this was a limited study conducted with a small sample, the results are encouraging. Implications for further studies of designer behavior and also integration of later results into automated tools for design assistance show promise.

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APPENDIX A: COMPLETE DESCRIPTION OF 42 FLIGHT SCENARIO EVENTS

A.1 Adaptive Aiding Flight Scenario Generation

A.1.1 Purpose

Scenario generation is an integral part of the crew systems design process. During the initial requirements and specification stages, the flight scenario serves as both a vehicle for understanding the operational capabilities of the new aircraft and an initial indicator of systems functionality for systems designers to use in formulating detailed design requirements.

Scenarios are generated as part of the initial requirements analysis process. An understanding of the system requirements is gained by the review of documents provided by the sponsoring agency (usually the government branch responsible for managing the overall contract). This leads to the generation of scenarios which reflect system requirements, derivation of functionality, information needs, and control-display requirements for the aircraft.

Two scenarios were generated by Midwest Systems Research for use on this contract. However, only one (i.e., the beyond-visual-range (BVR) scenario) was used as experimental material during this study. In the following sections, the background material used in constructing the scenario events and method used to generate the events are described. The task analysis method used in employing the method is discussed, as well as the enhancements that were added to the events to properly represent the task environment for aiding. The complete event listing for the beyond-visual-range scenario is provided at the end of this appendix.

A.1.2 Source and Method

The scenarios were generated based on the operational expertise of Midwest Systems Research's pilot factors engineers. Two scenarios were generated: an advanced fighter strike mission and an beyond visual range air-to-air attack mission.

The scenario selected for the strike mission paralleled portions of those developed in support for Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) and Low Altitude Night Attack (LANA) systems integration and evaluation work. These systems, in the F-16C/F-15E and A-7, respectively, involved the specifics of systems integration and operation in full and part-task simulation and later, flight test. This detailed work and the more generic GFE scenarios were enough alike in terms of requirements to make them compatible.

The air-to-air mission as described in the GFE documents was similar to those being worked in the Integrated Control and Avionics for Air Superiority (ICAAS) program with which Midwest Systems Research has been associated. The BVR aspects, dealing with target acquisition, prioritization, and reprioritization present a challenge to the systems design community and aircrew members alike. Accordingly, these tasks were selected as likely candidates in need of adaptive aiding technology.

A.2 Scenario Task Analysis for Adaptive Aiding

A.2.1 Introduction

In order to properly specify adaptive aiding within the scenario context, decomposition of the scenario into manageable pieces was necessary. The scenario, as delivered, was written in the third person and consisted of a text narrative describing the specific year 2000+ mission.

First, the scenario was segmented according to decomposable event occurrences in the text. A decomposable event was defined as a significant change in pilot focus, noticeable environmental change requiring pilot input, etc. Next, the scenarios were task analyzed using the *Identification of Advanced Technology Crew Station Decision Points and Information Requirements* report breakdown (Cohen, 1990). This document allowed for a systematic analysis of the events via mission phase and concurrent task representations.

After the first iteration on the scenarios, it became evident that the breakdown was not specific enough for adaptive aiding analysis. It appeared that some important information, both task and operator related, was missing. Recall that the purpose of this analysis was to provide a well structured breakdown of the scenario from which designers could specify opportunities for aiding. Towards this end, three deficiencies were identified:

No indication of attentional focus - Under the resulting task analysis, there were no provisions for the analyst to indicate where the pilot's attention was currently focused. In particular, there were no provisions for documenting when a novel event would (in the analyst's opinion) capture the pilot's attention (e.g., when a high priority situation assessment task would demand pilot input, steering attention away from the currently active tasks, etc.). Since aiding can be of significant value in this type of situation, a notation was necessary to highlight the difference in attention levels related to specific, concurrent tasks.

Missing representation of the novel task - Scenarios were decomposed into specific "events" during the analysis. Events were marked by a novel task occurrence in the environment. There was no notation available to the analyst allowing for a new task (or task type) representation. The task analysis breakdown was available. However, a more general notation was necessary to show task type.

Confusion over which "actor" was executing the task - In the scenario, a certain level of automation is already assumed (recall that the year is "2000+"). A more careful delineation of who was executing a task (either human or computer) was necessary. There were two approaches available: either delineate directly between human and computer or ensure that the general task type unambiguously indicated the actor in each event.

A.2.2 Modified Analysis Method

A modified task analysis method was developed to compensate for the deficiencies. The idea was to produce accurate task breakdowns for aiding analysis without significantly increasing representation complexity. The approach developed consisted of using the task representations of Cohen (1990) and enhancing it with Rouse's general user-system task taxonomy (Rouse, 1991). Further, the task listings were broken out into foreground vs. background tasks allowing the analyst to show where the pilot's attention was currently focused. Finally, events that consisted of both automated and manual tasks were segmented and isolated so that the actor in the event was clear. Each of the modifications is discussed below.

General User-System Task Taxonomy - Rouse (1991) describes three general user-system tasks present in any human-machine system (Figure 1). *Execution* *and monitoring* consists of carrying out an accepted plan of action, monitoring the execution of the plan, and evaluation of the plan's success. *Situation assessment : information seeking* consists of generation and/or identification of information sources, and evaluation and selection of a source to satisfy the seeker's goal. *Situation assessment: explanation* involves these activities as applied to the alternative explanations available for phenomena. Finally, *planning and commitment* focuses on the possible courses of action and possible operator tasks on them.

This taxonomy characterizes the general tasks being undertaken in any scenario event. It allows the analyst to quickly evaluate what type of task is being undertaken and fit the appropriate type of aiding to the event.

Foreground-Background Task Breakdown - Task characterizations were further categorized as either foreground or background tasks. A *foreground* task was defined as that novel task in the event. The pilot's attention was oriented towards the task as a results of its occurrence in the scenario. *Background* tasks, on the other hand, are those tasks that are still critical in the environment, but are currently not the focus of attention (e.g., flight tasks are relegated to background status during a complex situation assessment task, etc.). In the resulting representation, foreground tasks were denoted by a single graphic box around the task listing, background tasks were denoted by a double graphic box around the task listing. No attempt to estimate how long attention would remain shifted was made.

Event Characterization By Actor - There were several methods available for identifying the actor in each event. We chose to decompose the events further based on the actor instead of introducing a new representation for event actor. This approach allowed for finer grained event representation and consistent actor identification without another piece of notation in the analysis.

This enhanced method appears to have increased the amount of information necessary to specify adaptive aiding for the scenario events without increasing representation complexity. It also addresses the identified deficiencies in the base task analysis representation. It facilitates understanding of the event in terms of the adaptive aiding analyst's perspective and will also support automated assistance in analyzing future scenarios. The *Beyond Visual*

Range Attack Scenario was analyzed using this method and used during the specification experiment. The complete scenario event breakdown is presented in the following section.

A.3 BEYOND-VISUAL-RANGE SCENARIO EVENTS

This section contains the complete event description used during this study. All section headings and material are unchanged from the original stimuli used.

INTRODUCTION

This brief Beyond Visual Range (BVR) scenario has been prepared to address some of the issues that will arise in the BVR environment and differ significantly from what we have experienced in the past.

Recent improvements in long range detection and identification techniques, combined with longer range tracking weapons and improved fire control systems, may make BVR combat feasible in future conflicts. Similar advancements by potential adversaries may make it a necessity.

BACKGROUND

From the beginning, virtually all air combat has been conducted in the "within visual range" arena, due in part to weapons limitations, but to a greater extent by the requirement for a visual ID.

In the 1950's-1960's time frame a type of BVR combat was envisioned in Air Defense operations. In this scenario, international tensions, point of origin, route of flight, force size and formation, and other clues were considered adequate to determine intent. Air Defense Command units close to our borders were prepared to launch intercept, and, if necessary, fire on intruders in night and all weather conditions. As it turned out, happily, all of these things never occurred at the same time and the result of most ADC launches from the alert hangers was to identify and monitor the activities of possibly hostile aircraft. If an attack had been made, however, ADC was prepared to conduct BVR operations using a combination of ground based radar stations (netted) and aircraft carrying airborne attack radars to direct air-to-air fighter aircraft to within their own radar range and guided and unguided missiles.

Between Korea and Vietnam there grew the feeling that, with tracking radar and guided missiles, air combat would be done at greater ranges and that the tail chase and shoot 'em were things of the past. Some of these feelings were shelved fairly early in the Vietnam experience when then Col. Fred Blesse, commander of the F-4 wing at DaNang sent a note to the Pentagon - "I need a gun."

In the following paragraphs, we will describe a segment of a generic BVR encounter focusing on some of the things that will be unique to this kind of air combat in terms of pilot decisions and activities from initial detection/identification through the approach to merge where weapons and tactics will revert, essentially, to those experienced today. Topics to be addressed include many of those covered in the NADC draft document, Identification of Advanced Technology Crew Station Decision Points and Information Requirements, January 1990. Special emphasis has been placed on target search/identification, target assignment, reassignment and attack. These functions appear in the document under Combat Air Patrol from 5.0 Assume Cap (pg. 27) 5.1.4 - 5.1.6, 5.4 Preliminary Raid Assessment (pg. 28) 5.4.1 - 5.4.3, 6. Intercept (pg. 29) 6.1.3 - 6.1.7, 6.4, Raid Assessment (Sorting) (pg. 30) 6.4.1 - 6.4.7, to 7.0 Attack (pg. 31) 7.1.3 - 7.1.5 and 7.1.8. Similar functions are called out in the same portions of the Deck Launched Intercept mission.

Before a flight, pilots are briefed in detail on the mission, how it should be flown and what to expect in the line of weather, the threat (air and ground), areas of relative safety, standoff support, location and schedule for air refueling and others. As long as the mission proceeds in accordance with what is expected, the challenge is relatively low. It is when one or more of the mission variables changes significantly that things can get extremely complicated. Several key technologies are being examined to help crewmembers in these situations. Major areas of concern that we have encountered in a number of programs, some of which have involved fairly high fidelity simulation, are:

a. Multiple sensor management/control and interpretation.

b. Use and control of increasingly sophisticated self-protection sensors, controls, and systems.

c. Availability of a wider range of weapons with varying capabilities and applications.

d. Use of increasingly sophisticated command and control systems.

e. All of the above combined to expand the need for crewmember awareness or concern with increasing volumes of information and things to control.

Begin scenario:

Note:

The initial BVR analysis was conducted as follows: Each significant scenario event was broken out and identified as one of the three general user-system tasks (situation assessment, planning and committment, or execution and monitoring) taken from Rouse. Appropriate tasks were then extracted from the "Identification of Advanced Technology Crew Station Decision Points and Information Requirements report by David Cohen and attached to significant scenario events. This listing ensures that the analysts later specifying opportunities for Adaptive Aiding are working from the same set of operator tasks in each event.

User-system task type headings are abbreviated as:

sa: Situation Assessment
  Subtasks:
    Information seeking
    Explanation
pc: Planning and Committment
  Subtasks:
    troubleshooting
em: Execution and Monitoring.

Foreground tasks are enclosed in single line boxes. Background tasks are enclosed in double line boxes. New background task boxes will only be present when there is significant change in the task's status.

Combat Air Patrol (CAP)

In this scenario, Blue Flight of four fighters has launched on a mission to proceed to a preplanned CAP orbit under the control of CROWN, a standoff Airborne Command, Control and Communications (ABCCC) type of platform. In this case, the Command, Control, Communication and Identification (C^3I) environment could include the ABCCC, JTIDS, perhaps SATCOM or a combination of all of them. In any case, there is external support that will aid in target and threat detection plus identification. This support will also provide at least initial target assignments at the flight level as the flight develops. All communications between CROWN and Blue Flight will be via the secure net except in a bona-fide emergency.

Assumed automated:

5.0 Assume CAP
5.1.2 Select pilot relief mode
5.1.7 Activate mission recorder system
5.1.8 Determine frequency of visual search
5.6.4 Set EMCON

5.1.1 Control Aircraft
5.1.3 Monitor systems status
5.1.5 Set Formation
5.5.1 Monitor position
5.5.2 Monitor course
5.5.3 Monitor speed
5.5.4 Monitor altitude
5.5.9 Perform nav system update

1. sa:

|Enroute to the orbit, Blue Flight receives targeting information from CROWN.

5.6.5 Perform SATCOM

2. sa:
|A group (two formations of four), of probably hostile aircraft, are approaching from the northeast at a range of approximately 200 NM.

5.3 Coordinated sensor activities
5.3.2 Correlate on-board data/information
5.3.3 Correlate external data with on-board data/information

3. sa: Information seeking and explanation

|Positive identification is not available yet, but their speed (in excess of Mach 1) indicates fighters possibly configured for air-to-air combat. There is no correlation with known friendly forces and their present course indicates that they could have been launched to disrupt the CV Task Force air defenses in preparation for a direct attack on the CV Task Force itself.

5.2 Response to threat
5.2.2 Determine threat degree
5.2.3 Determine Imminence of threat
5.3.4 Interpret sensor data/information
5.4 Preliminary raid assessment
5.4.1 Perform target search/detection
5.4.2 Perform target acquisition
5.4.3 Perform target ID/classification
5.6.5 Perform SATCOM

4. sa: Information seeking

|CROWN provides as much targeting information as possible as the two forces close to about 150 miles. This information is transmitted to the Blue Flight's aircraft fire control systems via secure link where it appears on each aircraft's tactical situation display.

6.0 Intercept
6.3.3 Correlate external data with on-board data/information
6.4.2 Perform target acquisition
6.4.3 Perform target ID
6.4.4 Assess raid
6.4.5 Determine target assignments
6.4.6 Determine preliminary targeting

6.1.5 Maintain formation/mutual support

5. em:

|As this is being done, the members of Blue Flight activate and verify the operation of their threat warning and self-protection systems and check their weapons readiness status.

6.1.4 Monitor weapons status 6.2.1 Monitor threat detection systems

6. em:

|So as not to advertise their presence, Blue Flight has been operating in a very quiet mode limiting emissions to only those required for intra-flight coordination.

(this event is obviously out of order) 5.0 Assume CAP 5.6 Communicate 5.6.4 Set EMCON

7. pc: troubleshooting

|Blue Lead becomes a little concerned that this mode of operations may have to be abandoned soon. He must validate/coordinate CROWN's inputs for the rare case that CROWN cannot provide final verification of target type and precise position and altitude.

6.1.7 Analyze tactical situation 6.2 Response to threat 6.2.3 Determine imminence of threat 6.3.2 Correlate on-board data/information 6.3.3 Correlate external data with on-board data/information

8. em:

|While there are intermittent threat warnings during this period of time, none are of a persistent nature, so Blue Flight continues with its self-protection systems in the semi-automatic mode. (Armed in an automatic mode, the system might unleash its fury on a chance, and only temporary, lock-on. This reaction would announce the presence of Blue Flight to everyone.)

6.2.1 Monitor threat detection systems

9. pc:

|Blue Lead's concern increases as no activity is indicated from his IR sensors and there are no indications that his wingmen have detected any either. Without specific altitude information from CROWN, this could indicate the the closing flight is at a lower altitude than anticipated, and could be sacrificing altitude for the protection afforded by moisture in high cirrus clouds. While the new IR equipment is much better than that used in the 1990's, it still succumbs to the basic laws of physics and the bad guys know this.

6.1.7 Analyze tactical situation

6.5.5 Adjust flight plan, as needed

As the approaching groups close to within approximately 100 miles of each other, CROWN's information begins to improve.

10. sa: Information seeking

|Blue Flight receives good flight information on the approaching aircraft.

5.6.5 Perform SATCOM 6.3.3 Correlate external data with on-board data/information 6.4.4 Assess raid

11. em:

|The tactical situation display indicates their altitude to be at FL 350, approximately 100 NM in front of him, crossing his flight path at an angle.

6.3.4 Interpret sensor data/information 6.4 Raid assessment (sorting) 6.4.1 Perform target search/detection 6.4.2 Perform target acquisition

12. pc:

Preliminary target assignments are made; Blue Lead and Two will take on the lead element (one the left) - Three and Four will engage the (slightly trailing) flight on the right.

6.4.5 Determine target assignments 6.4.6 Determine preliminary targeting

13. sa: explanation

|The aircraft type is confirmed as enemy

6.2.2 Determine threat degree 6.4.3 Perform target identification/classification

14. pc:

|- Cleared to Fire!

7.0 Attack • 7.1.1 Control aircraft (now in foreground) 7.2 Response to threat 7.2.5 Determine to avoid or suppress 7.4 Final targeting 7.4.5 Obtain clearance to fire

15. em:

|As Blue Lead selects an expanded image mode on his tactical display,

7.3.1 Operate sensors

16. em:

|signals arm up,

6.6.2 Communicate secure voice

17. em:

|and initiates first target designation,

7.4.3 Comply with targeting assignments

18. em:

|the threat warning system signals search, lock on and then track.

7.2.2 Monitor threat detection systems 7.2.4 Determine imminence of threat

The two hostile flights have gone fully active.

19. sa: explanation

|All evidence points to the fact that the enemy is fully aware of their presence and intent.

7.3.4 Interpret sensor data/information

20. em:

|Blue Lead quickly selects auto on his self-protection systems,

7.2.6 Perform threat response

21. em:

|switches his radar out of stand-by to a multitarget search and track mode,

7.3.1 Operate sensors

22. sa: explanation

|and quickly confirms correlations between CROWN and his on-board sensor data -- they agree.

7.3.3 Correlate external data with on-board data/information 7.3.4 Interpret sensor data/information

23. pc:

|With only seconds to a maximum range firing solution, the opposing force starts a turn to convert their angle-off heading to head on.

7.1.5 Analyze tactical situation 7.1.8 Analyze disengagement criteria

7.7.5 Adjust flight plan, as needed

24. sa:

|The hostile trailing group of four aircraft crosses behind the lead group and the two groups begin to separate slightly. This tactic was developed in the mid-nineties when it was discovered that target assignment (or reassignment) and some prioritization was accomplished manually by the Flight leaders. This caused confusion and required valuable time to accomplish, allowing the hostile forces extra time to penetrate into our defenses, maneuver into better positions and, sometimes, launch their weapons.

7.3.4 Interpret sensor data/information

25. sa: explanation

|As the two hostile groups begin to separate, two more groups of four images appear on Blue Flight's tactical displays. These two additional groups of hostile targets appear to be clustered near to the original two groups but are slightly faster and off to the side.

7.1.5 Analyze tactical situation 7.3.4 Interpret sensor data/information

26. em:

|To confirm target acquisition Blue Lead activates his decoy detection device to confirm the new target signatures (radar, IR, Laser, etc.).

7.3.1 Operate sensors

27. sa: explanation

|Eight of the sixteen hostile targets disappear from the screen. Blue Lead confirms his eight hostile target aircraft are the same as those identified by CROWN. - They are.

7.3.3 Correlate external data with on-board data/information 7.3.4 Interpret sensor data/information

28. pc: by computer

|Blue Flight's mission computers detect this evasive decoy tactic and automatically re-prioritize the targets.

Assumed automated

29. em:

|Blue Lead and Two are assigned the port group of aircraft, while Blue Three and Four are assigned the starboard group of four.

7.4.1 Determine dynamic geometry maneuvers required 7.4.3 Comply with targeting assignments

30. em:

The hostile group of four, assigned to Blue Leader and Two, are just inside the lethal range of their advanced long range air-to-air missiles (ALRAAM) and still outside the hostile group's long range missiles.

7.3.4 Interpret sensor data/information 7.4.4 Select weaponry

31. em:

|Blue Leader launches two ALRAAMs, followed almost instantly by Blue Two's launch of two.

7.5 Weapon delivery 7.5.1 Select weapon/weapon mode 7.5.2 Committ weapons

32. em:
|Blue Lead notes a warning that one of his missiles has malfunctioned.

7.1.4 Monitor weapons status

33. sa: explanation

|Further checks reveal that it never left the launcher and the Fire Control Computer has switched to Medium Range Missiles and associated firing modes and displays.

7.1.4 Monitor weapons status 7.1.5 Analyze tactical situation 7.5.1 Select weapon/weapon mode

34. em: by FCC

|The three ALRAAMs are guided by CROWN's signals until midway to the target when they take over their own active guidance to their assigned targets. Each of the three missiles are assigned to three hostile targets.

7.5.4 Provide weapon steering data/illumination

35.em:

|Blue Three and Blue Four have also launched four ALRAAMs against their respective group of four hostile aircraft.

7.1.3 Maintain mutual support, as required

36. em:

|The situation Display in Blue Leader's aircraft signals the "kill" of three of the four hostile aircraft in his assigned port group with no signs of hostile missiles in flight.

7.6 Damage assessment 7.6.1 Determine target damage

37. pc:

A backup missile must be used. At this point, Blue Leader and number Two are approaching the range of their Advancad Median Range Air-to-Air Missile (AMRAAM) and

7.6.2 Assess reattack options

38. sa: explanation, then **pc:**

|Blue Leader detects the sole survivor of the hostile group is in a hard Starboard break.
|He is attempting to disengage.

7.1.5 Analyze tactical situation 7.2.5 Determine to avoid or suppress

39. em:

|Blue Leader allows for his automatic weapon selection to select and arm one of his AMRAAMs. As the single hostile fighter sweeps through Blue Leader's launch range in his turn to run,

7.2.6 Perform threat response

40. em:

|Blue Leader launches his AMRAAM. This missile guides and tracks to the kill.

7.6.3 Execute reattack, as required 7.5.2 Committ weapons

41. em:

|The Blue Three and Four missile launches against their starboard group of four hostile fighters were successful on their first launch.

6.6.3 Perform D/L comm w/friendlies 7.6 Damage assessment 7.6.1 Determine target damage

42. pc: CROWN provides plan, Blue committs

|CROWN confirms the "kills" and provides vectors to a tanker orbit in the vicinity of the Task Force. Blue Flight's remaining missiles will be held in reserve pending the outcome of an intercept in progress, on a flight of suspected attack aircraft approaching the CTF from the east.

6.6.5 Perform SATCOM 6.3.4 Interpret sensor data/information

6.1.6 Monitor systems status 6.1.8 Monitor fuel status

end of scenario.

The requirement for high levels of sophistication (automation) and decision-making can vary greatly from mission to mission. At the beginning, there are normally Rules of Engagement (ROE) that arrive from on high, to which units and crewmembers are expected to adhere. Tactics are developed around those rules and tactics (and capabilities) expected to be employed by the enemy.

Note: Some of the data correlation exercises may be background tasks.

APPENDIX B: DECISION MAKING ATTRIBUTE CHARACTERIZATION

B.1 Purpose for Decision Making Characterization

Although the framework for aiding specification addressed the general issues to be considered during aiding specification (see pg. 7, body of report), it made no provisions for considering the designer's decision making model used in during the process. A decision model is obviously used in specifying any complex system. Currently, the system designer conducts the decision making process in his/her head while specifying intended functionality.

A goal of this investigation was to determine what types of information are valued by the designer. Through this process we could identify the decision process and define methods and tools for aiding the designer.

To understand the process of design decision making, we began formulation of a decision making model of designers engaged in an aiding specification exercise. Most of the modeling effort consisted of identifying the decision attributes that would comprise the model. In the following sections, the process used, sources of decision attributes, and model development are discussed. The final set of attributes were evaluated during the investigation.

B.2 Sources of Decision Making Attributes

While analyzing adaptive aiding specification parameters, it became obvious that we cannot expect to aid the design process without understanding the decision space in which these specifications are made. In order to bound the space of possible decision attributes, only those concerned with the three primary aiding design decisions were initially considered:

1) type of aiding to be employed,
2) whether aiding was appropriate for this application,
3) intended operator-aid interaction characteristics.

A large initial number of attributes (28), were compiled. This listing was compiled from numerous adaptive aiding references (Primary references: Rouse, 1988; Rouse, Geddes, and Curry, 1986; Revesman and Greenstein, 1986; Noah and Halpin, 1986; Morris, Rouse, and Ward, 1985b; Andes, 1990; Andes, 1987).

In addition to those found in the literature, a few were generated to cover obvious voids in the literature base. The generated set of attributes was large and unwieldy; some of the attributes were taken from the specification framework; some not well documented. Most of the attributes were not easily parameterized, and further, some of the attributes appeared to be confounded with others. The complete listing of compiled attributes is given below.

1. Accuracy of result / performance required

In most system applications, the accuracy of the result of aiding, or minimal aid performance required is of paramount importance in the decision of whether to specify adaptive aiding or not.

2. Acceptability of achievable aid performance

Although several of the attributes have bearing on this attribute (e.g., technology available, accuracy of result, etc.), the acceptability of aid performance (from the designer's perspective) affects the decision to specify adaptive aiding.

3. Desired intervention criterion

There are several intervention criterion upon which aid intervention is based (e.g., unacceptable operator performance, number of concurrent tasks, operator errors). The desired criterion must be considered in the context of desired aiding.

4. Ease of aiding introduction

The designer must consider the ease with which aiding can be introduced into the task environment. For example, will the operator perceive cognitive disunity (i.e., "Is this a new task, or an alteration of the previous task?") when a task transformation is introduced?

5. Ease of aiding removal

It is also important that the negative cognitive and perceptual effects of removal of adaptive aiding be minimized. In this respect, the designer must consider the costs of removal vs. the benefits of allowing the aid to execute a task to completion (if discrete).

6. Technology available to support aiding

The designer must consider what role technology push/pull will play in implementing adaptive aiding systems.

7. Preconfigurability of aiding

Some adaptive aiding subsystems may have to be preconfigured based on the particular mission context. Alternatively, it may be impossible to preconfigure some functional aspects of the aid, specifically when an error situation arises.

8. Task environment effects on aiding

Based on research, task recency effects (i.e., the task just completed affects operator performance on the current task) must be considered. In these situations, the designer must plan for a change in the operator ROCs (response operating characteristics).

9. Accountability

The designer must consider to what level the system will be accountable for its actions and to what degree the adaptive aiding system designer will be responsible for aid behavior.

10. Levels of user discretion available within aiding system

The amount of user discretion can be understood as parameterization of functionality, verbosity and type of feedback about aid activity, etc.

11. Granularity of user control over aiding

The amount that aiding parameters can be adjusted, not just distinct levels (i.e., continuous adjustmen rather than the 3 levels of adaptive aiding).

12. Cost of communication vs. cost of aiding operator errors

The designer must consider this tradeoff in specifying the aid/operator communication interface.

13. Training vs. aiding decisions

This attribute refers to the utility tradeoff of when to train the operator vs. when to provide adaptive aiding on these tasks. Can be economically, technologically, or psychologically motivated, to name a few.

14. Validity of aiding

How valid is adaptive aiding technology within this task context?

15. Reliability of aiding

How reliable can we expect the adaptive aiding to be within this task context?

16. Viability of aiding

Is adaptive aiding viable within this task context? Can another type of aiding or system redesign solve the problem?

17. Desirability of aiding

Is adaptive aiding the desired solution within this task context? Further, how is this attribute value changed based on the perspective (e.g., designer vs. user of system).

18. Predictability of aiding

In order to foster user acceptance of the system and specify the aiding system, the designer must have some reasonable level of confidence in the adaptive aiding system's behavior.

19. Anticipated difficulty of aid implementation

This attribute can be used in the go/no go aiding specification by the designer. In addition, the attribute can be considered in terms of the level of aid functionality and level of technology embedded.

20. User attitude towards particular aiding

Some types of aiding are more acceptable to a user population than others. If the designer is specifying a risky adaptive aiding system from the user's point of view after considering this attribute, there probably is a valid, defendable reason.

21. Number/applicability of HCI/aiding models

Tools, task models, simulations, etc. allow the designer to gain insight into the process that he wishes to aid. In addition, embeddable models may facilitate better interaction and aid functionality.

22. Psychological comfort of aid presence

This is related to fostering user acceptance, however this attribute addresses the more subtle effect of adaptive aiding presence: "How does the aid's presence increase the operator's confidence?"

23. Information requirements for task aiding

The information requirements necessary in a task environment, both information requirements of the aid and information requirements of the operator will drive how and what will be aided in the system. For example, if an information requirement of a specified aiding system is to get a P300 (i.e., evoked response potential from the brain) from the operator as an enabling condition, it is probably not reasonable to specify this particular aid.

24. Aid tailorability

How much of the aid's behavior can be tailored based on individual differences, population differences, or not at all.

25. Risks of aiding: Designer, Technology, and User

The general categories of risk are of paramount importance to the specification of an adaptive aiding system. Although these are more general categories of other specified attributes, the higher level interactions may be more important to specification.

26. Granularity of aid/operator communication

Related to communication vs. aiding, this attribute must be considered from the viewpoint of: "What level of communication is necessary and what is possible given time and operational constraints?"

27. "Efficient frontier" of aiding specification/performance

This attribute comes from decision analysis. Considered to establish what optimizations, tradeoffs, etc are reasonable between the design and the intended user population.

28. Level of integration of aiding into avionics

Is the adaptive aiding system to be embedded in "to be built" systems or as an add-on, etc? What cooperation between intelligent systems can be expected? This attribute refers more to supporting structure for aiding, but is a primary design concern.

This preliminary list appeared to provide a reasonable basis for identifying the salient decision attributes in aiding specification. However, it was unreasonable to assume that we could evaluate such a large list under experimental conditions. Structuring and categorization of the attributes was undertaken in an effort to organize and reduce the set of attributes before evaluation.

B.3 Decision Making Attribute Categorization

Upon analysis of the generated list, four type categories emerged. Preliminary categorizations were:

Aid functional design
Aid performance
Aid-operator interaction
Supporting technology

The set of 28 attributes were reduced to 12 as a result of the analysis according to the method described in the report body. Table B.1 below depicts the design attributes according to category.

Attribute Category	Attribute Name
Aid Functional Design	Anticipated intervention criterion Training vs. aiding decisions Difficulty of aid implementation
Aid Performance	Reliability of aiding Types of aiding communication Overall Risk
Aid-Operator Interaction	Information requirements for aiding Ease of aiding introduction/removal User attitude towards aiding Level of aid tailorability
Supporting Technology	Available operator models Available hardware

Table B.1 - Decision Attributes by Category

Complete definitions for the 12 attributes used in the investigation are provided in the report text. The next section describes how the decision attributes were used.

B.3.1 Role in Adaptive Aiding Experiment

As stated earlier, it was a program goal to gain greater understanding of how designers' decision making processes influence the specification and design of the aiding system. Towards that end, rating data were collected on the attributes during the empirical investigation. The data consisted of rating the attributes in terms of importance to the overall success of each aid specified.

We probed the decision process of subjects by requesting them to rate the importance of the 12 purported design decision attributes during the specification experiment. A rating sheet of the attributes was filled in by the subject immediately following each event specification. Further discussion of the data collection process is described in the body of the report.

It was suspected that the attributes would be weighted differently for different designers as well as under different task circumstances. As discussed in the results section of the report, this set of attributes appeared to cover designers' decision attribute space adequately -- at least for the small population studied.

Refinement and validation of the attributes should allow us to assist the designer in the initial specification phase. Further, decision models constructed for both the designer and intended user population should highlight preference differences, resulting in a system that is not only designed well, but is easy to use.

APPENDIX C: DESIGN HEURISTICS

C.1 Introduction

During the experiment debriefing, subjects were questioned about their approach to design. In particular, the experimenter inquired about design rules that subjects developed during the specification process. Each subject discussed at least four possible design rules.

Although these data were not formally analyzed, the designers stated that they utilized rule-based behavior; primarily for design consistency. From the belief system analysis (Figure 9), it would appear that designers focused on different areas of the belief system matrix for rule-based behavior. Clearly, these behaviors that could be described influenced the resulting designs. However, much more investigation is necessary to determine the actual mapping of these behaviors to the belief system employed.

The listing of rules by subject below provides a reasonable start on collecting design rules and guidelines for adaptive aid design. Additionally, they provide initial insight into how to use design the strategies and rule-based behaviors to support the design process.

C.2 Design Heuristics

Subject 1

1.
IF: tasks to aid occur in same basic context (i.e., similar task situation),
THEN: attempt to aid consistently with previous tasks.

2.
IF: difficult, multi-facet situation assessment task
THEN: aid all parts that can be automated, and leave most uncertain to pilot

3.
IF: task is data verification & validation or aircraft to aircraft communication,
THEN: automate it and notify pilot of high priority information or inconsistencies in data comparison

4.
IF: novel foreground tasks and high workload and not under attack,
THEN: aid background tasks

5.
IF: desire to aid tasks by type (e.g., situation assessment)
THEN: aid execution and monitoring first, then situation assessment, then planning and committment type tasks (aiding precedence).

6.
IF: Well scripted sequence of actions
THEN: allocate to automation

7.
IF: complex task with scripted, contingent decision making tasks
THEN: partition according to rule number 2.

8.
IF: beginning of plan execution
THEN: transform displays to show plan and estimate future status (momentarily).

<u>Subject 2</u>

1.
IF: everything is going as expected
THEN: do nothing

2.
IF: preoccupying events occur,
THEN: aid background tasks according to change in performance

3.
IF: difficult situation assessment task
THEN: try to aid via partitioning
ELSE: transform displays

4.
IF: a tactic, etc. is well-known (e.g., 16 decoys problem),
THEN: have automated situation assessment configured to check for pilot

5.
IF: critical (e.g., launch weapon) task,
THEN: allocate fully to pilot

6.
IF: event is something the system definitely understands,
THEN: let the event occurrence drive aiding need.

Subject 3

1.
IF: just beginning the specification process,
THEN: do Fitt's law (static allocation) analysis first.

2.
IF: specifying an cognitively complex task,
THEN: look to partition task first.

3.
IF: specifying aiding information output,
THEN: product information priority is always high.

4.
IF: the source of the information used in aiding is important,
THEN: process information has high priority.

5.
IF: environmental or system status information is important,
THEN: procedural information has high priority.

6.
IF: true (i.e., dynamic) adaptive aiding is specified,
THEN: there will be a shift in the design model coefficients according to the dynamics.

Subject 4

1.
IF: specifying aiding for a sensor fusion task,
THEN: allocate task to aiding.

2.
IF: critical decision,
THEN: allocate decision to pilot.

3.
IF: high level decision alternatives being evaluated,
THEN: allocate to pilot.

4.
IF: aiding produces alternatives for pilot to evaluate,
THEN: process information has high priority.

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