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JOB AIDING/TRAINING TRADEOFF DECISION METHODOLOGY AND PROTOTYPE SUPPORT SYSTEM

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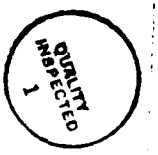

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SUMMARY

This report presents a methodological framework for analyzing tradeoffs among alternative combinations of aiding and training for personnel in complex systems. Each of fifteen steps is described in detail as it applies to the conceptual methodology and to its implementation as part of a decision support system prototype. Two operational analyses of AFHRL approved specialties are then presented, documenting the results of the user/system dialogue at each step. Finally, a series of "lessons learned" from this phase of effort have been compiled and presented as they apply to this and other aiding/training decision paradigms.

I. INTRODUCTION

The ever increasing complexity of operational Air Force systems continues to place greater demands on the personnel operating and maintaining them (AFHRL Report, 1986). The increased sophistication of these systems coupled with decreased force levels, declining entry-level skills, and the need to limit military training spending are forcing Manpower, Personnel, and Training (MPT) agencies to seek more efficient methods of maintaining and improving operational readiness (Booher, 1978; Duncan, 1985).

In this environment of "doing more with less", the issues of training and job aiding are paramount. Technical training serves as the source of knowledge and skills essential to task performance. In other words, training "creates the potential to perform" (Rouse and Johnson, 1989). Job Aiding, collectively, refers to those devices with the capacity to store and retrieve the "How", "What", and "When" information pertinent to a particular task performance. Job aiding, therefore, directly augments the potential to perform (Rouse and Johnson, 1989).

Selecting from among the wide variety of training and aiding alternatives (and their possible combinations) is difficult when a myriad of interdependent factors such as performance-related effectiveness, development/implementation costs and system design impact must be simultaneously resolved. For example, as an information storage device, a job aid facilitates performance by reducing the task related memory requirements. This, in turn, reduces the training requirements for that job and generates the potential for reducing immediate resource expenditures. Training, on the other hand, imparts more general knowledge applicable to a variety of related tasks. In this case, the initial costs of training a small, multi-disciplinary work force may, in the long-term, be offset the reduced costs of supporting a larger, more specialized team.

The formulation and evaluation of these aiding/training tradeoffs is a necessary component of the decisions made by MPT analysts, system designers, and personnel supervisors through-out the Air Force. To the extent that these tradeoffs have been addressed in the past, the analyses have relied heavily on prior experience with similar systems. Typically, these types of analyses have required many person-years of effort. Often, the result has been a time-consuming and expensive effort that provided insights which were too late to be implemented in any substantial way. (Rouse and Johnson, 1989) Whether for evaluating current AFS job performance,

selecting among new system design alternatives, or ensuring flight-line personnel are task qualified, a methodology for efficiently producing consistent, timely, and supportable aiding/training decisions is a must.

In response to this need the Air Force Human Resources Laboratory, Brooks AFB has sponsored the Job Aiding/Training Allocation Technologies (JATAT) program. The purpose of JATAT is to develop a conceptual decision aiding methodology and a corresponding computer-based decision support system designed to assist in identifying applicable training/aiding alternatives and evaluating combinations. The expected benefits of such a system include faster response times to identified aiding/training requirements, accurate performance-based recommendations, and reduced military training costs.

This report documents the second phase of effort in the development of the JATAT aiding/training decision methodology, the Phase 2 prototype system, and the analyses of two Air Force approved Air Force Specialties (AFS's) using the JATAT methodology. To support this goal, this report is divided into three sections; an overview of each of the 15 steps in the methodology, the Phase 2 Decision Support System Prototype, and a summary including "lessons learned" during concept development and implementation. Appendix A contains a step-by-step analysis of the two operational AFS's.

II. METHODOLOGY OVERVIEW

Overall Description

In a prior report, Rouse and Johnson (1989) suggested three computational approaches for supporting trade-off decisions between training and job aiding. The first approach involves compiling general guidelines for training/aiding decisions based on cumulative experience and experiments. This results in a "rule-based" approach in which the tradeoffs are embodied in rules based on mappings from task performance requirements to training/aiding decisions.

The second approach involves predicting human-machine system performance based on attributes of specified training and aiding alternatives. This approach enables the analyst to specify the appropriate performance measures and acceptable levels of performance in different situations and with different priorities. This requires computational models that predict the measures of interest based on the available

attributes of the training or aiding alternatives. It is a more "visible" form of the first approach in that the first approach may "hide" the measures and requisite levels of performance in the rules or guidelines.

If the rules, guidelines, or computational models do not exist or are not adequate, then the analyst can use simulation techniques to estimate performance measures of the human-machine system using different training or aiding alternatives. This third approach is actually a special case of the second. In this case, the analyst must develop or tailor a simulation model to predict the chosen measures of performance.

The methodology described in this report encompasses these three approaches placing them in the larger context of a training/aiding trade-off analysis (see Table 1). Steps 1 and 2 of the method reflect a typical systems engineering approach to the analysis. Step 3 indicates a human-centered approach to identifying the requirements that will be addressed in the analysis. Steps 4 through 15 of the method (in which the analyst determines the alternatives and formulates, analyzes, and integrates the tradeoffs) describe an ordered approach to the complex problem of analyzing multiple, interdependent tradeoffs between aiding and training the human.

Although presented as an ordered list in Table 1, these steps are not necessarily sequential. Some of the steps may be repeated several times as the analyst/designer works through the tradeoffs under various conditions and with various combinations. The following sections discuss these steps in detail.

Individual Step Description

1. IDENTIFY TASKS - Understand the Job

In the context of analyzing job aiding/training tradeoffs, the analyst must understand three different aspects of the job: the tasks involved in the job, the equipment used in the job, and the personnel expected to do the job. This knowledge is necessary to determine the job requirements and system constraints that must be satisfied. Obviously, complete knowledge of these variables for all tasks is unrealistic. In fact, the required level of understanding is directly dependent upon the problem at hand. For example, a decision to train or aid personnel to perform a job requires far less detailed information than a decision among combinations of training and aiding technologies for a specific task.

Table 1. Methodology Overview.

IDENTIFY TASKS

1. Understand the job
2. Decompose via a task taxonomy

ASSESS HUMAN LIMITATIONS, ABILITIES, AND PREFERENCES

3. Assess human limitations, abilities, and preferences

DETERMINE ALTERNATIVES

4. Map limitations, abilities, and preferences to a taxonomy of training alternatives
5. Map limitations, abilities, and preferences to a taxonomy of aiding alternatives

FORMULATE TRADEOFFS

6. Make obvious choices
7. Coalesce interdependent tradeoffs

ANALYZE TRADEOFFS

8. Choose measures of performance
9. Choose input/output representations
10. Identify requisite structure and parameters for representations
11. If necessary, represent learning process
12. Apply methods of analysis to representations
13. Interpret results

INTEGRATE TRADEOFFS

14. Compile assumptions and consequences of tradeoffs
15. Form sets of tradeoffs with consistent assumptions and consequences

2. IDENTIFY TASKS - Decompose via Task Taxonomy

The second step is to further decompose the tasks into more primitive tasks; refered to as subtasks or activities. This decomposition defines the level of granularity for subsequent steps (the assessment of the human's limitations, abilities, and preferences). A task taxonomy is useful in this step, particularly if the human's limitations, abilities, and preferences are readily determined for the task elements in the taxonomy.

3. ASSESS LIMITATIONS, ABILITIES, AND PREFERENCES

In this step, the analyst determines the qualities of the human in the system that either require (through human limitations) or influence (through human abilities and preferences) training/aiding decisions. It is this focus on the human capabilities, limitations, and preferences in the system that makes this a human-centered approach.

This assessment draws its primary input from the task decomposition in the previous step, which provides an "index" for human limitations, capabilities, and preferences. In subsequent steps, these assessments will be used to identify training and aiding alternatives. It is important, then, to maintain a consistent level of detail across these tasks, limitations, and alternatives. A task composition that is too coarse leads to identifying general human limitations that are not sensitive to the aiding/training alternatives available. A task decomposition that is too fine grained leads to identifying human limitations that require premature detailed design of aiding/training alternatives to evaluate.

4. DETERMINE ALTERNATIVES - Map Limitations, Abilities, and Preferences to Taxonomy of Training Alternatives.

5. DETERMINE ALTERNATIVES - Map Limitations, Abilities, and Preferences to Taxonomy of Aiding Alternatives.

Through Steps 4 and 5, the analyst uses the limitations and abilities identified in Step 3 to guide the identification and selection of alternative training and aiding techniques. This is done by identifying the knowledge and skill requirements of a task and mapping the required changes in knowledge and skills to candidate

aiding/training methods through guidelines. The mapping is guided by available expert guidelines or empirically developed heuristics.

From a pragmatic perspective, other factors may also go into this process, such as resource availability and existing training or aiding techniques for this or similar jobs. Depending on the maturity of the analysis and the expertise of the analyst, these considerations may either prematurely constrain the solution space (early in the analysis) or provide timely guidance leading to practical solutions (later in the analysis).

6. FORMULATE TRADEOFFS - Make Obvious Choices

In this step, the analyst selects among training/aiding alternatives that are straightforward and require no additional analysis. This step allows for the situation in which part of the problem is easily addressed by conventional solutions. For example, printed procedural job aids may be an obvious solution for a task which is similar to one already using that type of aid extensively.

Clearly, these choices depend upon the expertise of the analyst as well as the data and tools available to the analyst. A relatively novice analyst may be unable to independently make obvious choices, but may be able to rely upon tools such as heuristic guidelines, decision flow charts (Booher, 1978), or expert judgement models (Irvin, Blunt, & Lamb, 1988) for making broad categorical decisions (e.g., train, aid, both, or either). A more experienced analyst may want to use these tools to verify their choices.

Making the obvious training/aiding choices now, however, does not remove them from further consideration. Their interdependencies must still be considered in later steps.

7. FORMULATE TRADEOFFS - Coalesce Tradeoffs Involving Interdependent Tasks

To this point in the analysis, the number of viable alternatives has been relatively unlimited. However, once obvious choices have been made, subsequent analyses can be quite extensive. Therefore it is usually necessary to narrow down the number of candidate solutions by grouping training and aiding alternatives according to their interdependent relationships and characteristics.

For example, a particular task element may suffer from a limitation that may be addressed by one of three alternatives: training alone, aiding alone, or some

combination of training and aiding. It is likely that these task elements will be functionally or temporally interrelated. Similarly the training and aiding alternatives will probably have interdependent characteristics such as methods or content. The analyst must identify these interdependencies and coalesce the training/aiding alternatives into a smaller set for subsequent analysis.

8. ANALYZE TRADEOFFS - Choose Measures of Performance

Accurately evaluating the resultant training/aiding alternatives requires selecting the appropriate performance measures. These measures are clearly domain dependent. Cost, for example, is a basic measure of performance common to all domains; although its importance will vary accordingly. Other examples include time to perform, probability or number of errors, mean time between failures, etc.

The choice of performance measures is also influenced by the available modeling tools and the modeling expertise of the analyst. While a more experienced analyst may choose to tailor the available modeling tools or develop new models to produce a variety of performance measures, a novice will probably have to choose among "pre-determined" models that are readily available.

9. ANALYZE TRADEOFFS - Choose Input/Output Representations

To compare training/aiding alternatives, an input/output (I/O) representation (i.e., a model) must be chosen that can produce the selected measures of performance. The I/O representation must reflect realistic inputs from available data and the desired outputs including the performance measures.

Once again, the experience level of the analyst strongly influences the extent of this step. Again, while a more experienced analyst may be able to adapt existing models or develop new ones, for a novice the choice of I/O representation may follow directly from the choice of a performance measure.

10. ANALYZE TRADEOFFS - Identify Requisite Structures and Parameters

Employing the chosen I/O representation frequently requires modeling the human as an integral component of the system. In doing so, it may be necessary to determine the structures and parameters that represent how the human performs the task. If the analysis includes only aiding alternatives, these requirements may be essentially

constant throughout the analysis. In analyses that include training alternatives, these requirements will vary to simulate the impact of different training alternatives.

11. ANALYZE TRADEOFFS - If Necessary, Represent Learning Process

In some analyses, the performance measures may be sensitive to the human process of acquiring knowledge and skills. In these cases, the learning process must be reflected in the model. This representation may be as simple as retrieving data from a database or as complex as employing learning curve or learning process models.

12. ANALYZE TRADEOFFS - Apply Methods of Analysis to Representations

This step invokes the targeted analysis; input data is supplied, the model is exercised, and performance data is collected for each of the training/aiding alternatives of interest.

13. ANALYZE TRADEOFFS - Interpret Results

Next, data collected during the previous step is analyzed and interpreted in the context of selected analyses. This step may be repeated several times in conjunction with steps 10 through 12 as the analyst investigates the effects of various assumptions or the sensitivity of the performance measures to variations of the parameters within the model.

14. INTEGRATE TRADEOFFS - Compile Assumptions and Consequences of Tradeoffs

In an extensive analysis with a number of different tasks and training/aiding alternatives, organizing the assumptions and consequences of the trade-off analyses is a large bookkeeping task.

The purpose of this step is to compile all the common aiding/training alternative characteristics and decisions in order to implement the predetermined aggregation guidelines in the following step.

15. INTEGRATE TRADEOFFS - Form Sets of Tradeoffs with Consistent Assumptions and Consequences

In the final step of the methodology, the training/aiding alternatives are integrated into sets satisfying the requirements developed from the human limitations, abilities, and preferences identified in Step 3. In addition to satisfying these requirements, each set incorporates the common assumptions and consequences (i.e., learning and retention abilities of humans or productivity improvements with job aiding) identified in the previous step.

While most analysts will probably not have the final decision-making authority necessary to implement the recommendations produced in a JATAT analysis, this methodology generates a logical justification supporting these recommendations. The purpose of this step, therefore, is to compile a clear, coherent summary of that justification.

III. DECISION SUPPORT SYSTEM

Implementing the JATAT decision support system prototype, as described in the following sections, presented several unique design challenges. First, unlike other complex decision aiding environments where the end user population is a highly specialized, well-defined segment of the general populace, the characteristics of the JATAT user were intentionally left ambiguous. This decision reflects our conclusion that training/aiding allocation decisions are currently made across a variety of disciplines, organizations, and individual experience levels. Throughout our preliminary design process, this ambiguity allowed sufficient design flexibility to satisfy numerous potential user functional needs.

Second, a workable, yet intuitive, user interface metaphor was needed to adequately represent the JATAT method and to exploit a newly identified 'value added' quality of the prototype system. This "value-added" concept was a result of the aggregation of resources necessary to support the decision process and was a natural, albeit secondary product of the implementation effort. The interface metaphor, in this case, graphically reflects the user's cognitive model of the system. More specifically, this interface metaphor design strives to represent a conceptually new system with an analogy familiar to the user (i.e., a process control and resource available environment).

Finally, the system complexity required the exploration of an intelligent support function. Therefore, the Decision Support System (DSS) section has been further divided into the following four sub-sections: the User, the Environments, the Advisor, and Support Data Types.

The User

An important notion in the development of a supportive system interface is to clearly define the user requirements and capabilities. In this case, an exact definition of the user's characteristics was complicated by the multiplicity of intended JATAT user characteristics. It was hypothesized that the JATAT "user" could fall anywhere along a continuum from an individual tasked with making a short response time, categorical level aiding/training recommendation for a previously established task, to a team of users employing the JATAT system as an integral part of a long-term, detailed system design decision. This "user" may be performing a particular analysis with known data and an established process, or pursuing multiple decision alternatives involving estimated data and a personalized decision methodology. And, equally important, the "user's" level of knowledge of the personnel, the tasks, the aiding/training environment, and the JATAT system, as well as other similar dimensions, is likely to vary within each analysis.

The number of individuals employing the JATAT system, the multitude of purposes for which the system is employed, and the variety of limits and abilities of each potential user requires an interface with the power and flexibility to support the needs of the user at any level, at any given step in the process. Good human factors principles demand that the complexity of the design be transparent to the user. This notion of transparency implies that by the nature of the decisions and choices the user makes at each juncture in the system, their level of capability is inherently defined. This eliminates the need for explicit user classification of their level of required assistance.

In order to identify the system support requirements and create a useful interface metaphor for such an environment, our design team created three user categories based on expected capabilities; novice, journeyman, and expert. Each level of expertise category is defined below.

A novice JATAT user is defined as having fairly limited expertise in each of the following areas; the domain of the Air Force Specialty (AFS) under analysis, the aiding/training problem space, modeling, and the JATAT software package. The

novice's interaction with the system is expected to be constrained to supplying available input values (i.e., personnel, equipment, and task data, design changes, etc.), explicitly accepting default values and system recommendations, and executing recommended procedures. Conceptually, the system would be responsible for guiding data input through methodological queries, and providing default values (i.e., decisions, models, etc.) and best recommendations based on available taxonomies and expert heuristics.

The journeyman is also expected to have limited expertise in the AFS domain but is more likely to be moderately knowledgeable regarding the aiding/training problem space and modeling, and to have had previous experience exercising the JATAT software package. The interaction of the journeyman with the system would be less constrained and more proactive. At this level the system would supply the user with several alternatives for mappings, recommendations, models/parameters, etc. along with the original default values. Selection of a particular alternative would then allow the journeyman more control in guiding the direction of the analysis. An important notion at this level is that the system remain "knowledgeable" about each decision made by the user (i.e., the available taxonomies and heuristics are sufficiently robust to map to the potential responses of the user).

The expert is likely to be well versed in all areas of the analysis, lacking only specific knowledge regarding the particular AFS and task under analysis. This level of expertise implies the ability (and possibly the desire) to deviate from standard decision practices in pursuing unique solutions. These characteristics define the highest level of flexibility required by the system interface. At each step in the process, the system should provide the appropriate decision template and recommendations/alternatives, while allowing completely unconstrained user input. This level of support portrays the JATAT methodology concept in its purest form; a guided aiding/training decision framework.

It should be noted that the system's allowance of unconstrained input would limit its ability to provide intelligent guidance and recommendations to those inputs for which taxonomies and expert heuristics exist in its knowledge bases. At a minimum, the system should identify those user input values that are not supported.

Since the user's level of expertise can vary for each step of the process analysis, a break-out by process step and user category was generated to assist in the identification of potential system support functions. (See Table 2.)

STEP \ USER	NOVICE	JOURNEYMAN	EXPERT
1	Standard Job Descriptions Supplied	Job Description and Templates Compared	Job Description Templates Supplied
2	Task Descriptions Supplied and Used	Descriptions and Taxonomies Compared	Alternative Task Taxonomies Supplied
3	User Supplies Minimal Inputs	Relevant Limitations, Abilities, Etc. Recommended	Choice Among Task Taxonomies Maps to Taxonomy of Limitations, Abilities, Etc.
4	Direct Mapping to Training Alternatives	Alternative Mappings to Training Taxonomy Recommended	Choices Among Limitations, Etc. Maps to Training Taxonomy
5	Direct Mapping to Aiding Alternatives	Alternative Mappings to Aiding Taxonomy Recommended	Choices Among Limitations, Etc. Maps to Aiding Taxonomy
6	Choice(s) Recommended	Alternative Choices Recommended	User's Choice(s) Evaluated
7	Standard Formulation Supplied	Alternative Formulations Recommended	User's Formulation Evaluated
8	Standard Performance Measures Supplied	Standard Measures and Taxonomy Compared	Taxonomy of Relevant Measures Supplied
9	Pre-Configured Models Supplied for Standard Formulations and Measures	User Supplies Criteria and Rank-Ordered Set of Alternative Models Supplied	User Chooses Among Set of Relevant Modeling Approaches
10	User Supplies Parameters for Limited Number of Equipment and Personnel Characteristics	User Chooses Among Alternative Templates and Makes Straightforward Modifications	User Configures Structure of Model and Obtains Parameter Estimates
11	Standard Learning Curves Used at Most	User Chooses Among Learning Curve Models and Behavior/Learning Models	User Configures Behavior/Learning Model and Obtains Knowledge and Skills
12	Pre-Configured Models Exercised	Models Exercised with Options for Range of Outputs and Intermediate Results	Models Exercised with Wide Range of Options Including Debugging
13	Predictions Compared to Performance Requirements	Prediction Compared to Typical Model Outputs (for Verification) and Performance Requirements	Facilities for Sensitivity Analyses and Optimization Supplied
14	Audit Trail Compiled and Available	Audit Trail Presented and User Edits and Augments	Audit Trail Presented and User Assesses Consistency and Acceptability of Analyses
15	Sets of Tradeoffs Recommended	Alternative Sets of Tradeoffs Recommended	User's Set of Tradeoffs Evaluated

Table 2. Nature of JATAT User Support

The Environments

While investigating alternative means for simplifying access to the functionality of the JATAT 15 step process, it was discovered that many of the system support functions were inherently useful independent of the methodology. In other words, aggregating numerous modeling tools into one common application or creating a single unified interface to various databases results in an inherent "value added" to the system (i.e., the power of the tools independent of the process). Further pursuit of this idea resulted in the formulation of a concept of independent resources centralized in a separate system component.

In response to this discovery, it was necessary to create a user/system interface metaphor which would intuitively delineate the support and analysis functions associated with the 15 step methodology from those generated as part of the "value-added" concept. The result was two parallel environments living within the same "world" (system). Between these two environments the user can easily travel via the environment "gateway".

The first environment contains each of the 15 steps associated with the conceptual aiding/training trade-off decision methodology. When followed sequentially, these steps describe the "process" by which the analyst formulates and analyzes the aiding/training tradeoffs for a given design. This environment is referred to as the "Process Environment".

The "value-added" concept evolved from the aggregation of several inherent system support functions. The independent utility of these functions served as "resources" for the user in a variety of applications. Hence, the second interface environment, an aggregation of these resources, is referred to as the "Resource Environment".

The Process Environment

The purpose of the Process Environment sub-section is to describe, in detail, each of the 15 steps of the JATAT methodology as implemented in the Phase 2 prototype system. The issues addressed by each of the following 15 segments include the user/system interface design, user input requirements, and current system capabilities.

1. Understand the Job. Initiating a successful aiding/training decision analysis requires an initial compilation of the appropriate knowledge, including the decision catalysts (i.e., those situations whose consequential impact necessitates a new aiding/training analysis; for example, new/modified equipment designs, or new/modified manpower/personnel requirements), the affected factors (i.e., personnel, equipment, and tasks), and candidate solutions (i.e., aiding devices and training methods which satisfy environmental constraints) pertinent to that specific situation.

While these requirements apply to all aiding/training analyses regardless of the availability of computer-based assistance, its importance to the JATAT user is due to the system's reliance upon direct user input of certain vital data. In the absence of such data, subsequent knowledge-based heuristics are less effective and the resultant responses less accurate. With no direct means of inferring the knowledge gained by the user during this process, the computer-based system must implicitly ascertain this information through user responses to system queries. Information of this type can then be fed directly into subsequent analysis processes to assist in making obvious choices among alternatives and influence performance and behavioral predictions. In essence, this knowledge applies to both the user and the computer-based system; the user must understand the job in order for the system to do the job.

During the development of the JATAT system concept, we assumed the user to have some level of knowledge regarding the special conditions motivating the analysis, as well as the job aiding/training decision domain in general. While this is plausible, it is less likely that they will have a similar level of knowledge regarding the personnel, equipment, and tasks being analyzed. Therefore, some method by which this information can be obtained must be incorporated into a fully functional support system. While the integration of context specific data (i.e., decision catalysts and environmental constraints) may be beyond the scope of the JATAT concept, on-line access to databases of relevant archival data is well within the purview of such a computer-based decision support system.

JATAT accessible data banks would most reasonably include survey data pertaining to the operational target personnel, equipment, and tasks for which aiding/training analyses would be performed. In this case, knowledge of the target personnel must include the AF specialty and related job responsibilities, previous job related experience, individual aptitude along relevant dimensions, level of formal education, current training procedures, etc. Knowledge of the equipment must include some level of understanding of the technology and the design employed. And, knowledge of the tasks requires the ability to identify those tasks which are directly

affected by changes to the job responsibilities and equipment as specified in the analysis scenario.

Accessing this knowledge across a variety of data sources would best be accomplished through a single, unified interface. For example, in Figures 1 and 2, the information from numerous data sources (i.e., the Occupational Research Data Bank (ORDB), AF Regulations, Career Development Manuals, etc.) have been made available through a common, interactive interface method. A well-implemented support system would maintain this common interface for both embedded and remote access databases. Due to storage and resource limitations the current DSS prototype has embedded only subsets of the ORDB data for the AFS's being analyzed (i.e., 426X2 and 911X0) and on-line access to remote data banks has not been implemented.

Of primary importance during this step of the process is the user specification of the task or tasks which are affected by the decision catalysts. Specific knowledge of an affected task is highly improbable and the large number of tasks assigned to each AFS diminishes the practicality of an exhaustive sequential search. Therefore, some form of intelligent search through an existing task listing is required. Currently, a keyword search is implemented for locating the task of interest. Other potential search schemes could include a direct numeric access procedure or a scrolling categorical search.

In the absence of a designated AFS or equipment about which to reason, the JATAT methodological framework could still produce reasonable, although much less accurate, recommendations. But an ill-chosen task or the complete absence thereof results in, at worst, misleading recommendations or, at best, no recommendations at all.

2. Decompose via Task Taxonomy. Once the target personnel for a given aiding/training analysis have been determined, the associated individual and equipment data extracted from the available databases, and the appropriate affected task(s) specified, the next step is to decompose the task(s) to the level most appropriate for the analysis. For the purpose of this report, a single level of task decomposition results in a number of task-related activities referred to here as sub-tasks or activities. It is this sub-task/activity level at which the current JATAT system version is designed to perform. This decomposition of the task(s) can be based upon either pre-established lists of sub-tasks/activities or general taxonomies; both of which can be easily provided by the system.

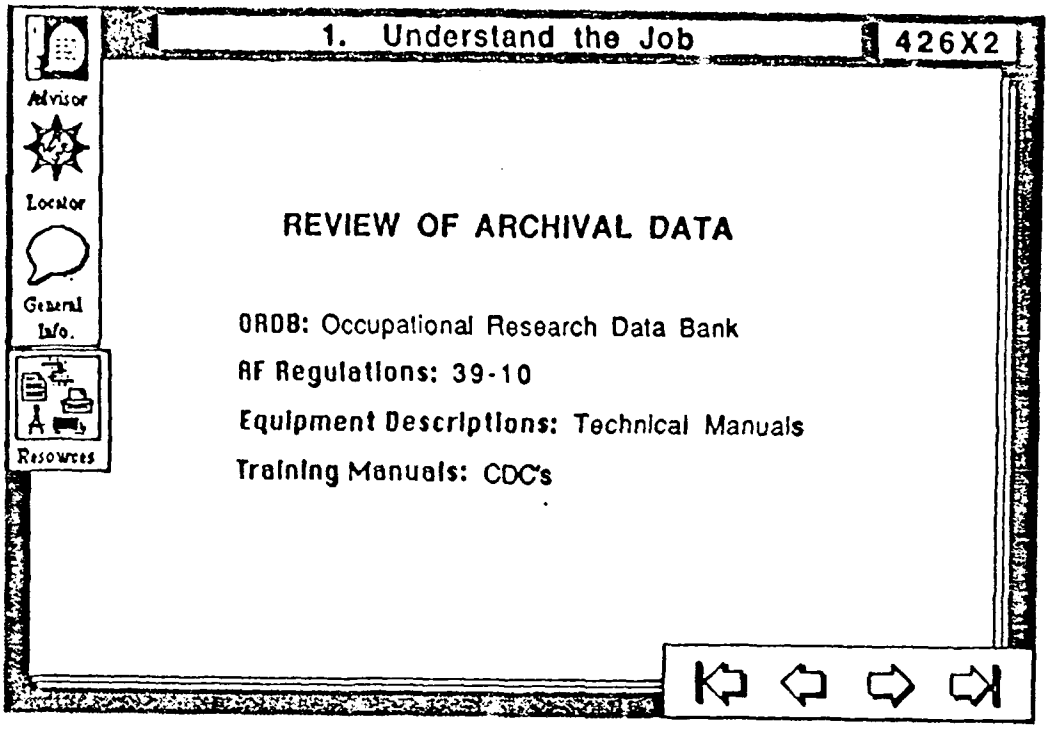

Figure 1. Prototype Archival Data Interface

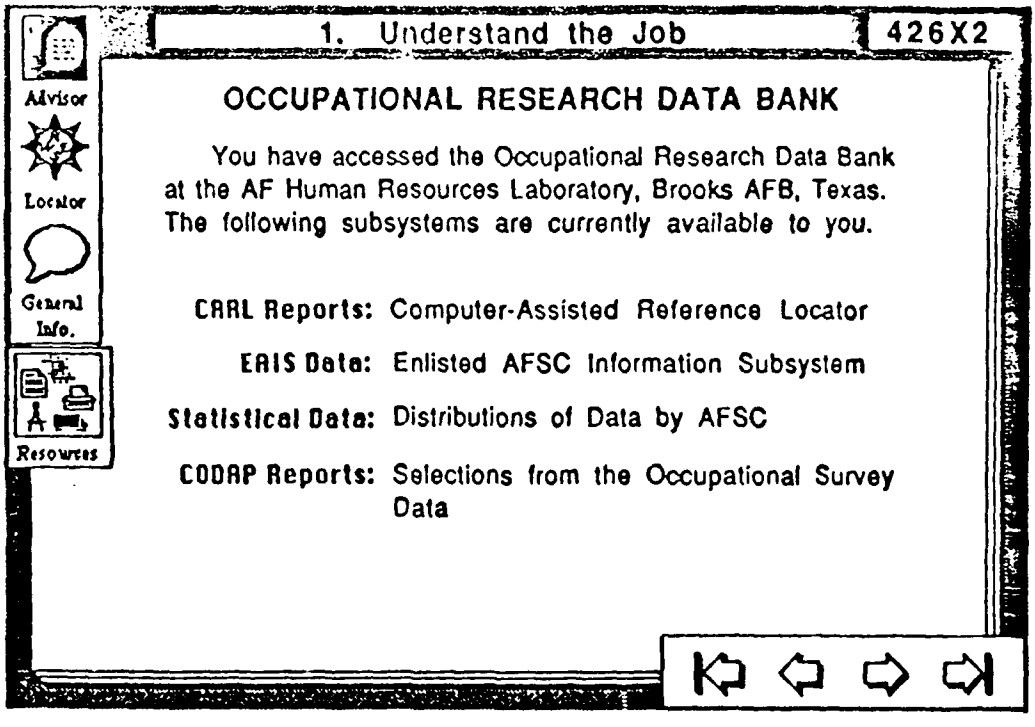

Figure 2. Prototype ORDB Interface

The pre-established activities are formalized procedures extracted from current technical manuals and are inextricably linked to specific tasks. Direct database linkages between these technical activities and their associated tasks could be encoded directly into the JATAT system, such that selection of one would result in the automatic retrieval of the other. This is the most accurate method of task decomposition.

A series of general activity taxonomies could also be provided for those classes of tasks not having pre-established technical procedures (See the example in Figure 3). This solution enables the continuation of the analysis in the absence of specific activities. However, the guidance and recommendations produced are at a significantly lower level of accuracy.

Once the decomposition has occurred, it is necessary for the user to further pare the general list down to those activities specifically impacted by the decision catalysts and to modify them to appropriately reflect the changes in the target system. The capabilities and knowledge necessary to perform this action implicitly define the minimum level of knowledge of the user necessary to successfully complete this step of the analysis process.

At this point in the current framework, the user is expected to have attained a sufficient understanding of the personnel and job parameters to employ other available, non-task dependent aiding/training decision models. Interactive versions of the Job Performance Aid Selection Algorithm (Booher, 1978) and Training/Job Performance Aid Model (Irvin, Blunt and Lamb, 1988) have been implemented in the Phase 2 DSS prototype. (See Figure 4.)

3. Assess Limitations, Abilities, and Preferences. Determining an appropriate training method or aiding device for assisting the performance of a particular activity requires an understanding of the two following components of that activity; the activity itself and the individual's ability to perform that activity. The former was resolved in the previous step. The limits and abilities of the target personnel are the focus of this step.

Individual limits and abilities can be defined in terms of knowledge and skills. In the current system, limits are operationally defined as the lack of knowledge required to perform the specified activity. Conversely, abilities are implicitly defined as an individual's capacity to manifest a minimum level of knowledge about the specified activity. (Individual skills and preferences in performing the selected activities were not addressed in the Phase 2 effort.)

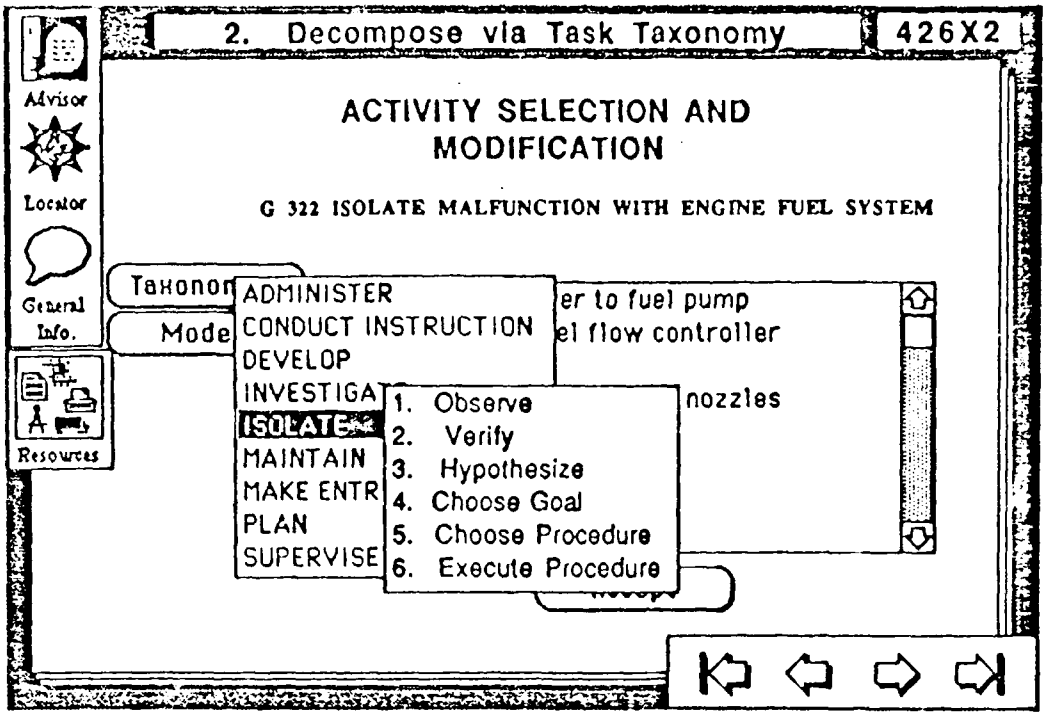

Figure 3. Example Task Decomposition Taxonomy

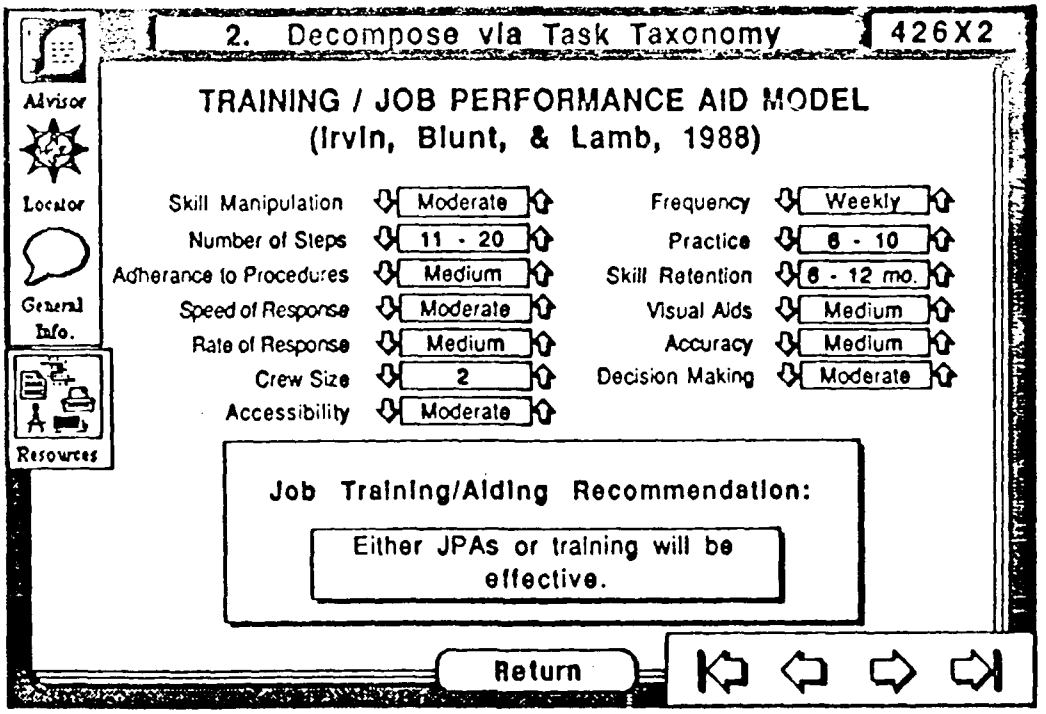

Figure 4. Training/Job Performance Aid Model Interface

The knowledge associated with a given activity can be further classified as either operational or system. Operational knowledge refers to information about the way in which tasks are performed (i.e., "How to work the system"). System knowledge refers to information about the equipment system with which operators and maintainers perform their tasks (i.e., "How the system works") (Rouse and Johnson, 1989). (See Figure 5.)

Within each knowledge type the specific knowledge requirements can also be categorized into subsets designed to answer the questions of "how", "what", and "why". Knowledge requirements can also be ranked upon several levels of abstractness, from the very concrete factual information to the abstract principles and theories. When categorized along both dimensions simultaneously, nine specific knowledge requirements emerge for both operational and system knowledge classes. (See Figures 6 and 7.)

Although the terms operational and system knowledge apply most directly to the operator or maintainer as the target personnel, the schema remains intact for other job types as well. The structure of the underlying knowledge bases responsible for mapping limits and abilities to aiding/training recommendations also remains consistent. In fact, in order to analyze activities as varied as instructing and troubleshooting it is only necessary to recompose the descriptive language of each knowledge requirement relative to the activity being analyzed. For example, Principles of Group Interaction is more applicable to the instructional task of a 911X0 than is the Mathematical Principles/Theories associated with the maintenance task of a 426X2. Note, however, that both denote a highly abstract level of operational knowledge about their respective domain. (See Figure 8.)

It is conceivable that the relevant knowledge requirements would be pre-established for each current activity and would be automatically recalled with each activity analysis; however, it will still be necessary for the JATAT user to be able to specify differences of knowledge requirements due to the changes of interest. This choice identifies the minimum level of ability necessary for even a novice user at this step in the process.

The second aspect of target personnel limits and abilities addresses the issue of overall trainability. Used in this context, trainability predicts those knowledge requirements that can not be satisfied using a training method alone. Although not affected by the specific task being analyzed, trainability is influenced by the technological state and design of the target equipment. (See Figure 9.) Currently, the trainability algorithm also requires ordinal measures of aptitude and experience.

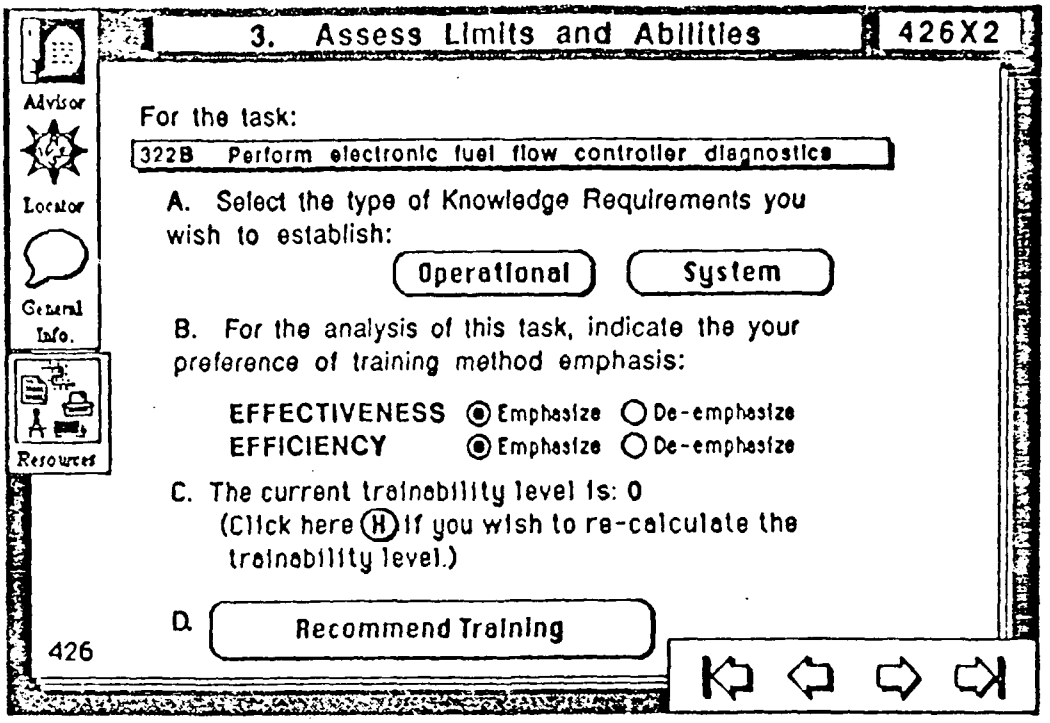

Figure 5. Assessing Target Personnel Limits and Abilities

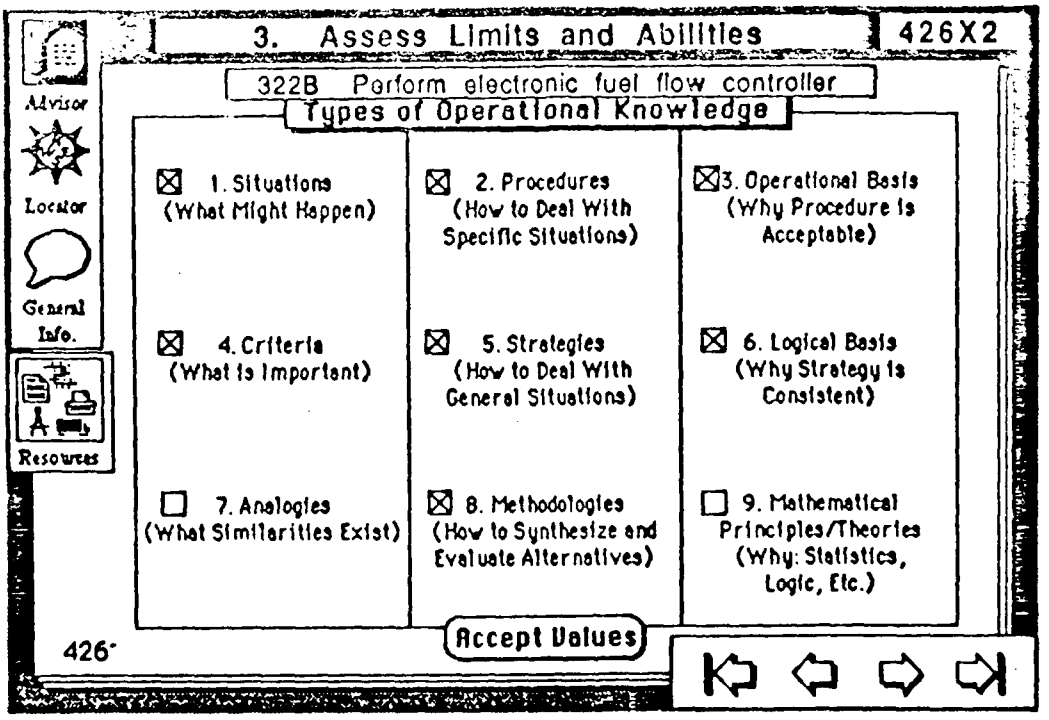

Figure 6. Operational Knowledge

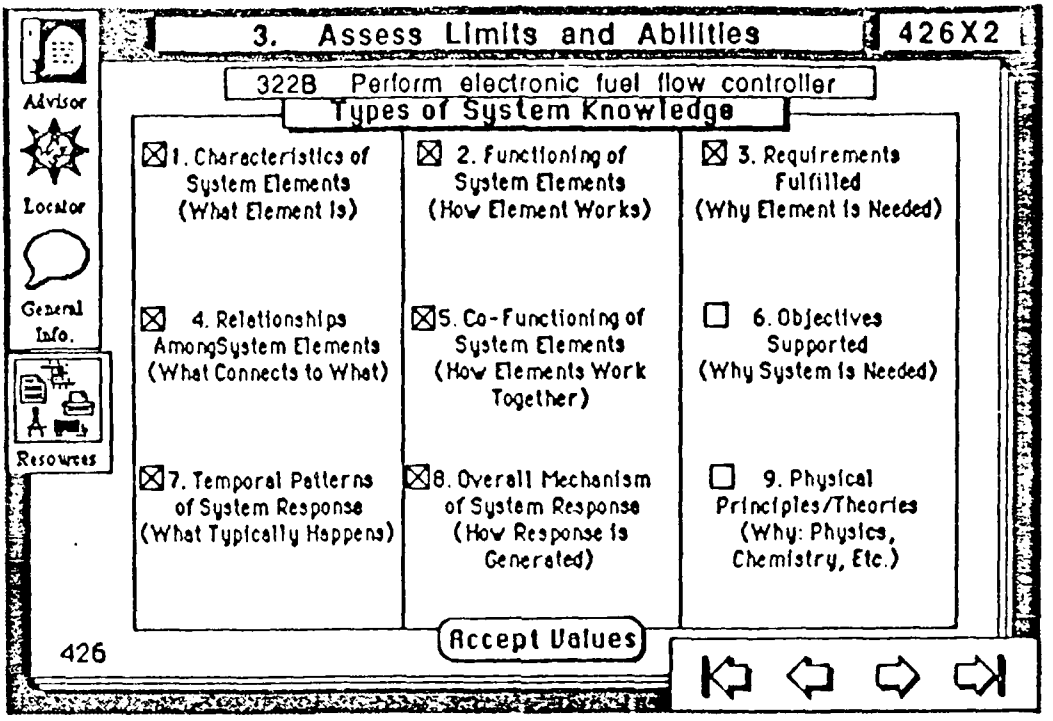

Figure 7. System Knowledge

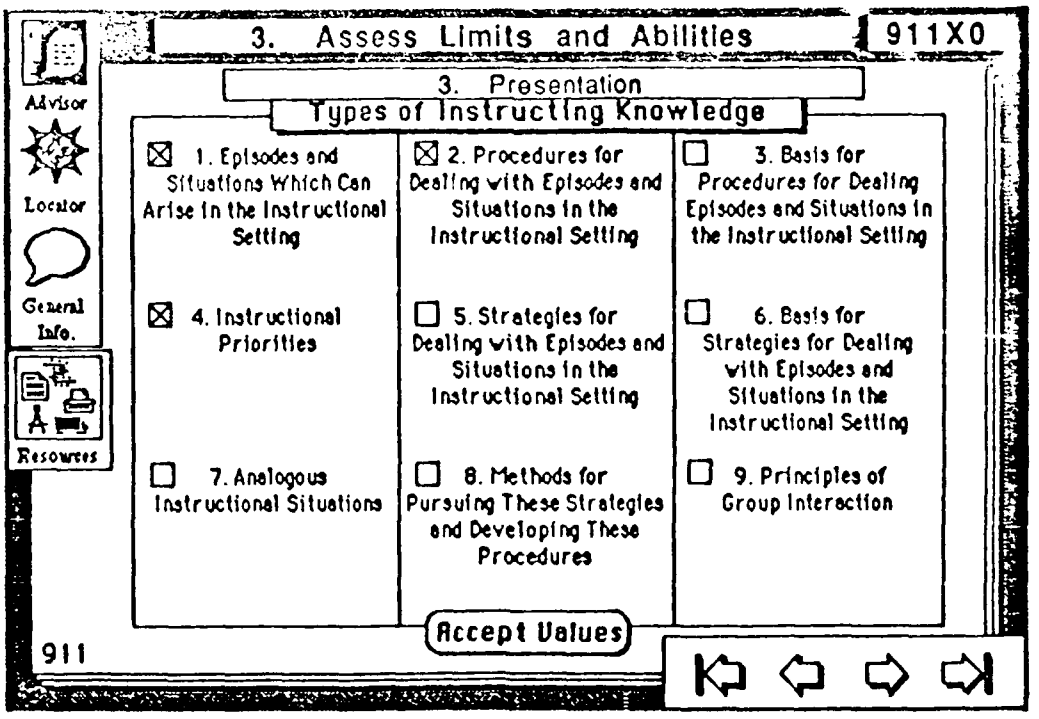

Figure 8. Instructing Knowledge

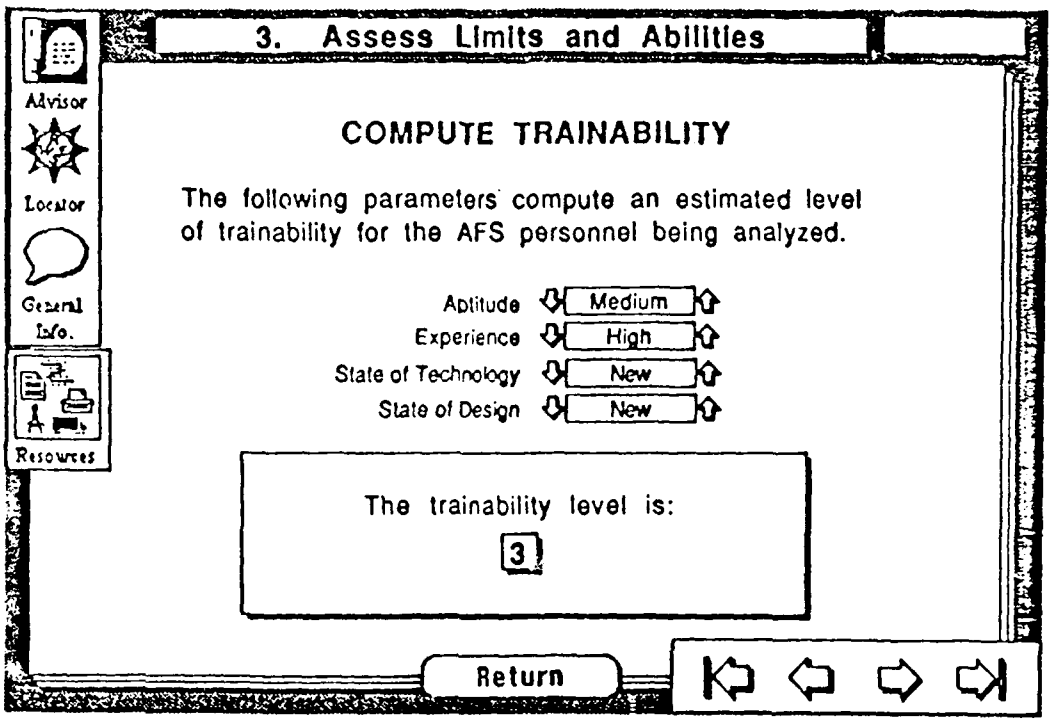

Figure 9. Computing Trainability

4. Map Limitations, etc. to Taxonomy of Training Alternatives. The process of mapping the previously established knowledge requirements to a viable training recommendation is performed automatically at the system level based on the expert rules encoded in the system knowledge base.

Currently, two additional parameters also influence the mapping outcome; trainability (as established in the previous step) and effectiveness/efficiency emphasis. The latter, although implemented within the previous step, acts as a user manipulated modifier. This is a preliminary method by which such factors as training cost and availability, time allotted, etc. (i.e., knowledge not readily available to the system) can indirectly affect the recommendation analysis. Emphasizing effectiveness implies a need for task proficiency regardless of cost. Emphasizing efficiency implies a limited availability of resources to accomplish the training.

Once the user has satisfactorily responded to all the necessary input queries for a specified activity, the system will respond with recommended training methods for both the operational and system knowledge requirements (See Figure 10.). Associated with each recommendation is a "next best" alternative. At this point, the JATAT user can continue the analysis with both options, or proceed after choosing to continue with only the recommendation or the alternative.

Note that in Figure 10 two recommendations/alternatives are given for both operational and system knowledge types. This is due to the expert heuristics which allow the possibility of a different type of training method for the "why" knowledge versus the "how" and "what" knowledge.

A list of the specific knowledge requirements satisfied by each recommended/alternative training method is also provided. Although this information is most useful for the most advanced JATAT users, its derivative, those knowledge requirements that remain unsatisfied, is an important part of the subsequent "Make Obvious Choices" step.

The rules implemented in the Phase 2 DSS prototype for deriving recommended training methods were based on the taxonomies identified in the final report for the Phase 1 effort.

5. Map Limitations, etc. to Taxonomy of Aiding Alternatives. As in the preceding step, aiding device recommendations/alternatives are automatically derived from previous user inputs. In fact, the aiding device recommendations and alternatives provided by the Phase 2 prototype system are based on a subset of the input factors

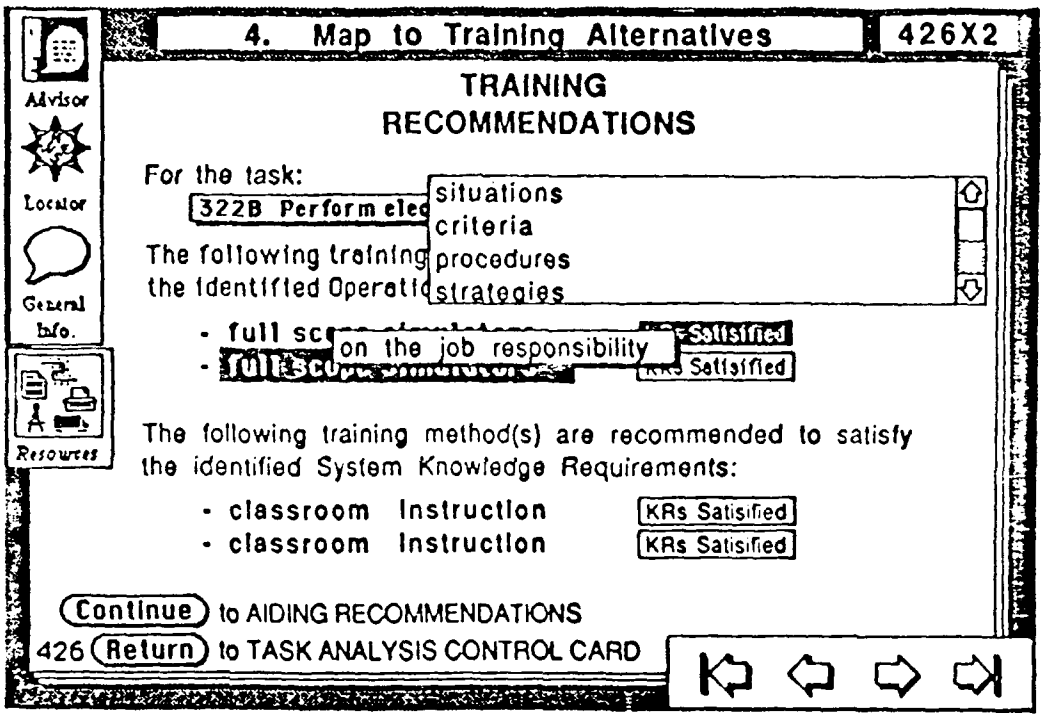

Figure 10. Training Recommendations

associated with the previous training recommendations/alternatives (i.e., operational knowledge, relative importance of effectiveness/efficiency, and trainability).

Although the current aiding recommendation scheme is based upon the knowledge requirements associated with the analyzed activity, it is hypothesized that there may be a more direct link between the activity itself and available aiding devices. Exploration of this potential link and associated heuristics, as well as other candidate input factors, is still under consideration.

As explicitly noted on Figure 11., and implicitly acknowledged in the list of satisfied knowledge requirements, system knowledge cannot be aided. Preliminary investigation indicates that only a combination of training methods and design automation will suffice in this case.

6. Make Obvious Choices. The purpose of this step is to identify those aiding/training recommendations/alternatives which satisfy a significant portion of the aiding/training requirements independent of potential combinations with other recommendations/alternatives. This process involves two basic tacts; the exploration of untrainable system knowledge requirements, and the consideration of activity specific factors.

The importance of untrainable knowledge requirements stems from the inability of aiding devices to serve as satisfactory solutions for achieving sufficient levels of proficiency regarding system knowledge. If a system knowledge requirement is untrainable (i.e., target personnel cannot achieve satisfactory levels of knowledge of the specified activity through available training methods) the "obvious choice" is to automate or redesign that activity. (See Figure 12.) This solution reveals an underlying JATAT philosophy: a less than satisfactory solution to a given knowledge requirement is always considered unacceptable.

Activity specific factors influence the "obvious choice" decision by considering ancillary issues inherent to the activity or equipment in question. For example, the existence and extent of Automatic Test Equipment (ATE) and Built-in Tests (BITs) within a particular system will greatly influence the methods by which a troubleshooting task is trained or aided. Continuation of the JATAT analysis into the modeling/simulation phase is based on the number and characteristics of the remaining aiding/training recommendations/alternatives after the paring process of this step.

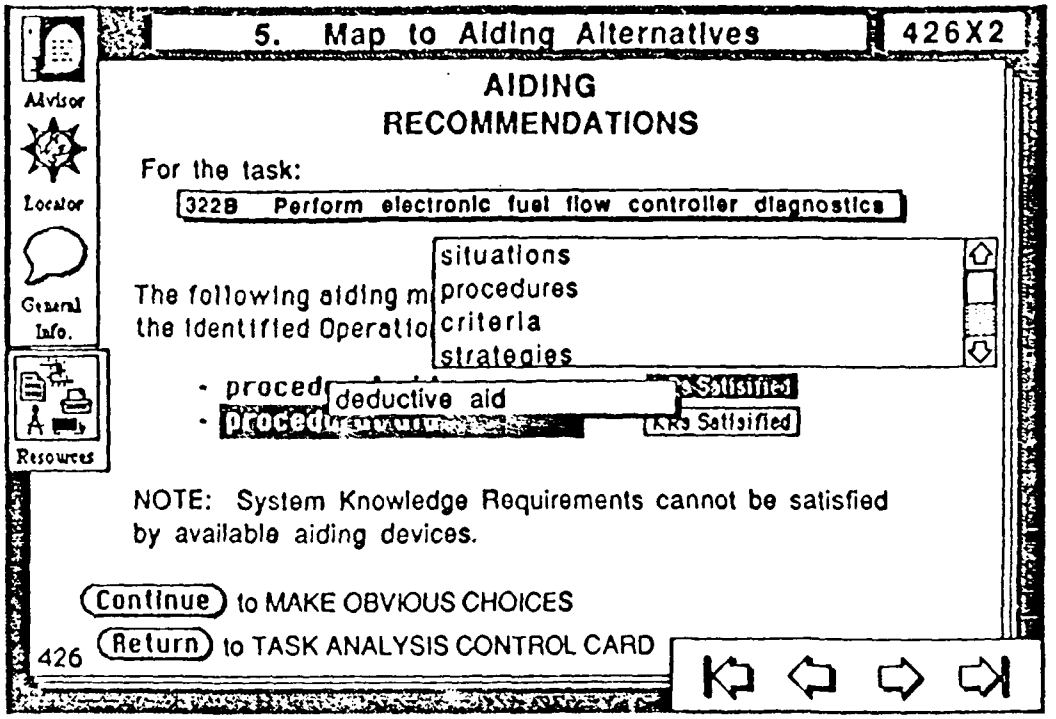

Figure 11. Aiding Recommendations

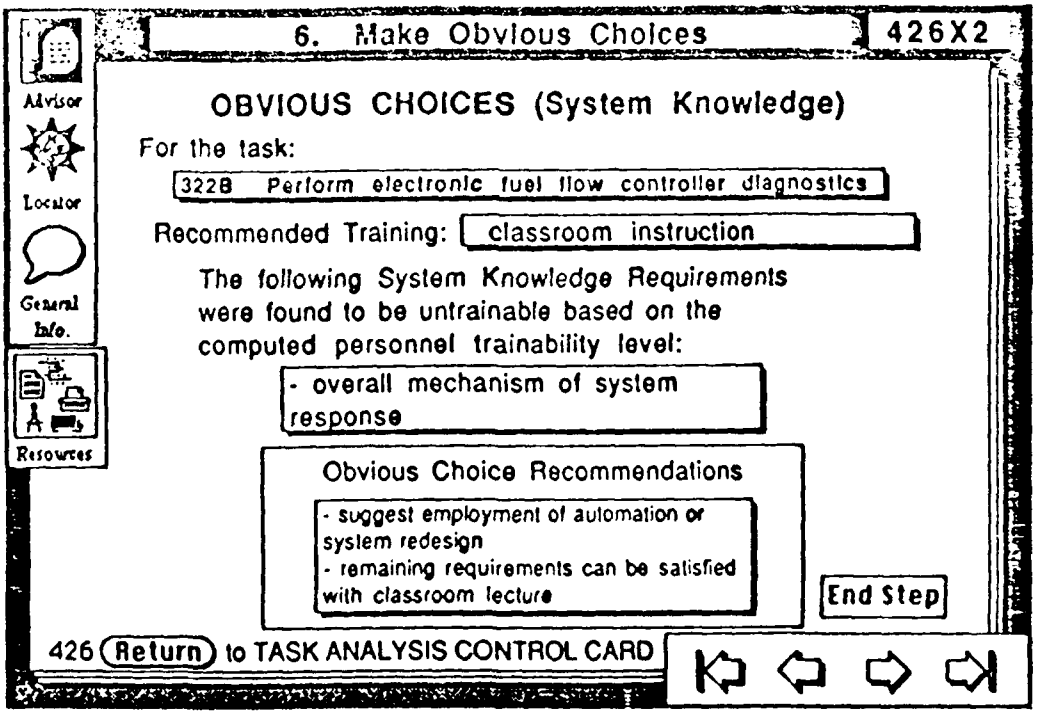

Figure 12. Obvious Choice Recommendations

7. Coalesce Tradeoffs Involving Interdependent Tasks. The by-product of removing the "obvious choice" aiding/training recommendations/alternatives from the compilation of all possible solutions in the preceding step is a complimentary list of aiding devices and training methods for which no unique advantages exist. At this level of the analysis, one or more of the aiding/training alternatives appear to satisfy the specified knowledge requirements with some level of parity. This ambiguity provides the basis for the formulation of particular aiding/training tradeoffs to be analyzed in the subsequent modeling phase of the methodology.

The actual trade-off analysis can be simplified and the power of the results increased by employing an intelligent aggregation scheme across related activities and subsequently optimizing the trade-off components. The current aggregation philosophy is to first combine candidate aiding/training solutions according to the interdependency of certain characteristics of the activities. For example, it would be reasonable to combine all troubleshooting tasks for electronic components into one group and those associated with mechanical components into another. These newly formed groups are then re-evaluated for further aggregation potential based on characteristics of the aiding/training alternatives. For instance, within the electronic trouble-shooting tasks it is plausible that the combined on-the-job training and procedural aid solution would be more effective than either alternative alone. (See Figure 13.) It is these solution sets which are traded off against one another during the modeling/simulation phase of the analysis. (Note that this coalescing process is "scripted" in the Phase 2 prototype system; no dynamic functionality has been encoded.)

An interesting side-effect of these aggregations is the potential for initiating another iteration of the "obvious choice" process. Specific activity-type factors will influence the evaluation of each aiding/training solution set much as the individual aiding/training solution evaluations were influenced during the first execution of "Make Obvious Choices". If the outcome of this process is only one viable solution set, the analysis is considered completed and the modeling portion of the framework is ignored. Should more than one component of the trade-off be accepted, the preparatory steps of applying a quantitative model are initiated.

8. Choose Measures of Performance. Choosing the measures of performance is the first in a series of steps for identifying the most useful quantitative model for analyzing a particular trade-off. The performance measure selected provides the

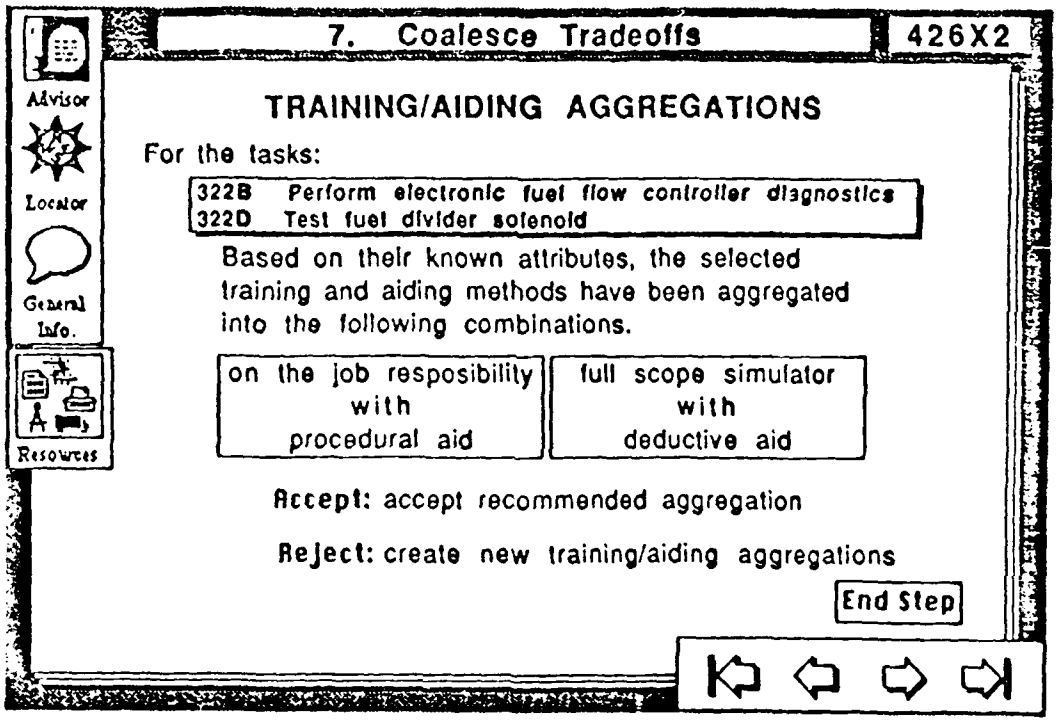

Figure 13. Tradeoff Coalescence

dimension across which each trade-off component is evaluated relative to the others. Example measures of performance include mean time to repair (MTTR), probability of error, number of errors, number of components (i.e., system complexity), etc. (See Figure 14.)

The system's response to a user's selection of a particular measure of performance is to identify the available quantitative model(s) which produce the appropriate output value.

While the system may be able to provide some descriptive guidance regarding the measures of performance it has knowledge about, it is still the responsibility of the user to determine which is most appropriate for the intended analysis. This situation defines the minimum knowledge necessary for the novice user to complete this step and is common to each of the following three steps.

9. Choose Input/Output Representations. The second step in the process of selecting a useful quantitative model is to choose the input/output representation most appropriate to the trade-off being analyzed. 'Appropriate', in this case, can be addressed as either of two dimensions; that which most accurately represents the task, and that for which the most data is available. Successful execution of the final quantitative evaluation (i.e., reliable, accurate output values) will be significantly affected by the user's ability to provide the model with an accurate description of the target system.

Comprehension of the input/output representation is an important factor in this step; the user must be able to apply the chosen input/output representation as part of the execution of the quantitative model. This application task can vary from altering single parametric values for individual system components, to providing the entire system design architecture, to a generic simulation tool. The Phase 2 prototype system permits system representation through either a functional or a physical perspective. (See Figure 15.)

10. Identify Requisite Structure and Parameters. In order to fully support the input/output representation, the user must identify the structure and parameters of the quantitative model. The purpose of this structure and parameters is to reflect the machine and human components within the system. Modeling the machine components requires certain structures such as timed sequences of specified discrete events or simulations of continuous interactive systems. Modeling the human component generally requires the simulation of certain procedures or strategies. For

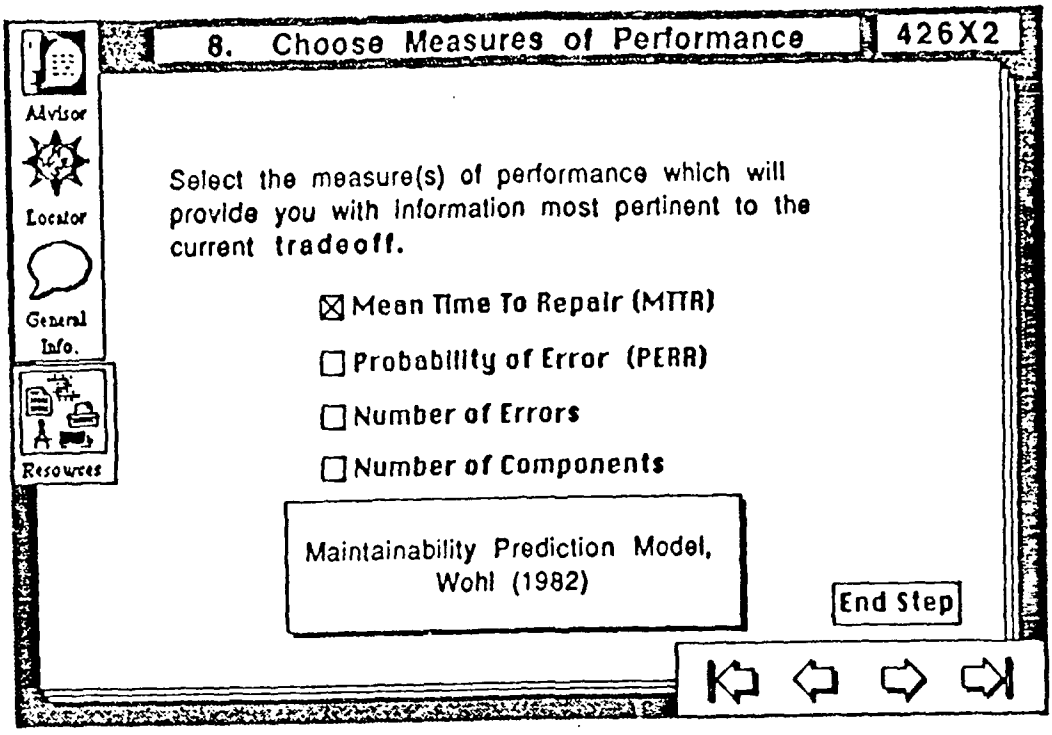

Figure 14. Measures of Performance

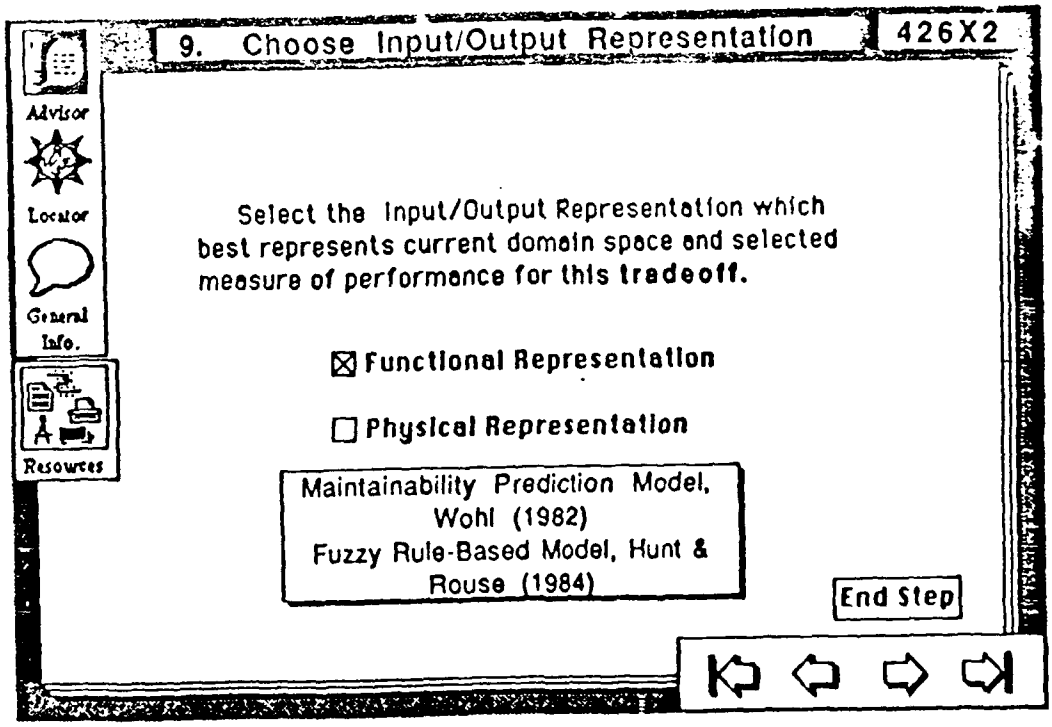

Figure 15. Input/Output Representations

instance, one trouble-shooting model may employ a "half-split" strategy (i.e., the goal of each test is to reduce the search space for the failed component by half) as its action selection criteria while another may employ a "least cost first" strategy (i.e., tests are prioritized to minimize incurred costs). In this case, the user must select the paradigm which most closely resembles the action selection criteria employed by the target personnel in the operational environment.

The extent of this step will be defined by the scope of the input/output representation and the availability of existing quantitative models. Representations of individual components or representations that are already extensively modeled will only require the identification of the parameters to be manipulated. Other situations may require extensive analysis to identify and develop the underlying structures to support the quantitative models.

11. If Necessary, Represent Learning Process. The execution of some quantitative task performance models requires a representation of the learning process by which the target personnel achieve proficiency at that task. As mentioned earlier in this report, the representation of these learning processes can range from simple database retrievals to complex learning curve models, and address such issues as cost, time, retention, etc. The user is responsible for selecting the most accurate representation for the specified task for which sufficient data is available.

12. Apply Methods of Analysis to Representations. Based on user selections in the four preceding steps, the JATAT system will present a set of recommended models (i.e., one or more based on availability and selection criteria) applicable to the trade-off being analyzed. Presentation of these recommendations, in future systems, could be in two forms; a hierarchical structure based on some weighting scheme (i.e., number of criteria satisfied), or a tabular form showing the entire model subset and associated dimensions.

The user must then select from this set that model which best suits his/her needs and apply it to each component of the trade-off in question. (See Figure 16.) The need to fully execute the selected model for each component of the trade-off in question implies several iterations of model execution, each of which requires unique user supplied input parameter values. Managing these multiple analysis iterations requires an interface design which clearly indicates the trade-off component being evaluated and its associated parametric values. (See Figure 17.)

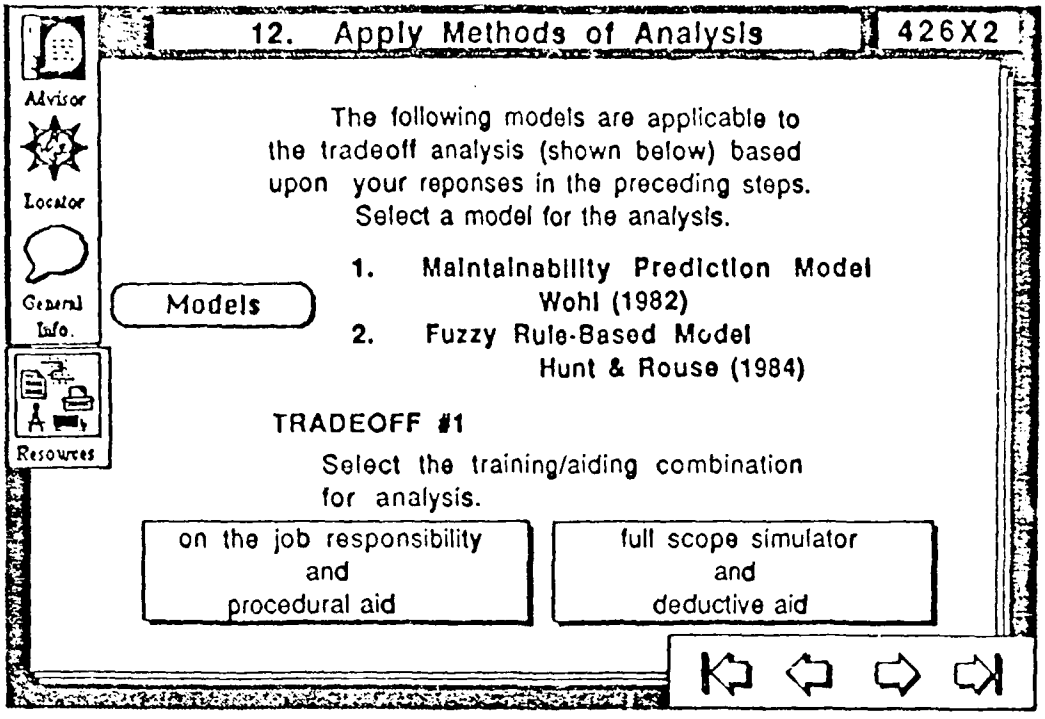

Figure 16. Applying the Methods of Analysis

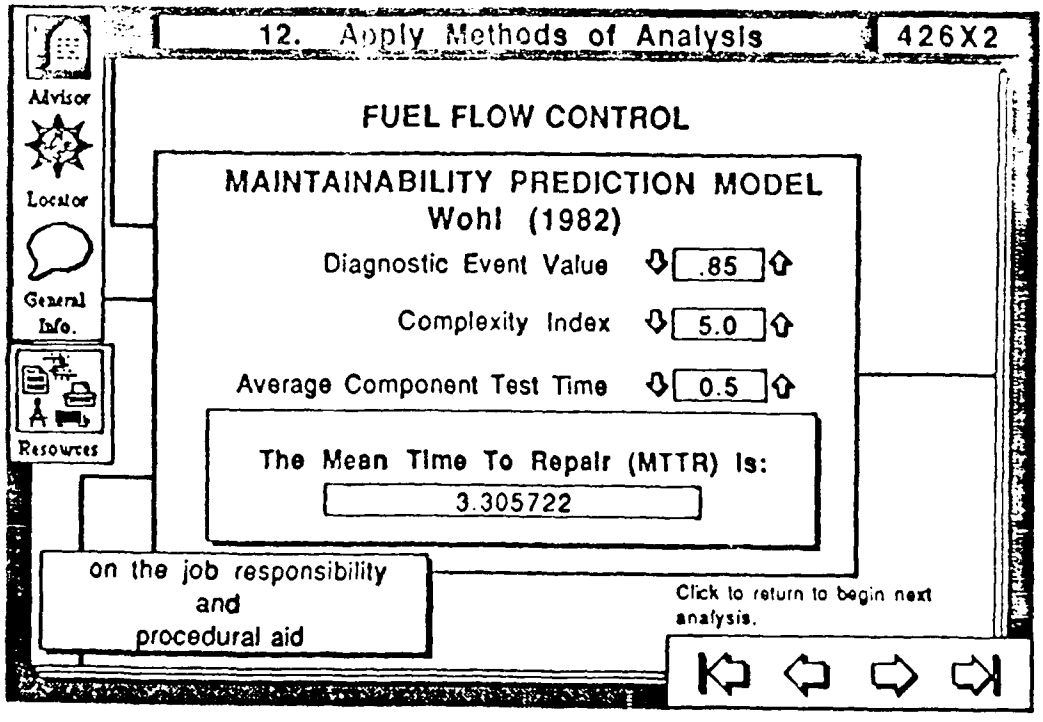

Figure 17. Interface for Maintainability Prediction Model

The model's output for each trade-off component analysis is a numeric value; not a decision. The final decision must still be made by the user in conjunction with the results from each of the other component analyses. This decision is made as part of the "Interpret Results" step.

13. Interpret Results. Result interpretation has two fundamental components; the system process, and the user decision.

The system process is similarly decomposed into two components; aggregation of results and relative assessments. Aggregation of results is the process of compiling the output values from each execution of the selected model and presenting them, along with their associated trade-off components and input parameter values, in some comprehensive manner. This step is necessary due to the potential number of trade-off components and the variable time factor for a given analysis. The system can then perform a relative assessment of the output values along some appropriate dimension (i.e., percent difference, ranking, etc.) to assist the user's final aiding/training selection decision.

As mentioned in the previous step, the quantitative modeling process results in output values and relative assessments, not a decision. The user is still responsible for making the final decision. This decision is purely textual input in nature and is not processed or reasoned about by the system. The decision is simply integrated into the documentation file for later presentation.

At this point the analysis phase of the process is complete, some level of resolution of the initial problem has been achieved, and the remaining steps in the methodology are to simply provide documentation functions to support the presentation and defense of the decision.

14. Compile Assumptions and Consequences of Tradeoffs. Due to the volume of information being generated and exchanged between the system and user during a JATAT analysis, the potential for long periods of time to transpire between the performance of successive steps in the process, and the need to document the intermediate decisions leading to a final aiding/training solution, some form of automated audit trail is necessary in a complex decision support system.

The design solution as envisioned for the JATAT DSS prototype is a log file containing each user input, decision made, path taken and system response. This file is maintained in real-time during each analysis. The existence of such a log file will

allow users to automatically update and re-initialize an analysis after any length of delay in the process, as well as output the stored information in a specified report format to assist the user's defense of the final recommendation.

15. Form Sets of Tradeoffs with Consistent Assumptions and Consequences. This final step is included to aid the user when a large number of tradeoffs have been analyzed as a result of a single originating design catalyst. The goal is to assist in identifying commonalties across each of the tradeoffs permitting a more efficient application of the aiding/training solution sets to the operational environment.

This step was not developed for the Phase 2 DSS prototype.

The Resource Environment

The JATAT support functions which led to the evolution of the Resource Environment have been categorized into the following five resources; Clerical, Data Archives, Modeling, Process Control, and Shipping/Handling. The following descriptions are provided for each resource.

Clerical. The objective of the Clerical resource is to enable system log file management independent of accessing the 15 steps and to provide tutorial guidance regarding system editorial capabilities. Management of the log files should include aspects of directory manipulation, individual file parameter and commonality searches, file editing, and identification of individual file requirements.

Data Archives. The underlying concept of the Data Archives resource is to enable access to various existing databases, for the purpose of data retrieval, while employing a single consistent interface. In the resource environment the user should be allowed access to the information across any dimension (i.e., AFS, task, equipment, etc.) and should not be restricted to those databases which are contained within the JATAT system. It is conceivable that communications protocols and access parameters would be incorporated into the system allowing remote access to numerous databases that are useful but too large to be contained within the JATAT system. The information contained within the Data Archives resource should also

include mapping and decomposition taxonomies, databases of survey data and expert heuristics, and on-line versions of training and technical manuals.

Modeling. The Modeling resource is designed to be an aggregation of independent quantitative modeling tools for solving a variety of computational problems. Within this resource the user should be able to investigate and exercise each available model -- independent of a complete methodological analysis. Modeling resource support functions should include guidance regarding associated measures of performance, input/output representations, and learning models as well as model execution and result interpretation.

Process Control. The Process Control resource is expected to function as a JATAT methodology tutorial. The function and role of each process step would be described in detail with a sample analysis employed as an example. An environment 'gateway' would allow direct access to a particular step in the process environment from its corresponding step in the Process Control resource; and vice versa.

Shipping/Handling. The Manpower, Personnel, and Training (MPT) domain space encompasses a vast number of issues from basic training graduate requirement predictions to aircraft sortie rate estimation. JATAT is just one of several decision aiding systems and simulation models in development or currently operational (e.g., LCOM,SUMMA, and TDS), designed to provide accurate solutions to these needs. In a properly integrated environment, data generated by one tool would be used as input to another.

The responsibility of the Shipping/Handling resource would be to assist in forming useful links (both data and conceptual) between JATAT and other known models. This objective would be supported through a tutorial of roles and requirements of other known MPT tools and a data processing capability which would format the JATAT results and decisions to expedite the potential data transfer process.

The Advisor

In order to successfully employ an aiding/training decision support system with the level of complexity equivalent to that expected of a fully developed JATAT system, the user will require some form of simple, elegant, yet powerful method of assistance. From this predicted need has evolved the current concept of the intelligent advisor.

The role to be played by this intelligent advisor is as the unobtrusive, ubiquitous mentor. This implies that the advisor would be discreetly aware of each interaction the user has with the system, but becomes visible for advice only upon command.

The advice and assistance provided must span several levels of detail and abstractness. This would be manifest in the ability to identify the user's current status in the overall analysis process, recall previous inputs and decisions, and predict likely implications of the historical behaviors. The advisor's knowledge repertoire should also include a history of the user's movement through the system, decisions made at each juncture, data input and data deficits, and procedure transgressions. It is also important that the advisor be able to provide advice at various levels of detail corresponding to each category of user abilities, as well as to know which level of advice is appropriate.

The current implementation of the advisor function is "scripted" and very context specific. The target goal for such a function, however, would likely be a context-sensitive expert system.

Supporting Data Types

Similar to other decision aiding paradigms, the models necessary to support the JATAT methodology are extremely information dependent. The type/format of data required by each component of the decision process will vary as a function of the characteristics of the intermediate decision constructs. For JATAT, these data requirements can be classified into three types; archival data, user provided contextual information, and expert rules/algorithms inherent to the system.

Archival data is operationally defined, for the purpose of this report, as the factual personnel, task and equipment information typically collected through occupational surveys or compiled from system operation and maintenance documents. This includes such data as task/sub-task listings, performance times/probabilities/and requirements, task and equipment complexity, aptitude/experience, and training indicators. In the JATAT aiding/training decision support paradigm, archival data serve as both the target data to be processed by the JATAT models, and as the user's source of domain knowledge. Currently, this information resides in a miscellany of data sources which include the Occupational Research Data Bank (ORDB), AF Regulations, career development training manuals, Air Training Command Plans of Instruction (POI's), and equipment technical manuals.

Contextual information is the abstract, highly situation specific data which represents the background scenario of the archival data. This information is primarily characterized by its relational nature. It encompasses those factors which preceded (and subsequently, effected) the aiding/training analysis (i.e., decision catalysts), and the environmental ramifications (i.e., political, temporal, and resource-related) of the candidate aiding/training solutions.

The context specific/temporal nature of this data precludes simple codification. Rather, a JATAT analysis is dependent upon the user as the sole source of this information. This data is presented to the system in two manners; direct input to system queries (e.g., choosing to emphasize the effectiveness or efficiency of the training method) or indirect process guidance decisions (e.g., opting to analyze only two of three recommended trade-off components).

System inherent data contains the knowledge which guides the analysis process, intelligently responds to user decisions, provides advice, simulates target system performance, and makes aiding/training recommendations. This data is primarily in the form of taxonomies, and expert rules resident in the system knowledge bases. Included in this category are potential training/aiding methods, training philosophies, operational/system knowledge requirements, modeling packages, input/output parameters, etc. This knowledge is established during the system design and development phases and is obtained through knowledge acquisition sessions with relevant domain experts.

IV. SUMMARY

This final section of the report is a compilation of the "lessons learned" during the Phase 2 JATAT concept development, execution, and implementation. These "lessons", which address such issues as the characteristics of the data required to execute the methodology, additional support functionality, and MPT model integration/standardization, can provide valuable insight to future aiding/training decision support efforts.

For the purpose of this summary, lessons learned have been divided into the following two categories; those addressing the development of an implementable aiding/training decision support methodology, and those addressing system application oriented functionality.

Methodology Lessons

Standard Task Definitions

The importance of formulating universally accepted, standardized task definitions (i.e., terminology and level of resolution) represents a single, cogent conclusion drawn from three independent issues. First, the accuracy and responsiveness of a computer-based decision aiding application is directly dependent upon the mapping of unfamiliar task to well-understood taxonomies. Complicating this mapping by representing tasks at various levels of abstraction decreases the power and success of the aiding/training recommendations. The second issues supporting the pursuit of a standardized task definition effort is that current task listings lack consistency in their granularity of task specification. For example, the Air Force Occupational Research DataBank specifies both form completion and propulsion system trouble-shooting at the task level. No explicit standard is established regarding time required, number and/or type of activities involved, focus of aiding/training solutions, etc. This inconsistency among critical task dimensions also complicates the process of transitioning information among different decision models. Recent Air Force emphasis on MPT model integration, the third issue, is directed toward developing consistency and relatedness among the numerous decision models. Definition standardization within, and across, models and databases is essential to facilitate such a concept.

Data Availability

In the pursuit of the archival data necessary to perform the operational AFS analyses (see Appendix A) for this effort, it became evident that data availability is an issue of great importance as well. Specifically, data availability in terms of the data's format (i.e., how closely the existing data format conforms to that required by the system defines the degree of pre-processing necessary) and the medium within which the data resides (i.e., hard, bound copies vs. a computer-based data bank). Each level of extrapolation, interpolation and media transformation required to apply the data to the methodological framework, in essence, decreases the inherent utility of the data. Unfortunately, current data sources vary widely along both of these dimensions. Therefore, commitment and effort will be required to structure available data sources to more directly support the integrated environment of the many new decision aiding and modeling systems.

Knowledge Deficits

In the current JATAT framework, Operational and System Knowledge Requirements are specified for a given activity independent of consideration of the personnel responsible for performing that activity. Hence, the system generated aiding/training recommendations implicitly assume 100% knowledge deficit for each specified knowledge requirement. This assumption disregards the likelihood of transfer of knowledge based previous experience and training. Continued investigation is necessary to identify the impact of varying levels of knowledge deficit on the formulation of aiding/training recommendations.

Individual Skills

This phase of effort focused on knowledge as the dimension along which the limitations and abilities of the target personnel was measured. While this perspective provided the foundation for aiding/training recommendation heuristics, it was also clear that individual skill plays an equally important role in this selection process. Future development of these aiding/training rules must consider the impact of skill related limitations and abilities and their interaction with previously established knowledge-based heuristics.

Application Oriented Functionality

Simulation Environment

The availability of simulation models for predicting human-system performance is highly domain dependent. For instance, while there are a fair number of maintenance and/or operations models in existence, the availability of similar models for instructional or clerical tasks is extremely limited, if at all existent. Frequently, those models or tools which do exist are so highly specific that the analysis of related, but slightly different tasks are currently unsupported.

To create and implement models or tools to support every potential task analysis would be an insurmountable effort. More reasonably, this situation necessitates a single, robust simulation environment which can be applied generally to a class of tasks.

Modeling Tutorial

Another related functionality essential to an operational JATAT system is a modeling-domain tutorial. One assumption made regarding each potential JATAT user was that while they would be fairly knowledgeable about the aiding/training domain in general, they would be less so regarding the particular the application of specific performance prediction models. In this case, it is imperative that a final JATAT system provide some level of tutorial functionality for accessing and executing each of the available quantitative models. This would include start-up, data input, and result interpretation instructions for those models developed independently of the JATAT system, as well as the aforementioned generic simulation environment.

Model Selection

In the current methodological scheme, quantitative model selection is based on a series of sequential steps during which model characteristics applicable to the specific analysis are identified. However, the performance of the operational AFS analyses (as described in Appendix A) indicated that this process need not be so highly sequential. It appears, instead, that this process can occur with equal success given the same selections regardless of order. As a result, future interface functionality development should be directed at supporting this phenomenon.

In summary, the success of the Phase 2, Job Aiding/Training Allocation Technologies effort has been threefold. It has resulted in the development of a general aiding/training trade-off decision methodology, the application of this methodology to two independent analyses of operational AFS's, and the implementation of this methodology into a computer-based decision support demonstration system. While these successes make no implications regarding the maturity and readiness of the technology, they do indicate that the solution is tenable. It will be further research into the areas of the input factor relationships within aiding/training domain, continued trade-off decision methodology formulation, supporting database development, predictive model generation, and the design of decision support system functionality that will help bring the JATAT concept to reality.

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APPENDIX A

OPERATIONAL AFS ANALYSES

The purpose of this section is to document the analyses of the two AFHRL approved AFS's (i.e., 426X2 and 911X0) using the decision framework and expert heuristics developed during this phase of the JATAT effort. The dialogue of inputs, decisions, and recommendations between the user and the system is documented for each step in the JATAT methodology to assist in guiding the user through each complete, DSS aided analysis process.

426X2, Jet Engine/Turbo-Prop Maintenance Analysis

Scenario:

The AF has recently approved the modification of the Pratt-Whitney F-100 Engine. One component of this modification includes replacing the original electro-mechanical fuel flow controller with a newly developed solid-state controller. Maintenance of this engine and the respective fuel system is the responsibility of the 426X2, Jet Engine/Turbo-Prop Maintenance Technician. The task of the JATAT user is to identify the necessary changes to the current training/aiding scheme for fuel flow controller maintenance.

1. Understand the Job

The user initiates a directed search for the 426X2 AFSC and the system responds with the available archival data for:

AFS: 426X2, Jet Engine/Turbo-Prop Maintenance Technician

The user's knowledge of this AFS is sparse so a review of the available data including AF Reg 39-10, the CDC Manuals and the ORDB reports and statistics is conducted.

2. Decompose via Task Taxonomy

During the ORDB data review, the user accesses the list of tasks for which the 426X2 is responsible. The large number of identified tasks (i.e., approximately 700) precludes an efficient sequential search for those tasks affected by the design change. Therefore, the task search space is narrowed through an automated search on the key word "fuel". The user selects only one of the returned tasks for analysis:

Task: G322 Isolate Malfunction with Engine Fuel System

(It is the only one which deals directly with the engine fuel flow controller.)

Decomposition of this task occurs automatically based upon pre-established procedural activities as defined in the equipment technical maintenance manuals.

Activities:

G322 A Verify power to the fuel pump
G322 B Perform fuel flow controller diagnostics
G322 C Inspect fuel injector nozzles
G322 D Test fuel divider

The user then identifies activities B and D as those affected by the proposed design change and edits them accordingly.

Edited Activities:

G322 B Perform electronic fuel flow controller diagnostics
G322 D Test fuel divider solenoid

3. Assess Limitations, Abilities, and Preferences

The user identifies the knowledge requirements (limits) associated with each target task from the Operational and System Knowledge taxonomies.

G322 B Perform electronic fuel flow controller diagnostics
Knowledge Requirement Limits (Operational)

Situations
Procedures
Operational Basis
Criteria
Strategies
Logical Basis
Methodologies

Knowledge Requirement Limits (System)
Characteristics of System Elements
Functioning of System Elements
Requirements Fulfilled
Relationships Among System Elements
Co-Functioning of System Elements
Temporal Patterns of System Response
Overall Mechanism of System Response

G322 D Test fuel divider solenoid
Knowledge Requirement Limits (Operational)
Situations
Procedures
Criteria

Knowledge Requirement Limits (System)
Characteristics of System Elements
Functioning of System Elements
Relationships Among System Elements
Co-Functioning of System Elements
Temporal Patterns of System Response

4. Map Limitations, Etc. to Taxonomy of Training Alternatives

The user then specifies the relative importance of effectiveness and efficiency for determining the training recommendations and alternatives.

Effectiveness = High
Efficiency = Low

A final factor the system requires prior to formulating the training and aiding recommendations is a general level of ability (relative to the knowledge requirements) the target personnel can be expected to achieve. This is represented as the trainability of the personnel and is computed based upon user input to the following queries.

Aptitude: Medium
Experience: High
Category of Technology: New
Category of Design: New

The system determines a trainability level of three (3) for an individual in this situation.

Based on this input and the knowledge requirements chosen in the previous step, the system responds with the following training recommendations and alternatives and presents the knowledge requirements satisfied by that particular recommendation/alternative.

G322 B Perform electronic fuel flow controller diagnostics
Active Training = Full-Scope Simulator
On-the-job Responsibility (Alternate)
Situations
Procedures
Operational Basis
Criteria
Strategies

Passive Training = Classroom Instruction
Classroom Discussion (Alternate)
Characteristics of System Elements
Functioning of System Elements

Requirements Fulfilled
Relationships Among System Elements
Co-Functioning of System Elements
Temporal Patterns of System Response

G322 D Test fuel divider solenoid
Active Training = Full-Scope Simulator
On-the-job Responsibility (Alternate)
Situations
Procedures
Criteria

Passive Training = Classroom Instruction
Classroom Discussion (Alternate)
Characteristics of System Elements
Functioning of System Elements
Relationships Among System Elements
Co-Functioning of System Elements
Temporal Patterns of System Response

5. Map Limitations, Etc. to Taxonomy of Aiding Alternatives

No further input is required of the user for this step; the recommendations are based on previous inputs. Simple user access of this step is all that is required to investigate the system's aiding recommendations. The DSS indicates that no System Knowledge Requirements are satisfied by the prescribed aiding recommendations/alternatives while noting that they cannot be satisfied through the use of aiding devices. (This situation is dealt with during the Make Obvious Choices step.)

G322 B Perform electronic fuel flow controller diagnostics
Aiding Device = Procedural Aid
Deductive Aid (Alternate)
Situations

Procedures
Operational Basis
Criteria
Strategies

G322 D Test fuel divider solenoid
Aiding Device = Procedural Aid
Deductive Aid (Alternate)
Situations
Procedures
Criteria

6. Make Obvious Choices

The level of resolution provided by the DSS mapping heuristics allows this step to be performed automatically by the system. Thus, the user must simply access the step in order to investigate the system's recommendations. Since aiding devices are not applicable for the System Knowledge Requirements, Obvious Choice recommendations are initially based on those which can be trained and indicates those knowledge requirements which, based on the pre-established trainability level, can not be trained.

G322 B Perform electronic fuel flow controller diagnostics
Training Method Recommendation:
Classroom Instruction

Untrainable System Knowledge Requirements:
Overall Mechanism of System Response
(Requires automation or system redesign to satisfy.)

G322 D Test fuel divider solenoid
Training Method Recommendation:
Classroom Instruction

Untrainable System Knowledge Requirements:
None

7. Coalesce Tradeoffs Involving Interdependent Tasks

At this point in the process, the aiding/training recommendations and alternatives are combined across activities to form viable sets of aiding/training solutions. Each set forms one component of the overall trade-off decision.

Component #1:	Component #2:
On-the-job Responsibility	Full-scope Simulator
with	with
Procedural Aid	Deductive Aid

The user may accept this aggregation and continue with the analysis or reject it and formulate their own. Acceptance ensures continued system support.

The system may also enter an iterative loop at this point (based upon known characteristics of the decision domain and the trade-off in question) to establish more Obvious Choice selections. This would be indicated by specialized DSS queries. User responses to these queries would result in different paths through the remaining analysis. For example:

Are Automatic Test Equipment (ATE) or Built-In Tests (BIT) available?

If ATE and BIT are not available, only component #2 is applicable; the trade-off decision is non-existent and the analysis could be considered complete. If ATE and BIT are available, both components remain applicable and the analysis must be performed to delineate them. (User responds to the affirmative to this query.)

8. Choose Measures of Performance

Currently only four measures of performance are available for selection (mean time to repair, probability of error, number of errors, and number of components changed); conceivably many more could be made available. Selection of a particular measure of performance results in a system response which indicates those models which satisfy that performance measure requirement.

The user's choice of Mean Time to Repair (MTTR) is answered with a system recommendation to employ the Maintainability Prediction Model (Wohl, 1982).

9. Choose Input-Output Representations

The input/output representation indicates the perspective with which the quantitative model views the problem space. The two available representations are physical (e.g., a schematic diagram) and functional.

The user opts to use a functional representation for this analysis. The available models which employ this form of representation include the Maintainability Prediction Model (Wohl, 1982) and the Fuzzy Rule-Based Model (Hunt & Rouse, 1984).

10. Identify Requisite Structures and Parameters

These structures and parameters are decision rules inherent to the model algorithm.

The user knows that a "half-split" test node selection strategy is used by the maintenance technicians in the field. This particular troubleshooting strategy is considered an Action Selection Criterion parameter and is thus selected. A Task Analysis is Not Available for this scenario. The resultant model is, again, the Maintainability Prediction Model (Wohl,1982).

11. If Necessary, Represent Learning Process

These Learning Representations usually include some form of learning curves, or human memory model applicable to that particular task and model.

This step is not applicable to the models under consideration.

12. Apply Methods of Analysis to Representations

The user must select the Method of Analysis (model) to execute for the analysis of this particular trade-off.

The Maintainability Prediction Model (Wohl,1982) is chosen. Each individual component of the trade-off is then analyzed separately using the same model. The following values are supplied to the model.

Component #1:	Component #2:
On-the-job Responsibility	Full-scope Simulator
with	with
Procedural Aid	Deductive Aid
Diagnostic Event Value = .85	Diagnostic Event Value = .85
Complexity Index = 5.0	Complexity Index = 2.5
Avg. Comp. Test Time = .5	Avg. Comp. Test Time = .5

13. Interpret Results

The system compiles all component analyses and presents them in one cohesive report with a low level analysis of the relative values.

Component #1:	Component #2:
On-the-job Responsibility	Full-scope Simulator
with	with
Procedural Aid	Deductive Aid
MTTR = 3.306	MTTR = 1.153

The MTTR for component #1 is approximately 100% greater than for component #2.

14. Compile Assumptions and Consequences of Tradeoffs

The system has retained all inputs, decisions, recommendations/alternatives, computational output as part of the log file. The user may chose to save or delete this file and/or print a hard copy.

15. Form Sets of Tradeoffs with Consistent Assumptions and Consequences

Since only one trade-off was analyzed, this step is declared Not Applicable by the system.

911X0, Aerospace Physiology Analysis

Scenario:

With recent discoveries of the effects of high altitude flight on aircrew members the Air Force has instituted a new instructional requirement for all aircrews regarding aircraft pressurization. The course will be a major revision of the current aircraft pressurization course taught by AF medical technicians, 911X0's, as an extension to the current in-flight physiology program. The course has been designed to include the latest in instructional aids and techniques so a training/aiding profile has been requested to assist these technicians in presenting the new material.

1. Understand the Job

The user initiates a directed search for the 911X0, Aerospace Physiology AFSC and, based on personal experience with previous analyses of this specialty, traverses the system directly to the Decompose via Task Taxonomy step.

2. Decompose via Task Taxonomy

The user accesses the Occupational Survey Research (OSR) list of tasks established for this AFS, narrows the search space through an automated search on the key phrase, and inputs "conduct classroom instruction". The following task is selected from those which satisfied the search phrase.

> Task: G199 Conduct Classroom Instruction on Principles of Aircraft Pressurization

Due to the variety of instructional tasks available, decomposition of this task is based on the generic activity taxonomy associated with conducting classroom instruction.

Activities:

G199 A Knowledge about Subject Matter
G199 B Knowledge about Instruction
G199 C Presentation
G199 D Interaction
G199 E Assessment
G199 F Diagnosis
G199 G Remediation

The user identifies all activities as being affected by the proposed new course and assumes them to be sufficient for the current analysis.

3. Assess Limitations, Abilities, and Preferences

The user identifies the knowledge requirements (limits) associated with each target task from the Operational and System Knowledge taxonomies.

G199 A Knowledge about Subject Matter
Assume No Deficits

G199 B Knowledge about Instruction
Knowledge Requirement Limits (Instructing)
Episodes and Situations Which Can Arise in the Instructional Setting
Procedures for Dealing with Episodes and Situations in the Instructional Setting
Instructional Priorities

Knowledge Requirement Limits (Instructional)
Characteristics of Elements of Instructional System

G199 C Presentation
Knowledge Requirement Limits (Instructing)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

Knowledge Requirement Limits (Instructional)

Characteristics of Elements of Instructional System

G199 D Interaction

Knowledge Requirement Limits (Instructing)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

Strategies for Dealing with Episodes and Situations in the Instructional Setting

Knowledge Requirement Limits (Instructional)

Characteristics of Elements of Instructional System

Functioning of Elements of Instructional System

Relationships Among Elements of Instructional System

G199 E Assessment

Knowledge Requirement Limits (Instructing)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

Knowledge Requirement Limits (Instructional)

Characteristics of Elements of Instructional System

G199 F Diagnosis

Knowledge Requirement Limits (Instructing)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

Knowledge Requirement Limits (Instructional)

Characteristics of Elements of Instructional System

G199 G Remediation

Knowledge Requirement Limits (Instructing)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

Knowledge Requirement Limits (Instructional)

Characteristics of Elements of Instructional System

Functioning of Elements of Instructional System

Relationships Among Elements of Instructional System

4. Map Limitations, Etc. to Taxonomy of Training Alternatives

The user then specifies the relative importance of effectiveness and efficiency for determining the training recommendations and alternatives.

Effectiveness = Low

Efficiency = High

A final factor the system requires prior to formulating the training and aiding recommendations is a general level of ability (relative to the knowledge requirements) the target personnel can be expected to achieve. This is represented as the trainability of the personnel and is computed based upon user input to the following queries.

Aptitude: Medium
Experience: Low
Category of Technology: Old
Category of Design: New

The system determines a trainability level of two (2) for an individual in this situation.

Based on this input and the knowledge requirements chosen in the previous step, the system responds with the following training recommendations and alternatives and presents the knowledge requirements satisfied by that particular recommendation/alternative.

G199 A Knowledge about Subject Matter
G199 B Knowledge about Instruction
Active Training = Student Teaching
On-the-job Responsibility (Alternate)
Episodes and Situations Which Can Arise in the Instructional Setting
Procedures for Dealing with Episodes and Situations in the Instructional Setting
Instructional Priorities
Passive Training = Classroom Instruction
Classroom Discussion (Alternate)
Characteristics of Elements of Instructional System

G199 C Presentation.
Active Training = Student Teaching

On-the-job Responsibility (Alternate)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

Passive Training = Classroom Instruction

Classroom Discussion (Alternate)

Characteristics of Elements of Instructional System

G199 D Interaction

Active Training = Student Teaching

On-the-job Responsibility (Alternate)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

Strategies for Dealing with Episodes and Situations in the Instructional Setting

Passive Training = Classroom Instruction

Classroom Discussion (Alternate)

Characteristics of Elements of Instructional System

Functioning of Elements of Instructional System

Relationships Among Elements of Instructional System

G199 E Assessment

Active Training = Student Teaching

On-the-job Responsibility (Alternate)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

Passive Training = Classroom Instruction
Classroom Discussion (Alternate)
Characteristics of Elements of Instructional System

G199 F Diagnosis
Active Training = Student Teaching
On-the-job Responsibility (Alternate)
Episodes and Situations Which Can Arise in the Instructional Setting
Procedures for Dealing with Episodes and Situations in the Instructional Setting
Instructional Priorities
Passive Training = Classroom Instruction
Classroom Discussion (Alternate)
Characteristics of Elements of Instructional System

G199 G Remediation
Active Training = Student Teaching
On-the-job Responsibility (Alternate)
Episodes and Situations Which Can Arise in the Instructional Setting
Procedures for Dealing with Episodes and Situations in the Instructional Setting
Instructional Priorities
Passive Training = Classroom Instruction
Classroom Discussion (Alternate)
Characteristics of Elements of Instructional System
Functioning of Elements of Instructional System
Relationships Among Elements of Instructional System

5. Map Limitations, Etc. to Taxonomy of Aiding Alternatives

No further input is required of the user for this step; the recommendations are bases on previous inputs. Simple user access of this step is all that is required to

investigate the system's aiding recommendations. The DSS indicates that no System Knowledge Requirements are satisfied by the prescribed aiding recommendations/alternatives while noting that they cannot be satisfied through the use of aiding devices. (This situation is dealt with during the Make Obvious Choices step.)

G199 A Knowledge about Subject Matter
Aiding Device = Computer-Based Instruction
Procedural Check-list (Alternate)
Episodes and Situations Which Can Arise in the Instructional Setting
Procedures for Dealing with Episodes and Situations in the Instructional Setting
Instructional Priorities

G199 B Knowledge about Instruction
Aiding Device = Computer-Based Instruction
Procedural Check-list (Alternate)
Episodes and Situations Which Can Arise in the Instructional Setting
Procedures for Dealing with Episodes and Situations in the Instructional Setting
Instructional Priorities

G199 C Presentation
Aiding Device = Computer-Based Instruction
Procedural Check-list (Alternate)
Episodes and Situations Which Can Arise in the Instructional Setting
Procedures for Dealing with Episodes and Situations in the Instructional Setting
Instructional Priorities

G199 D Interaction

Aiding Device = Computer-Based Instruction

Procedural Check-list (Alternate)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

Strategies for Dealing with Episodes and Situations in the Instructional Setting

G199 E Assessment

Aiding Device = Computer-Based Instruction

Procedural Check-list (Alternate)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

G199 F Diagnosis

Aiding Device = Computer-Based Instruction

Procedural Check-list (Alternate)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

G199 G Remediation

Aiding Device = Computer-Based Instruction

Procedural Check-list (Alternate)

Episodes and Situations Which Can Arise in the Instructional Setting

Procedures for Dealing with Episodes and Situations in the Instructional Setting

Instructional Priorities

6. Make Obvious Choices

The level of resolution currently provided by the DSS mapping heuristics allows this step to be performed automatically by the system. Thus, the user must simply access the step in order to investigate the system's recommendations. Since aiding devices are not applicable for the System Knowledge Requirements, Obvious Choice recommendations are initially based on those which can be trained and indicates those knowledge requirements which, based on the pre-established trainability level, can not be trained.

All Activities have same recommendation:

G322 A Knowledge about Subject Matter
G322 B Knowledge about Instruction
G322 C Presentation
G322 D Interaction
G322 E Assessment
G322 F Diagnosis
G322 G Remediation

Training Method Recommendation:

Classroom Instruction

Untrainable System Knowledge Requirements:

None

User Enters:

Class Size: Large
Course Frequency: Moderate

The user then responds (negative) to a query requesting the availability of Computer-Based Instruction. The system responds by formulating a single aiding/training component: Student Teaching with Procedural Checklist.

With only one viable aiding/training component, no tradeoffs exist and, therefore, further analysis is not applicable. The user can directly go to the Compile Assumptions step.

14. Compile Assumptions and Consequences of Tradeoffs

The system has retained all inputs, decisions, recommendations/alternatives, computational output as part of the log file. The user may chose to save or delete this file and/or print a hard copy.

15. Form Sets of Tradeoffs with Consistent Assumptions and Consequences

Not Applicable.