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SPECIFICATION OF ADAPTIVE AIDING SYSTEMS

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ABSTRACT

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. 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.

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.

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.

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 framework for design of adaptive aids, as well as 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.

A primary difficulty with these questions and alternative answers is a lack of data upon which to base choices among answers, as well as specify details of answers. The aforementioned limited set of design principles currently available are helpful, but by no means sufficient to cover the space of possible answers to the six design questions.

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 to shift the emphasis from potentially relevant data to specific requirements for design decision making. In other words, rather than attempt to compile data, as well as the resulting principles, to cover all possible answers to the aforementioned design questions, the focus should be on the answers that designers typically pursue and the supporting data that they seek in the process.

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.

METHOD

Aiding Scenarios

The experimental task 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.

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 by two independent analysts 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.

Each of the 42 scenario events were classified by the two analysts in 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 perceived 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 the detailed technical report on this effort (Andes & Rouse, 1991). This report 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. Specifically, the most important reason for aiding was to be ranked first, the next most important reason was to be ranked second, etc.

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.

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). 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.

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 - what the aid is doing.
- Product - what the aid's outputs are.
- Process - how the aid functions.

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 effective 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.

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 Andes & Rouse (1991). 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.

Subjects

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.

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%.

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.

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 make statistical comparisons of rank orderings.

Comparing the rankings of subjects 1 and 2 with those of subjects 3 and 4, attributes 4 and 11 (i.e., reliability and availability of technology) were the top two for both groups (albeit in opposite order). Attributes 7, 3, 5, and 8 (i.e., ease of introduction, difficulty of implementation, operator-aid communication, user attitude) completed the ordering for the first group, while attributes 8, 9, 1, and 7 (i.e., user attitude, information requirements, interaction criterion, ease of introduction) completed the second group's ordering. Thus, the two groups were similar except subjects 1 and 2 emphasized attributes 3 and 5 (implementation difficulty and operator-aid communication) while subjects 3 and 4 focused on attributes 9 and 1 (information requirements and 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.

Design Rule Elicitation

In order to gain further, albeit informal, 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 Andes & Rouse (1991).

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). These 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. These belief systems are discussed in the following section.

CONCLUSIONS

The data indicate that subjects were able to be highly consistent in their specification decisions, 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 noted above and discussed in detail in Andes & Rouse (1991). 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 why aiding is needed, but their disagreement on what 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.

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.

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<u>sa:</u> 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

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

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

1. Anticipated aiding intervention criterion
2. Tradeoffs between cost 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

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 Product Process	6.1 8.4 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 Product Process	6.0 7.8 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 Product Process	9.1 10.0 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 Product Process	1.2 8.8 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

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	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

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Predicted

Subject 1

Actual	Alloc.	Part.	Trans.	None	TOTAL
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

Actual	Alloc.	Part.	Trans.	None	TOTAL
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

Actual	Alloc.	Part.	Trans.	None	TOTAL
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

Actual	Alloc.	Part.	Trans.	None	TOTAL
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

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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

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	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

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