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Technical Report 612

Guidance for Designers of Field Artillery Tactical Data Systems

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a general approach for developing design concepts for later generation Field Artillery Tactical Data Systems (FATDS) or any remotely controlling military or industrial system. It will help FATDS program development managers to conceptualize the early design process for hybrid and later generation systems.

The Concept Design Management Approach (CDMA) described in this report possesses a number of significant features: (Continued)

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Item 20 (Continued)

1. It conceives of a FATDS as an information processing system with both human and machine components.

2. It incorporates a general cognitive model for guiding the analysis of commanding and monitoring activities.

3. It guards against the adoption of design concepts that fail to meet field requirements during the future target period or that are technologically outmoded by the time the system is fielded.

4. It identifies the judgments that need to be made to develop a FATDS design concept.

5. It identifies the personnel and group processes best suited for making each judgment.

6. It uses multi-attribute utility technology (MAUT) for assigning numeric values to judgments and for aggregating different kinds of judgments. It provides for weighting the various judgments to reflect management interests and concerns.

7. It specifies trade-off matrices for selecting and improving system design and interface concepts.

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FOREWORD

The Army has recently fielded the first generation Tactical Data System for the Field Artillery--the Tactical Fire Direction System (TACFIRE). TACFIRE is a capable system but it is recognized that this represents an outmoded tactical data system; current technology has made significant strides during the development, testing, and fielding of this system. Advanced tactical data system alternatives are being considered to modernize the Army's present capability but these alternatives are likely to be driven by hardware technology with less thought given to operator/machine transaction skills which are difficult to learn and/or retain unless the acquisition cycle can be influenced in its early phases. The Army Research Institute sought to develop a general approach for developing design concepts for later generations Field Artillery Tactical Data Systems (FATDS). The target audience for this effort is the managers and management teams responsible for developing advanced FATDS. This report should help to conceptualize the early design processes for these systems.

EDGAR M. JOHNSON
Technical Director

EXECUTIVE SUMMARY

This report describes a general approach for developing design concepts for later generation Field Artillery Tactical Data Systems (FATDS). The target audience for this report is the managers and management teams responsible for developing advanced FATDS. This report will help managers to conceptualize the early design processes for these systems.

It was determined that trade-off analyses among alternative concept designs for a system can not be developed and applied usefully without first specifying the characteristics of the inputs to the trade-off analysis, how those inputs are to be developed, and how the outputs from the trade-off analysis are to be used to further the development of the system design. The management approach described in this report distinguishes the concept design of a system from its engineering design. It includes procedures for developing alternative concept designs, for conducting trade-off analyses among the alternatives, and for integrating the better features of the non-selected alternatives into the selected alternative. The output from this approach provides the basis for the engineering design of the emerging system.

The Concept Design Management Approach (CDMA) described in this report is characterized by eleven significant features:

1. It is a rational approach for developing the design concept for a FATDS. It consists of two major processes:
    a. A front end analysis process (1) which collects or generates information about the environments and situations in which the FATDS will operate, (2) which identifies the response demands which must be met by the FATDS, and (3) which specifies the minimum human role which must be supported by the system.
    b. A design concept process (1) which allocates information processing activities in the emerging system concept to human or machine components and (2) which specifies the interface characteristics required to support mental information processing of commanders and operators of the FATDS.
2. It conceives of a FATDS (or any C^3 system) as being an information processing system performed both by machine and human components.
3. It provides a general cognitive model for insuring at least a minimum role for humans as commander/monitor of the system. This model provides guidance for analyzing the activities which make up this role.

4. It encourages the consideration of established technologies, state-of-the-art technologies, and foreseeable technologies to insure that the resulting system concept is not outmoded by the time the system is fielded.

5. It identifies the various kinds of human judgments that need to be made in developing a design concept for a FATDS.

6. It identifies the characteristics of personnel best suited for making each kind of judgment.

7. It specifies particular group process techniques for obtaining the best possible judgments from the appropriate personnel. These techniques provide for the mixing of personnel with different qualifications in each group so that each can bring his or her own special qualifications to bear on the judgments in an optimum manner.

8. It specifies techniques for assigning numeric values to judgments and for aggregating judgments from different raters. The aggregation procedures allow for the introduction of differential weights which reflect management interests and criteria.

9. It specifies trade-off techniques for using the numeric values assigned to judgments regarding the impact of alternative concepts on critical factors for selecting the best of several alternative design or interface concepts.

10. It specifies techniques for using the numeric values assigned to judgments regarding the impact of a design or interface concept on critical factors for improving the concept.

11. It provides a basis for developing a detailed audit trail of the entire design concept process.

The approach described in this report offers the design management team a number of attractive benefits:

1. It provides a rational and fully described approach which can either be incorporated into the project intact or used as a first approximation in developing their own fully explicated approach. The CDMA is very flexible and can be readily adapted to meet specialized needs and interests.

2. It provides a division of activities that can be used for measuring progress and making assignments.

3. It provides a basis for project stability even through major personnel changes. New personnel can readily review the audit trail of past activities and the projection of future activities.

4. It provides assurance that the design concept that evolves from the application of the approach is the best that could be developed at that time with the personnel and resources available.

At this time, the CDMA exists more as a very detailed proposal since it has not actually been tried out as an intact process. A tryout would help develop or firm up details in the process. However, all of its features are drawn from established behavioral science technology. There is no doubt about it being a workable process, but adjustments will be needed during its early applications.

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INTRODUCTION

BACKGROUND

The U.S. Army Field Artillery Branch has fielded its first generation tactical data system--TACFIRE. Hybrid and second generation systems are already being considered. During the next two decades, there will probably be a series of design and development efforts concerned with improving the existing TACFIRE system and with supplanting it in time with highly advanced tactical data systems. This report describes a concept for a general design process for developing improved or new tactical data systems. This design process emphasizes the design of systems (1) that will meet the battlefield needs for which they are designed and (2) that optimize usability of the system by operators and commanders. This design process is intended to be used by concept developers and system designers in structuring potential replacements for TACFIRE.

Command, Control, and Communication (C^3) Systems

The system design process described in this report is sufficiently general to be applied to the design of systems other than field artillery tactical data systems. It is more broadly applicable to the design of almost any command, control, and communication (C^3) system for either military or industrial uses.

A tactical data system is an information processing system. It coordinates command, control, and communication (C^3) activities within some larger system. The Field Artillery Tactical Data System (FATDS) coordinates information and decision flow within the larger Field Artillery system in a battlefield environment _to help accomplish the larger system's missions_.

A Common Mistake in the Design of C^3 Systems

The rapid development of powerful, automatic information processing technologies has led to a situation in which hardware technology has become the "driver" in the development of military and industrial C^3 systems. Functions have been relegated to the computer without much regard to the machine's actual capabilities or to human's information processing role in the larger system. The initial effort is focused on the design of fully automated systems. Later, when it is discovered that the C^3 system cannot function fully automatically, humans are "retrofitted" into the system to perform the functions that the machine cannot perform.

Recently, thoughtful people in the military development community have come to the realization that a more considered approach to the development of C^3 systems is required. A fully automatic system probably cannot exist. At the very least, humans will always have a monitoring and possible override role in the system. Monitoring is not a passive process: Rather, it is a highly active process in which the monitor builds and checks expectations about activities in the larger system and makes decisions about deviations from those expectations. Humans, as operators or commanders, must always be part of any C^3 system. There is a need for design processes which include humans as integral parts of the system from the inception of the design rather than "putting man into the loop" as an afterthought.

The Need for a New Focus in Human Factors Technology

In a human-machine system, the machine's displays and controls make up the interfaces by which transactions between human and machine occur. In the past two or three decades, human factors scientists and engineers have developed a technology for designing human-machine interfaces that minimize discrimination and action errors by operators (e.g., McCormick, 1976). This is a necessary but not sufficient technology for designing effective human-machine interfaces for C^3 systems.

C^3 systems involve humans at least as monitors and high level decision makers about some remote process--actions in a distant battlefield or air space, conditions in a distant industrial process, and the like. The roles of human beings require them to function as complex information processors in a complex information processing system. There is a need for a design process that allocates information processing functions which need to be accomplished by the system to its two major components, human and machine, on the basis of which can best perform each function. Best in this usage is defined in terms of the overall effectiveness of the larger system. Furthermore, the human-machine interfaces should be designed to support the functions assigned to humans and the functions that make up human's monitoring and override roles. The interfaces should select, organize, and display information to the operator/commander in such a manner as to facilitate his or her own thinking about the remote process no matter how "automatic" the machine might be.

With regard to automated industrial plants, Rasmussen and Lind (1981) observe:

> For industrial plants, the complexity faced by operators is determined by the representation of the internal state of the system which the interface allows the operator to develop for the various work conditions...(G)reat care should be taken when a computer is used to generate displays in order to match the representation used for displays to the operators' preferred work strategies and understanding of the processes. If this match is not successful, operators may be left with the even more complex situation of having to evaluate the information processes of the computer.

These authors present a general model of the total data processing task. (This model is greatly expanded in the general cognitive model described in the third phase of the front-end analysis in this report.) They further observe:

> Since the human capacity for analysis and decision in a non-routine situation is notoriously limited to consideration of a very limited number of items, the only way to cope with the high number of information sources and devices of elementary actions (e.g., switches and valves) found in an industrial plant, is to structure the situation and to transfer the problem to a representation at a level with less resolution. The total data processing task then is: To structure the information at a higher level representation of the states of the system; to make a choice of intention at that level; and then to plan the sequence of detailed acts which will suit the higher level intention . . .

There is a need for a human factors technology (1) which provides a basis for optimum allocation of information processing functions to human or machine and (2) which provide interfaces whose information representations match the natural representations used by operators and commanders in their thinking about the states of the system and the remote processes under their control. The system design process described in this report is a first step in the development of such a human factors technology. In its initial form, this design process depends heavily upon human judgment based on the best available experience. As this technology develops, research should provide tested information to replace some of the requirements for human judgment, but human judgment will always remain a substantial part of the design process.

THE PROBLEM

The initial objective of this project was to do a trade-off analysis among existing alternative FATDS concept designs. However, it was believed that the existing alternative concept designs were not sufficiently well specified to allow them to be entered directly into a trade-off matrix. This condition was believed to exist, in part, because the development process used for defining the concept design alternatives was not concerned with preparing inputs for entry into a trade-off procedure and, in part, because there was not a clear distinction between the concept design of the system and its engineering design. It was thought that trade-off procedures cannot be reasonably applied without specifying the characteristics of the inputs to the trade-off and without specifying how the outputs from the trade-off were to be used; that is, without specifying the development context in which the trade-off occurs. For these reasons, it was decided to formulate a total management approach for developing the concept design of a FATDS which includes the definition of alternative trial concept designs and their entry into a trade-off procedure which provides the basis for the engineering design of the emerging system.

AN OVERVIEW OF THE DESIGN PROCESS

A C^3 system is an information processing system which coordinates command, control, and communication functions in some larger system. Hence, the design of the C^3 system must be based on a description of the larger system. This description of the larger system establishes what kinds of information are to be processed towards what goals and what kinds of response demands the larger system places on the C^3 system in order to meet the goals of the larger system. The response demands imposed by the larger system specify the information processing functions required of the C^3 system, the range of information loads that it must be able to handle, and the speed and accuracy with which it must respond. These response demands for the C^3 system in turn are derived in part from the response demands imposed on the larger system by the environment and situations in which it operates.

The concept design management approach (CDMA) is divided into two major stages:

1. The front-end analysis.
2. The design and decision process.

The front-end analysis determines the situations in which the C^3 system must operate and the demands it must meet. The design and decision process develops a concept of the C^3 system in terms of hardware, software, and behavioral technologies that meets the demands identified in the first stage.

A field artillery system can operate in many different environments and in many different situations in those environments. The field artillery system may well require different characteristics to function optimally in these different environments and situations. These different environments and situations, and the characteristics of the larger system may, in turn, impose different functional requirements and different response demands on the C^3 system. Hence, the description of the larger system must include a description of the environments and situations in which the system is expected to operate and a description of the larger system's components and functions required to accomplish its goals in the expected environments and situations. The development of these descriptions constitutes the first part of the first phase in the front-end analysis for a FATDS. It is quite likely that most or all of these descriptions already exist or at the very least that the information base for developing them already exists.

The second part of the first phase of the front-end analysis consists of specifying the response demands imposed upon the FATDS by the larger system. The response demands are derived from an analysis of the performance of the larger system in the expected environments/situations. In order to establish response time demands, the results of this analysis will have to be represented on a time line; that is, the likely time required to perform each activity will have to be estimated and these estimates will have to be recorded as part of the description and aggregated across the activities required for effective performance in each expected environment/situation.

Once the expected environments and situations in which the field artillery system will operate have been described and once the larger system itself has been described, including its goals, functions, and components, then the conceptual description of the FATDS can begin. The initial conceptualization of the FATDS (C^3) system must be in terms of its information processing functions. This is the essence of the system.

The second phase of the front-end analysis consists of describing the functions that comprise the information flow leading to, through, and from the FATDS. These descriptions are developed for each expected environment/situation in which the larger system is to be able to perform.

The third phase insures that humans are built into the conceptual design of the system. At the very least, humans will perform the role of monitoring the operation of the FATDS and, if necessary, overriding some of the automatic functions built into it. The information processing functions required to perform this role in each expected environment/situation in which the larger system will operate need to be identified. This phase ends the front-end analysis process.

In the first phase of the design and decison process, the information processing functions identified in the latter part of the front-end analysis are allocated to either human or machine components of the emerging FATDS conceptualization. Criteria for allocating functions to human or machine components are derived from the state of equipment technologies. Several sets of these criteria can be developed to reflect different degrees of technological risk. For instance, one set of criteria may be based on well-established technology, another set may be based on state-of-the-art technology, and a third set might be based on foreseeable future technology. These different levels of technology will lead to the development of several alternative allocations of information processing functions. For instance, a function that cannot be performed adequately by a machine today might well be performable by a machine in the foreseeable future.

A consideration of these different levels of technological development is important for several reasons. Expected environments/situations will generally be based on projections into the future--likely international developments, likely technological developments by potential enemies, and so on. Established technology may not be capable of meeting the response demands resulting from such developments. Hence, it will be necessary to make similar projections about the development of new technology. It may be necessary to develop one or more new technologies before an effective FATDS can be conceptualized. Certainly, it is not desirable to invest resources into a conceptualization that could not meet the response demands for effective performance on the battlefield at the time it was fielded or very shortly thereafter. Nor is it desirable to believe that an inadequate conceptualization would work.

In the second phase of the design and decision process, the interfaces for matching the machine's information representations to the human's information representations involved in each human-machine transaction are designed. Again, there is a choice among established technologies, state-of-the-art technologies, and foreseeable technologies. These levels of technology lead to the development of several alternative design concepts for the human-machine interfaces. In fact, several design concepts might be developed within a given level of technology. For instance, several different foreseeable technological developments may be able to transmit the same kind of information across an interface.

The second phase of the design and decision process completes the conceptual design of a FATDS. This conceptual design consists of an allocation of information processing functions to human and machine components, an identification of appropriate technology for accomplishing each machine function, a specification of the machine's information processing representations in each human-machine transaction, and an identification of appropriate technology for establishing these representations. This conceptualization provides a basis for identifying technological developments required for development of the FATDS and for projecting a reasonable schedule for development of the FATDS.

The overview of the process would not be complete without briefly describing the trade-off procedure for selecting among the alternative design concepts in the two phases of the design and decision process. There are many attributes to consider in placing a value on an alternative design in order to compare it to other alternatives. Consequently, the procedure that is used is an application of multiattribute utility technology (MAUT). (For example, see Keeney & Raiffa, 1976.) It facilitates decision making by identifying and weighting all the design impact factors (DIFs) of the stakeholders in the decision. The DIFs, in this application, are concerned with the demands and resources for developing a FATDS. The procedure consists of obtaining judgments on each of various relevant factors and weights for these factors from the most knowledgeable sources for each judgment. The judgments and weights are then aggregated in various ways to provide figures of merit for different parts of an alternative conceptualization and for different alternative conceptualizations. Comparison of appropriate figures of merit provides a rational means for improving a conceptualization and for selecting among alternative conceptualizations.

In summary, the approach described in this report consists of two stages composed of a total of five phases, as follows:

STAGE 1. FRONT-END ANALYSIS:

1. Describe the larger system; i.e., field artillery in the battlefield. Specify the response demands imposed by the larger system on the FATDS (C^3 system).
2. Describe the information flow leading to, through, and from the FATDS (C^3 system).
3. Analyze human's monitoring and possible override role in the FATDS.

STAGE 2. DESIGN AND DECISION PROCESS

1. Allocate information processing activities to human or machine. Alternative information processing concepts are developed in this stage.
2. Develop interface designs that provide human commander/operators with as close a representation as possible to their own information processing representations in each human-machine transaction. Alternative interface concepts are developed in this stage.

The second stage applies a multiattribute decision making procedure for selecting among alternative conceptualizations and for improving the selected conceptualization.

STAGE ONE: FRONT-END ANALYSIS

The front-end analysis determines the situations in which the C^3 system (or FATDS) must operate and the demands it must meet.

PHASE ONE: DESCRIBE THE LARGER SYSTEM.

The outcomes of this phase will be: (1) a description of the operation of our own field artillery system in battlefield situations in the particular environments of most concern to us, (2) an identification of episodes in those situations which are most relevant to the design of a FATDS, and (3) a specification of the response demands imposed by the larger system upon the FATDS in the relevant battlefield episodes.

This phase consists of eight steps:

1. Identify the target period.
2. Identify the probable weapon characteristics and the probable tactics of both friendly ane enemy forces during the target period.
3. Develop categories of characteristics that will provide as broad an identification of environments and situations as possible.
4. Develop and apply an elimination strategy.
5. Define environments and situations by combining detailed characteristics from separate categories.
6. Develop action scenarios for each environment/situation.
7. Identify episodes in each action scenario that are significant to the operation of FATDS.
8. Identify the response demands imposed by the larger (artillery) system on the FATDS.

Step 1. Identify the target period

The first step in this phase is to identify the target period. This period must be projected far enough into the future to allow the time necessary to develop, produce, and field a FATDS, but not so far that significant periods of national threat are overlooked. Weighing these two sets of concerns in the selection of a target period requires a decision from very high policy making levels. This period establishes our tentative target date for fielding the system.

Step 2. Identify the probable weapon characteristics and the probable tactics of both friendly and enemy forces during the target period

The second step is to identify the probable weapon characteristics and probable tactics for enemy forces and for our own forces during the target period. Descriptions should be prepared of the probable deployment patterns that will be used by the enemy forces and by our own forces. Next, a listing of the general objectives relevant to each type of deployment should be developed. For instance, general objectives for field artillery might include statements such as:

> Deliver appropriate, accurate, and timely fire in response to fire requests.
>
> Deliver appropriate, accurate, and timely fire according to higher level fire plan.
>
> Deliver appropriate, accurate, and timely counterfire.
>
> Avoid delivering fire on friendly forces.

These general objectives determine how an engagement from a given deployment is likely to develop. They guide the selection of appropriate actions.

The information developed in the first two steps probably already exists. It is a necessary information base for almost any kind of future-oriented military preparation.

Step 3. Develop categories of characteristics that will provide as broad an identification of environments and situations as possible

The third step begins the identification of specific environments and situations. It is important to at least consider every possible relevant environment and situation. Failure to do so could lead to the development of a FATDS that cannot function effectively in some potentially critical environment or situation. One way of insuring that all possible situations are considered is to conduct a situation identification analysis (McKnight & Adams, 1972). A situation identification analysis proceeds in four phases. In the first phase, hierarchies of successively more specific characteristics for defining situations and environments are identified. In the second phase, a strategy is developed for eliminating those combinations of characteristics that are least relevant. In the third phase, relevant combinations of characteristics are formed to identify the environments/situations in which the FATDS will operate, scenarios are prepared for each environment/situation, and specific FATDS-relevant episodes are identified in each scenario. And in the fourth phase, judgments are made about the importance and frequency of the final episodes as a means of reducing the number that will be analyzed in the next phase of the CDMA. The second and fourth phases are included to reduce the final number of episodes to only those which are most meaningful. For instance, if each situation were defined by a combination of five characteristics drawn from five dimensions or categories (r) with an average of ten characteristics or values (n) for each dimension, then it would be possible to define $n^r = 10^5 = 100,000$ different situations. Clearly, some simplification is needed. The third, fourth, fifth, sixth, and seventh steps of the description of the larger system correspond to the four phases of situation identification analysis. (The third phase corresponds to two steps in the analysis.)

The objective of the third step is to develop categories of characteristics that will provide as broad an identification of environments and situations as possible. This is accomplished by applying a general to specific strategy for identifying successively more specific environment and situation characteristics. First, identify the broad categories of relevant environment and situation descriptors. At the highest level, environment categories would include terrain and weather. Situation characteristics would include enemy forces, own forces, and military context. Next, break each of these broad categories down into smaller categories. For instance, terrain might be broken into types of surfaces, types of ground cover, significant natural features, and significant human artifacts. Enemy forces and own forces might be broken down into strength, re-supply conditions, and intelligence capabilities. Military context might be broken into military state (stalemate conditions, own frontal push, enemy frontal push), supply state, and the like. Each of these smaller categories would then be broken into still smaller categories. For instance, types of terrain could be broken into tundra, desert, tropical forest, wooded hills, and so on. Strength of own and enemy forces might be broken down into weaponry, and personnel. Each level of division should break the next higher level into two to seven smaller categories. Each category is broken down until a level is reached with adequately detailed characteristics to allow unambiguous specification of how a military engagement in a given environment and situation might proceed. Different categories can be broken down to different levels. The breakdowns don't have to be uniform throughout. This analysis results in the development of a hierarchy of environmental and situational characteristics. The structure of such a set of characteristics is shown in Figure 1.

Step 4. Develop and apply an elimination strategy

In the fourth step, a strategy is developed for eliminating certain combinations of characteristics from consideration. The first part of the strategy consists of examining general categories of characteristics in combination with one another before addressing them at the level of individual

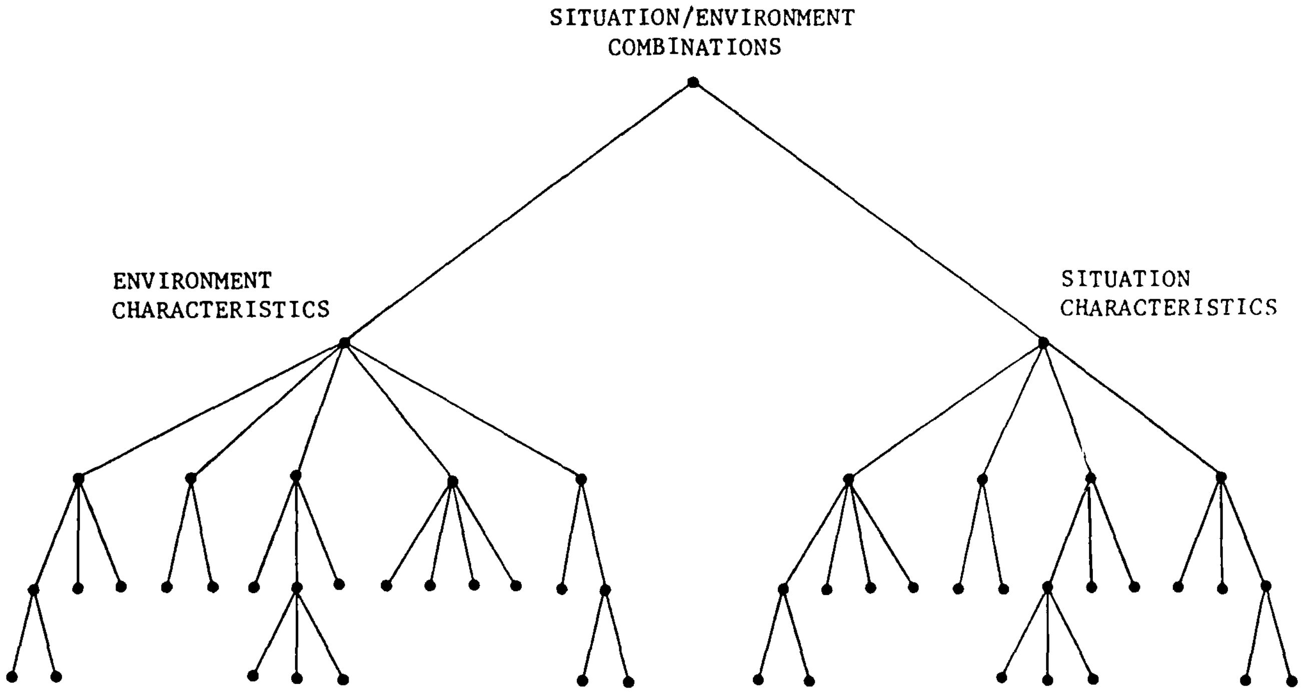


FIGURE 1. HYPOTHETICAL ENVIRONMENT AND SITUATION CHARACTERISTICS HIERARCHY

characteristics. Some combinations of general categories may be unimportant or may not make sense. In such cases, there will be no need to examine combinations of individual characteristics from the two categories. Such combinations of individual characteristics can be eliminated from consideration. The second part of the strategy restricts the number of categories from which characteristics are drawn in identifying situations. For instance, suppose a hierarchy contained five categories of characteristics with an average of five characteristics in each category. Taking one characteristic from each of the five categories to identify each situation would lead to the possible identification of 3125 different situations ($n^r = 5^5 = 3125$). However, if each situation was identified by only three characteristics--one taken from each of three different categories, then the number of possible situations would only be 1250 (10 combinations of 5 categories taken 3 at a time multiplied by 5 characteristics raised to the third power for the three categories used to define each situation). The same total number of characteristics divided into a few categories will produce fewer combinations than if they were divided into a larger number of categories. In general, it won't be meaningful to draw characteristics from more than three different categories to form situation defining situations.

The first part of the elimination strategy removes general categories of combinations of characteristics. The second part of the elimination strategy restricts the number of categories that are used to define situations.

Step 5. Define environments and situations by combining detailed characteristics from separate categories

In the fifth step, detailed characteristics from different categories are combined to define situations. For instance, an environment might be specified by the following detailed characteristics: tundra terrain and daily temperatures below freezing. A situation might be specified by the following detailed characteristics: enemy armored division, friendly armored division, no significant human artifacts in area (that is, no roads, bridges, towns, and so on), enemy mounting frontal push, enemy has difficult resupply, and so on. Next, the list of environments and the list of situations generated in this way is examined and judgments are made about the importance and frequency of each entry in each list. Only the more important and/or more frequent entries need to be retained. At this point, the objective is to reduce the list to the most representative combinations that can in fact be analyzed with the resources available. In this analysis, the next part of this step forms meaningful combinations of environments and sit uations. These environment/situation combinations can be clustered on the basis of the similarity of the actions most likely to occur in each. This step ends with a clustered list of relevant environments/situations for the selected target period.

Step 6. Develop action scenarios for each environment/situation

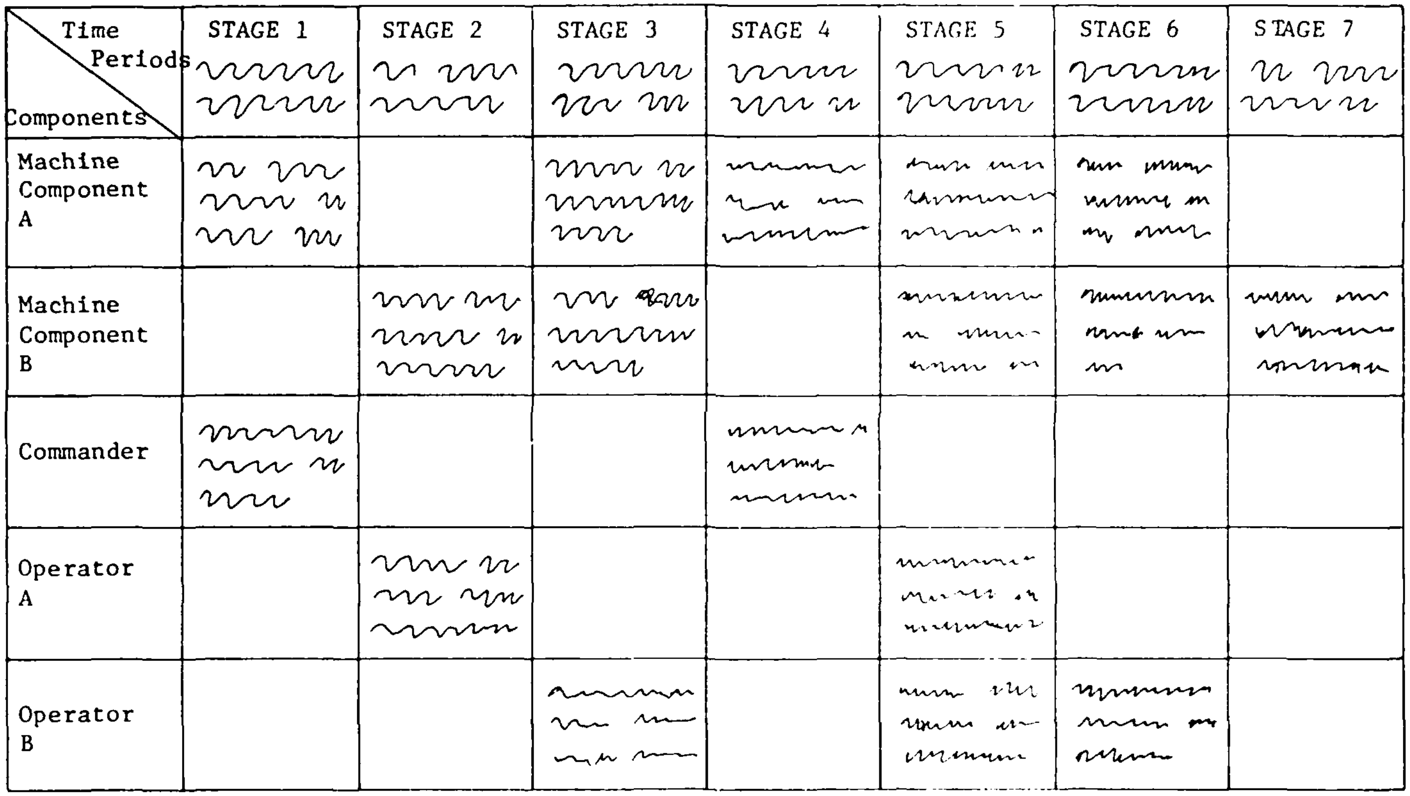
In the sixth step action scenarios are developed for each relevant environment/situation. An action scenario is basically a listing of the events that transpire as the situation develops. The events in the scenario should be listed on a time line with as accurate time estimates as possible. The events can be presented in list form, in a component (unit) by time period matrix, or in a parallel flowchart.

A component by time period matrix is illustrated in Figure 2. Each enemy and friendly unit is assigned a different row in the matrix. The scenario is broken into time periods and each time period in order is assigned to a different column of the matrix. The action performed by each unit in each time period is described and entered into the appropriate cell of the matrix. A parallel flowchart is illustrated in Figure 3. A parallel flowchart is similar to a component by time period matrix in that each unit is assigned to a different row. However, the horizontal dimension is not broken into time periods. Instead, it is defined as a time line and the actions taken by each unit are described in blocks and entered at the appropriate point in the time line in the row for the given unit. Blocks are then connected by lines both within and across rows to show the flow of information and actions in the scenario. The scenario should also be supported by a series of position and movement diagrams which depict the actions at each significant point in the scenario.

The actions in each scenario are derived from the general objectives and tactics identified in the earlier part of this phase. A given scenario may use several different kinds of presentations. For instance, the general actions in the scenario may be presented in a component by time period matrix. Detailed actions within each time period (columns of the matrix) may then be presented either as more detailed component by time period matrices or as parallel flowcharts. Different levels of position and movement diagrams might be developed to accompany each of these other presentations. Computer aided design (CAD) can be a very useful tool in the identification and development of these scenarios.

Step 7. Identify episodes in each action scenario that are significant to the operation of FATDS

The seventh step of the first phase is to examine the scenarios and identify episodes that are particularly significant with regard to the operation of the FATDS. Such episodes begin with an event that generates an input into the FATDS and ends with the outputs resulting from the input. The kinds of events that are most likely to generate inputs to the field artillery system and to the FATDS are the emergence of field artillery targets that pose an immediate or future threat to elements of friendly forces (including



Time Periods / Components	STAGE 1	STAGE 2	STAGE 3	STAGE 4	STAGE 5	STAGE 6	STAGE 7
Machine Component A							
Machine Component B							
Commander							
Operator A							
Operator B							

Figure 2. Hypothetical Component by Time Period Matrix

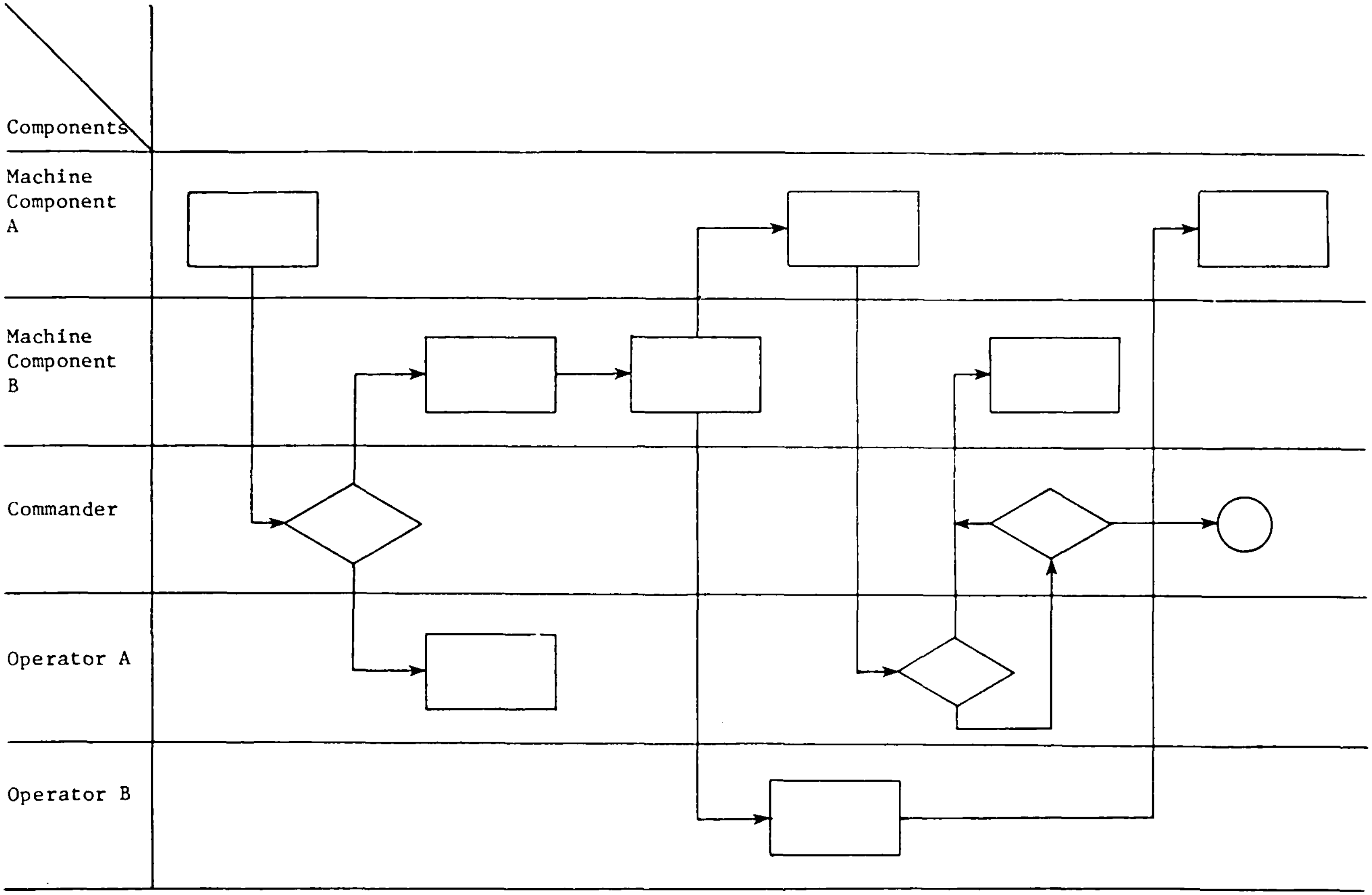


Figure 3. Hypothetical Parallel Flowchart

elements of the field artillery system itself) or to the implementation of battle plans. For this reason, a list of the general classes of field artillery targets and a list of the general kinds of threat conditions that can be generated against various kinds of friendly elements by enemy elements could be very useful in identifying specific episodes in each scenario. The description of each episode should include (1) a summary of the events and conditions in the scenario leading up to the episode, (2) the general military objectives specified for the scenario, (3) the specific field artillery objectives appropriate for the episode, and the (4) action descriptions and flow which make up the episode. The action descriptions and flow in the episode are taken from the scenario of which the episode is a part. The episodes are essentially "scissored" out of the scenarios. These episodes provide the basis for generating the design requirements for the FATDS. They will be analyzed into sequences of information processing functions in the next phase.

Next, the list of episodes is examined and judgments are made about the importance and frequency of each entry in each list. Only the more important and/or more frequent episodes need to be retained. At this point, the objective is to reduce the list to the most representative episodes that can in fact be analyzed with the resources available.

Step 8. Identify the response demands imposed by the larger (artillery) system on the FATDS

The eighth and last step in the description of the larger system is to identify the response demands imposed by the larger system on the FATDS. The response demands are derived from the episodes. Two sets of response demands are derived for each episode: (1) response demands for the field artillery system and (2) response demands for the FATDS. The latter are derived from the former.

The response demands are composed of two parts: (1) performance demands and (2) condition demands. The performance demands specify how quickly and how accurately either the field artillery system or the FATDS must respond in a given episode. These general requirements can be broken down to apply to specific elements in an episode. For instance, how much delay is tolerable from the emergence of a particular target until it is detected, identified, and located and entered into the FATDS communication loop? How accurate must the information about the target be? How quickly must the field artillery system respond? How accurate must the fire be? How much time is likely to be available from the time the fire order is received at the fire unit until it is carried out? How much time is left for the FATDS response? The performance demands for each episode should be attached to the episode descriptions. Once these performance demands have been specified for each selected episode, they can be aggregated across episodes to form general performance demands for both the field artillery system and the FATDS. These aggregated performance demands specify how well the FATDS must perform.

The condition demands specify the environment characteristics (humidity, temperature, sensory characteristics of the battlefield--light conditions, visual clutter, noise) which bear on the operation and maintenance of the field artillery system and the FATDS. How humid will the environment be? What will the temperature be? What are the sensory characteristics of the battlefield? Light conditions? Visual clutter? Noise? How long will the field artillery system and the FATDS have to sustain a given level of activity without degradation of their capabilities? The condition demands for each episode should be attached to the episode descriptions. After the condition demands have been specified for each episode, then they can be aggregated to form general condition demands for both the field artillery system and the FATDS.

PHASE TWO: DESCRIBE THE INFORMATION PROCESSING INTO, THROUGH, AND FROM THE FATDS

The outcome of this phase will be a description of the information processing actions and flow required to be performed by the combined human and machine components of the FATDS.

This phase consists of two steps:

1. Describe the information processing required of the field artillery system to perform effectively in each selected episode.

2. Describe the information processing capabilities required by a FATDS to perform effectively in the battlefield during the target period.

Each of these steps is now discussed in turn.

Step 1. Describe the information processing required of the field artillery system to perform effectively in each selected episode

In the first step each selected episode description (obtained in step 7 of phase one) is developed to include the more detailed information processing actions and flow required for the field artillery system to perform effectively in that episode. Information can be:

1. Created
2. Combined
3. Transformed
4. Ordered
5. Abstracted
6. Deleted
7. Stored
8. Communicated

Information is created, for instance, when a target is detected. Different information is created when the detected target is categorized as to type and number (or size). Still different information is created when the identified and categorized target is identified as friend or foe. And still different information is created when the target's location is specified. In locating the target, it's location may first be noted with respect to observable geographical features. This information is then transformed into map coordinates. Information is combined when all of these elements are formatted into a target specification in a fire request. Information is communicated when it is sent from a forward observer to the fire control center. Information is ordered when a fire order is entered into the waiting fire order list in a particular priority position. Each of these is a separate information processing activity.

Information includes more than just target and fire order data. Rules governing a decision process are information. A summary of yesterday's actions is information. Plans and expectations are also information. The outcomes of decision processes are information. Each of these has to be created or transformed so as to be available for use.

The information processing actions performed in each episode need to be specified in detail. If a target is detected, specify what kind of target and in what kind of sensory or energy environment. For instance, information processing actions should be specified with the following kinds of detail: "detect single tank at one kilometer distance at night," "categorize single tank at one kilometer at night," "identify single tank as friend or foe at 1 1/2 kilometers in wooded area on overcast day," "select type XYZ guns and XYZ round to fire against column of enemy tanks XX kilometers away," "transmit request for fire on column of tanks located at coordinates XX, YY," and so on.

Each information processing action should be identified in terms of the major component of the field artillery system that is to perform it. All elements of a major component must be located together geographically. For instance, major components include the forward observers, the battalion fire control center, and the division artillery tactical operations center. The elements that make up each of these components are physically co-located. The component that is responsible for performing each information processing action can be specified by developing a parallel flowchart (see Figure 3) for describing the information flow for each episode. Each component is assigned to a row in the flowchart. Information processing actions are then entered in order in the appropriate row of the flowchart and connected by arrows to specify the flow of information from one entry to another both in the same row and in different rows. Arrows which go from one row to another must always originate from a communication action.

There are some actions that may be difficult to identify in developing the parallel flowcharts. The need to store, delete, or abstract information may not always be apparent from the context of a single episode. One way of improving our ability to detect the need for these kinds of actions is to review the context (or past action) summaries in the original episode descriptions. These summaries should also provide indications as to the rate at which inputs are being made into the field artillery system and the FATDS during various kinds of military situations. Whenever a decision activity is entered into the flowchart, we should also check whether or not it requires application of a set of rules or principles and whether it requires a prior review of other information such as a summary of past actions. Developing plans and expectations will also require similar collateral activities.

The effort required to develop the information processing flowcharts might be reduced by sorting the episode descriptions into piles on the basis of the kinds of field artillery actions required to deal effectively with each one. A single analyst or team of analysts may then be assigned to each pile of similar episodes. In this way the analysts can develop implicit patterns for analyzing each pile of similar episodes. In fact, they may use the early flowcharts as models for the later ones. Developing the flowcharts on small computers using word processing software and appropriate graphics software would also greatly speed up their preparation, review, and revision. It would also make it easy for the analysts to insert pieces of previously prepared flowcharts into new flowcharts where appropriate. This is another way in which computer aided design could facilitate this kind of effort.

Step 2. Describe the information processing capabilities required by a FATDS to perform effectively in the battlefield during the target period

In the second step all of the flowcharts developed for the separate episodes are combined into as few flowcharts as are required to describe the information processing activities and flow in the field artillery system. As the single episode flowcharts are combined, they need to be examined for additional storing, deleting, and abstracting activities. Development of the combined flowcharts is principally a matter of combining and editing the single episode flowcharts. First, the single episode flowcharts can be sorted into piles on the basis of their overall similarities. Next, common routines consisting of similar or identical sequences of steps in the various flowcharts are identified and edited. Third, unique routines are identified. And, finally, the common and the unique routines are combined into several comprehensive FATDS flowcharts. If the single episode flowcharts were prepared on a computer and stored on disk, then the development of the combined flowcharts should proceed quite rapidly.

The comprehensive FATDS flowcharts specify the information processing activities and flow required in a field artillery system to perform effectively in the more significant environments/situations anticipated for the target period. These flowcharts will provide one of two major inputs to the first phase of the design and decision process in which the information processing activities will be allocated to either human or machine components of the various alternative FATDS concepts. The other major input will be prepared in the third phase of the front-end analysis, which follows.

PHASE THREE: ANALYZE THE HUMAN MONITORING AND POSSIBLE OVERRIDE ROLE IN THE FATDS

The outcome of this phase will be a description of the information processing activities required to monitor the FATDS operation and, if necessary, to override a FATDS decision. This phase consists of three steps:

1. Review the general cognitive model for commanders/monitors of remote systems. Monitoring a remote system requires essentially the same though processes as are required to operate the system. The general model provides guidance for identifying these thought processes.

2. Identify the conditions and situations of the field artillery system and its environment and the information bases that need to be monitored.

3. Describe the information processing activities required to monitor and, if necessary, to override the information processing activities of the FATDS.

Step 1. Review the general cognitive model for commanders/monitors of remote systems

The *first step* consists of reviewing the general cognitive model for commanders/monitors of remote systems. A remote system is one that is linked to its control center through human/machine interfaces that present only symbolic or abstracted representations of the state of the system and its environment to the human personnel who control it and that accepts control from these personnel only through symbolic or abstracted control actions. Commanders, operators, and monitors of remote systems are linked to the systems they control only through displays and controls in some remote control center.

An overview of the general model. Monitoring a system activity with a view towards overriding the decisions made in that system essentially requires that the monitor perform the same information processing activities in parallel with the system as performed by the system itself. If the monitor makes a decision that does not match the corresponding decision made by the system, then the monitor has to consider whether or not to override the system.

Figure 4 is a diagram which identifies the general activities required to command or monitor a remote system and shows the flow of information among the activities. The remote system, represented at the left side of the diagram, is separated from the commander/monitor by the human/machine interface. The interface consists of displays and controls. Information about the states of the field artillery system and its environment and about information bases within the system is made available to the commander/monitor by means of the displays. The commander/monitor implements his decisions through the controls. The remaining entries in the diagram represent the activities performed by the commander/monitor of the remote system. Those activities outside the dotted lines are required of both the commander of the system and the monitor. Those activities inside the dotted lines are added as a result of the monitoring and potential override requirement. The general model provides guidance for identifying the activities required of a system commander/monitor.

The upper string of activities represents the inputs to the commander/monitor. The lower string of activities represent the outputs from the commander/monitor. The intermediate activities represent the commander/monitor's decision processing. The model breaks the intermediate activities into three major functions: (1) The construction and maintenance of a representation of the current and emerging state of the remote system based in part upon its past states, (2) a decision process for identifying and selecting appropriate courses of action, and (3) a decision process for determining whether or not to override the system. The first function appears as a large circular loop of activities in the upper right portion of the diagram. The second appears as a diamond shaped array in the lower right portion of the diagram. And the third appears as a string of activities at the bottom of the diagram inside the box bounded by a dotted line.

The input branch of the model consists of three activities: (1) Discriminate the display elements, (2) identify the conditions of the remote system and its environment on the basis of the display elements, and (3) identify the present situations of the remote system and its environment based on the present conditions, the recent history of the system, and expectations about future situations. "Conditions" in this usage are discrete characteristics that make up more encompassing situations. For instance, the detection of movement in an enemy armor unit may be a condition in a more general situation consisting of the initiation of an assault by the enemy. The second and third activities in this branch successively

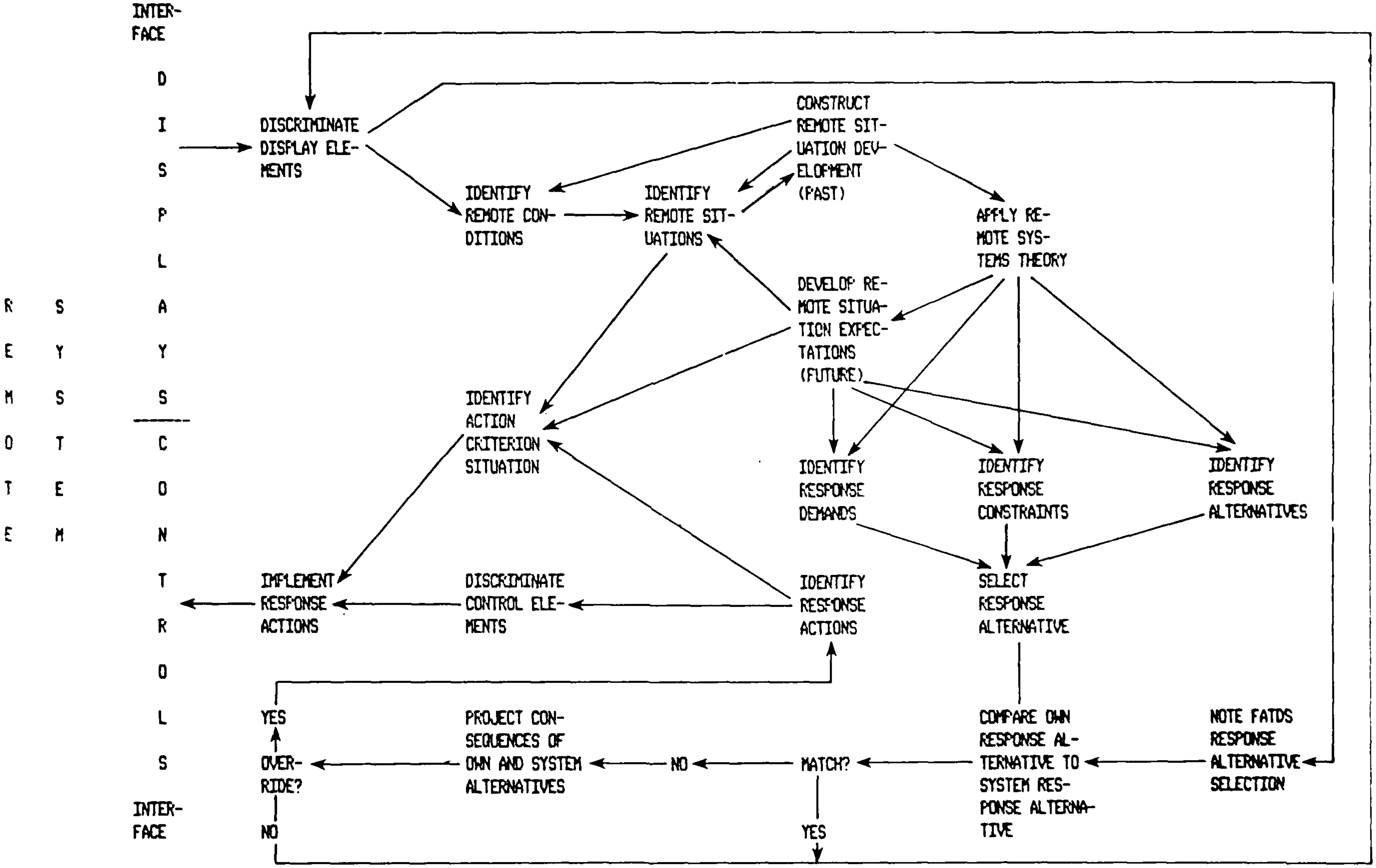


FIGURE 4. GENERAL COGNITIVE ACT MODEL FOR OPERATORS/COMMANDERS OF REMOTE SYSTEMS.

aggregate the display information at a higher level of abstraction. For instance, the detection of movement in an enemy armor unit may signal a local assault. Added to knowledge about an enemy build-up of supplies and the onset of bad weather, the inference might be drawn that the enemy is initiating a final assault to establish a more favorable position before a winter storm sets in. This inference is a higher level abstraction of the actual battlefield conditions. These successive abstractions are basically pattern recognition activities. (See Whitmore, Richards, and McIntyre, 1982, for a description of the recognize/classify Generic Activity Model.)

The output branch of the model also consists of three activities: (1) Identify response actions, (2) discriminate control elements, and (3) implement response actions. The input to this branch is the decision to override the FATDS response alternative.

The third activity in the input branch of the model (identify remote situations) is also the first activity in the "state of the system" loop. This identification of the remote situation is used in the next activity (construct remote situation development) to initiate or update a representation of the recent history of the remote system and its environment. The recent history information is then used in three subsequent activities. First, it is used to identify remote conditions that exist over time. Second, it can be used to identify remote situations that exist over time. And, third, it is the basis for applying remote systems theory: (1) for developing expectations about emerging events in the remote system and (2) for identifying and selecting response alternatives for dealing with problem situations in the remote system. Remote system theory for a FATDS consists of the principles of tactics used by friendly and enemy forces. These principles (or rules) are the statements applied by a commander/monitor: (1) to interpret the conditions and situations occurring in the remote system and its environments, (2) to develop expectations about what is likely to happen in the near future, and (3) to formulate action alternatives and select among them. They may well include more than just formally recognized principles of tactics.

The array of decision activities receive inputs from the remote systems theory (that is, the commander's application of principles of tactics from memory) and from expectations regarding developments in the remote systems (that is, the battlefield, enemy forces, and friendly forces). These two sources of information lead to (1) the identification of response alternatives, (2) the identification of constraints on the selection of a response alternative, and (3) the identification of demands (goals) on the selection of a response. These three activities, in turn, feed their information into the actual selection of a response alternative.

The string of monitoring-specific activities receives an input from the displays regarding the response alternative selected by the FATDS and an input from the monitor's previous processing (i.e., thinking) regarding his own response alternative selection. These two selections are compared. If they match, no intervention is required. If they do not match, then the monitor has to decide whether or not to override the FATDS selection. This decision is usually based on a projection made by the monitor regarding the likely difference in consequences between his selection and the FATDS selection. If the differences in projected consequences are significant and favor his alternative, then he identifies the response actions he needs to override the FATDS and proceeds into the output branch of the model.

One final activity in the model remains to be explained: Identify action criterion situation (near the center of the diagram). The action criterion situation may be viewed as a triggering situation for initiating a selected response alternative. It is defined from the identification of the response actions and from expectations concerning developments in the remote situation. When the current remote situation matches the criterion situation, the response actions for the selected response alternative are implemented. The action criterion situation represents a "Don't shoot until you see the whites of their eyes" condition.

Variations on the general model. Three principal kinds of variations can be introduced into the general model. First, certain activities might be omitted from the model. For instance, the identification of an action criterion situation may not be appropriate in some instances. Or it may not be necessary to consider the development of remote situations in the recent past. In an extreme instance, the identification of a remote condition may directly trigger the selection of a response alternative, completely omitting the "state of the system" loop and the decision process array. In this instance, indications of remote conditions serve directly as response signals.

The second kind of variation in the model deals with the certainty with which information can be processed. Aggregation on the input branch, for instance, can be deterministic or probabilistic. The identification of a remote situation might be based on the presence of a fixed set of conditions or it might be based on a variable set of conditions, with each one contributing a different amount to the identification; that is, it is a matter of uncertain judgment. The same kind of variation can also apply in the "state of the system" loop, the decision process array, the intervention string, and the output branch. Furthermore, some activities in the model might process information in deterministic ways and others might use probabilistic ways.

The third kind of variation in the model deals with the level of abstraction used in different activities in the model. It seems likely that the more complex the remote system the higher the level of abstraction needed for monitoring and controlling it. In regard to this point, Rasmussen and Lind (1981) note:

> Since the human capacity for analysis and decison in a non-routine situation is notoriously limited to consideration of a very limited number of items of information, the only way to cope with the high number of information sources and devices of elementary actions. . .is to structure the situation and to transfer the problem to a representation at a level with less resolution. The total data processing task then is: To structure the information at a higher level of representation of the states of the system; to make a choice of intention at that level; and then to plan the sequence of detailed acts which will suit the higher level intention. . .

But even a very complex system may involve a few very simple activities that can be processed at a low level of abstraction. It is also possible that different complex transactions may require different levels of abstration for most effective processing. With regard to the various levels of abstraction that may be involved in an activity, Rasmussen and Lind further note:

> When moving from one level of abstraction to the next higher level, the change in system properties represented is not merely removal of details of information on the physical or material properties. More fundamentally, information is added on higher level principles governing the co-function of the various functions or elements at the lower level. In human-made systems, these higher level principles are naturally derived from the purpose of the system; i.e., from the reasons for the configurations at the level considered.

For instance, a set of tactical principles may apply quite well to a high level abstraction of a situation, but make no sense at all when applied to a more detailed representation of the situation. The more detailed representation would have to be transformed into more abstract patterns or relationships before the principles would make sense.

Application of the general model. The general model can be used to guide the development of a description of the optimum information processing to be used by commanders/monitors of FATDS conceptualizations. There is nothing magic about the model. It serves principally to call the analyst's attention to a likely sequence of activities which may occur in the commanding or monitoring of a real system. The model was developed for this purpose by specialists who are trained and experienced in the analysis of human performances. It reflects some current points of view from theoretical cognitive/behavioral science, but it has not been subjected to controlled experimentation.

Step 2. Identify the conditions and situations of the field artillery system and its environment and the information bases that need to be monitored

Now that the commanding/monitoring role for a remote system has been described, it is necessary to determine what is to be monitored. What are the critical situations that can occur in the remote system to which the system should respond? What kinds of situations or conditions that precede the occurrence of a critical situation; that is, what are the possible signals that a critical situation may be developing? Critical situations may exist in the battlefield or in the firing units or with regard to other friendly forces or with regard to re-supply conditions. Critical situations can occur in any part of the field artillery system or its environment. The situation identification analysis done in the first phase of the front-end analysis might well be extended at this point to include other parts of the system and its environment. It can then be used as a basis for identifying potentially critical situations and conditions that either ought to elicit responses from the system or that ought to help to determine what response is most appropriate.

Step 3. Describe the information processing activities required to monitor and, if necessary, override the information processing activities of the FATDS

This step proceeds in two substeps. In the first substep, describe the information processing required to monitor each situation or condition identified in the second step using the general cognitive model reviewed in the first step to help identify potential information processing activities. The overall descriptions of the activity sequences should probably take the form of simple activity diagrams or flowcharts. The entries describing each activity in each diagram or flowchart should be very specific as in the first step of the second phase of the front-end analysis. It is necessary to be specific about what is identified, what tactical principles are applied, and so on. In the second substep, the descriptions developed in the first substep are combined into as few descriptions as possible.

The combined information processing descriptions developed in this phase and in the preceding phase provide the input to the first phase in the design and decision process which follows. In the first phase of the design and decision process, the information processing activities identified in these two phases are allocated either to human or machine components of the various FATDS alternative concepts.

STAGE TWO: DESIGN AND DECISION PROCESS

The objective of Stage 2 is to develop a concept for the C^3 system (FATDS) in terms of hardware, software, and behavioral technologies that meets the system response demands identified in the first stage. Stage 2 is carried out in two phases described as follows.

PHASE ONE: ALLOCATE INFORMATION PROCESSING ACTIVITIES TO HUMAN OR MACHINE

Phase 1 is concerned with the development of several alternative design concepts for a FATDS in which information processing activities are allocated to humans or to various machine technologies in different ways. Each design concept is then evaluated and the best of the concepts is revised to improve it, if possible. The phase consists of nine steps:

1. Develop the machine technology focus for each design concept.
2. Develop the human/machine allocation rationales for each design concept.
3. Allocate information processing functions in each design concept to humans or machines.
4. Determine the importance of each information processing activity to the attainment of field artillery objectives (missions).
5. Review the design impact factors (DIFs) and weight them according to their importance.
6. Obtain ratings for each information processing (IP) activity in each design concept on each DIF.
7. Obtain figures of merit (FOMs) on each DIF for each design concept.
8. Obtain aggregate FOM for each design concept.
9. Review the results of the two previous steps in an attempt to improve the highest rated design concept.

The outcome of phase 2 is a specification of the best human/machine function allocation for each information processing activity and the selection of a preferred machine technology for accomplishing each machine-allocated activity. Each design concept is evaluated in terms of its impact on factors such as personnel, training, system development (developmental time, technological risk, reliability, availability, maintainability, flexibility/adaptability), and performance. The valuing process is a variation of multiple attribute utility technology (MAUT). The suggested rating procedures represent an amalgam of various methods assembled for the purpose of conducting trade-off analyses. An interested reader may consult Hawley, Brett, and Chapman (1982) for more information on the rating procedures described herein.

Step 1. Develop the machine technology focus for each design concept

For the past several decades, information processing machine technologies have been in a state of rapid development. Consequently, it is necessary to consider not only those technologies currently available, but also emerging technologies that may well be available at the appropriate point in the development of the FATDS. It is also necessary to consider the possibility that existing technologies may not be capable of producing a FATDS design that can meet the system response demands for our target period. If that should prove to be the case, then we need to be able to identify precisely where the shortfalls lie and take steps to enhance the development of the appropriate technologies.

Alternative design concepts need to be developed that address at least three different levels of machine technology.

1. Existing technologies. The design concept at this level will draw only from those information processing machine technologies that are fully developed and on the commercial market at this time.

2. State-of-the-art technologies. The design concept at this level will draw not only from existing technologies but also from those technologies whose potential has been proven in research applications and perhaps in some prototype applications, but they are not yet commercially available.

3. Foreseeable technologies. The design concept at this level will draw not only from existing and state-of-the-art technologies, but also from technologies which are theoretically feasible but have not been tested in any applications.

Using these definitions as a guide, each information processing activity in the aggregated system descriptions is examined and potential information processing machine technologies at each level for performing each activity are identified, if possible. There may well be several technologies at the same level that apply to a single information processing activity. At this point, list them all. The persons who make these judgments should be knowledgeable concerning the various information processing technologies. Some of these experts might be military personnel, some might be Department of Defense (DoD) civilians, some might be scientists and engineers with manufacturing firms, and some might be scientists and engineers in research institutions or universities.

If the persons who are to make the judgments can be assembled in small groups in one place, it would be desirable to use a group process (see Delbeq, Van de Ven, & Gustafson, 1975) to facilitate face-to-face interaction among the individuals in arriving at their judgments. Group processes are designed to stimulate idea-getting. If the individuals cannot be assembled at one place at one time, then a Delphi approach would be useful. A Delphi approach consists of obtaining successive rounds of judgments from experts in writing with summarization of each round and feedback of the summarization to the individuals before the next round. Delphi can be conducted by mail, but it takes a long time to apply.

Step 2. Develop the human/machine allocation rationales for each design concept

Before information processing activities can be allocated either to humans or a machine, it is necessary to decide what kinds of performance characteristics are important in performing each information processing activity. In some instances, speed of response may be important, in other instances total throughput per unit time may be important, in other instances amount of information stored may be important or ability to abstract information may be important. Several performance characteristics might be important for any given information processing activity.

Performance characteristics should be specified for every single information processing activity in the aggregated system descriptions, regardless of whether or not it is to be allocated to a machine. These characteristics should be specified by those available personnel who have had the most intensive experience in commanding and operating existing FATDS in the most combat-like situations possible. However, they will need more than just their experience as a basis for specifying performance characteristics. They should also be provided with a summary of the system response demands and a summary of the selected episode descriptions from the front-end analysis (Stage 1) and time in which to review them thoroughly. Again, if possible, decisions should be made using a group process. If it is not possible, then use the Delphi technique.

Step 3. Allocate information processing functions in each design concept to human or machine

At this point, alternative information processing technologies will have been specified at each design level for many if not all of the information processing activities. Furthermore, performance characteristics will have been identified for every single information processing activity. If *no* machine technology is specified for an information processing activity at a given design level, the allocation automatically defaults to "human".

A judgment has to be made about each information processing activity at each design level for which one or more machine technologies have been specified. Humans are automatically added to the list of alternative technologies for each activity at each level. In a sense, humans are being treated as one more technological alternative for every activity at each design level. The list of alternatives for each activity at each design level is examined and compared to the performance characteristics for the activity. The alternative that offers the most performance potential is selected for that activity at that design level. If two or more alternatives are judged to be equally promising, then all of them should be selected. In this way, alternative design concepts can be developed at each level.

Sometimes it may not be possible for one technology by itself to perform a given information processing activity. The assignment of a technology to an activity in such a case is ambiguous. If one of those technologies is "human," it has been common practice to allow the designation of "shared" to that activity; that is, the performance of the activity is judged to be shared by human and one or more equipment technologies. In the approach outlined in this report, it is recommended that if an activity cannot be assigned unequivocably to one technology, then the activity should be divided into smaller component activities until a level of activity is reached that can be assigned unequivocably to single technologies. This procedure should be particularly stressed for ambiguous assignments that involve "human" as one of the technologies.

The judgments for allocating information processing activities at each level to the most appropriate technologies should be made by a mix of people who possess expertise in each of the relevant technologies. Since humans are always one of the alternatives to be considered, at least one fourth of the mix should represent expertise in human factors. Again, small groups should be formed with the appropriate mix of experts and a group process should be used to guide the interactions among the members of each group in arriving at their judgments. And, again, the members of the groups should be provided with summaries of the results of the front-end analysis and with the aggregate flowcharts. It is critical in this process that the best available experts in each technology participate in the allocation judgments. A non-expert or weak expert in one of the technologies can degrade the results, especially if that person is the sole representative for a given stakeholder.

The results of the allocation judgments should be presented in the form of parallel flowcharts with a different row assigned to each technology, including humans. Flowchart lines going from an entry in the row assigned to humans to an entry in one of the other rows represents a human-to-machine transaction. Flowchart lines going from an entry in one of the machine technology rows to an entry in the row assigned to humans represent machine-to-human transactions. It is these human-to-macine and machine-to-human transactions that will be considered in the second phase of the design and decision process.

The remaining steps in this phase are concerned with deciding which design alternative or alternatives to pursue.

Step 4. Determine the importance of each information processing activity to the attainment of field artillery objectives (missions)

Some information processing activities are more important for accomplishing the objectives of the field artillery system than are others. The mistake of investing a substantial portion of the project's resources into developing the means for performing relatively unimportant activities should be avoided. Nor should the project skimp needlessly on the relatively important activities. Consequently, it is necessary to assign each information processing activity a value that reflects its criticality for accomplishing field artillery missions.

The criticality judgments for the activities should be made by those available personnel who have had the most extensive experience in commanding and operating existing FATDS in the most combat-like situations possible. However, they will need more than just their experience as a basis for judging criticality. They should also be provided with a summary of the system response demands and a summary of the selected episode descriptions from the front-end analysis and time in which to review them thoroughly. Again, if possible, use a group process. If it is not possible, then use the Delphi technique.

The criticality judgments can be made any time after the front-end analysis has been completed. Since these judgments are obtained by the same general process, from the same general population of experts, and require that the experts have the same summary of the front-end analysis as required for specifying the performance characteristics for each information processing activity in the second step of this phase, then it seems reasonable to obtain the criticality judgments at the same time, in the same way, and from the same sources as the performance characteristics are obtained.

There are two different procedures that can be used for obtaining the criticality judgments. The first procedure is used if there are ten or fewer information processing activities--an unlikely possibility. The second procedure is used if there are more than ten information processing activities. Again, the rating technique is adapted from procedures described in Hawley, <u>et al</u> (1982).

<u>Procedure for ten or fewer activities</u>:

1. List the information processing activities in descending order of importance.

2. Assign the least important activity a rating of 10.

3. Consider the next-least-important activity. How much more important is it than the least important? Assign it a number that reflects that ratio. For example, if the second-least-important activity is judged to be four times as important as the least-important, it is assigned a score of 40. Continue up through the list of activities and assign each one a value in the same way. Check each set of ratios as new judgments are made.

4. Review the ratings to insure that they reflect the relative importance of each of the activities. Are the ratios of distances between activities correct? Make any necessary adjustments to the ratings.

5. Add the resulting scores and divide each score by the resulting sum. Round to two decimal places.

<u>Procedure for more than ten activities</u>:

1. Select one of the activities at random.

2. Randomly assign each of the remaining activities to groups of approximately equal size, with no more than five activities to a group.

3. Add the activity selected in (1) to each group and assign it a rating of 100. This "index" activity will serve to link each of the activity clusters later.

4. Rank each of the activities within each group in order of descending importance. Assign numerical ratings to each activity following the procedure outlined for ten or fewer activities. Keep the rating of the index activity fixed at 100.

5. Merge the groups to form one consolidated list of activities arranged in order of their associated importance ratings.

6. Add the ratings and divide each by the resulting sum. Round to two decimal places.

Step 5. Review DIFs and weight them according to their importance

There are four primary factors on which each design concept will be valued. Each of these factors is divided into two to four subordinate factors, as follows:

1. Personnel -- how many and what kind of personnel will be required to man each design concept and how much will it cost?
    a. Quantity
    b. Quality

2. Training -- how complex will the training development be and how much will it cost; how much new support will be required to train personnel and how much will it cost; how much time will be required to train personnel and how much will it cost; how risky will the training be?
    a. Development
    b. Delivery
    c. Time
    d. Risk

3. System development -- how long and how error prone is system development likely to be and how much will it cost; how much risk is involved in applying the particular technology and how reliable, available, and maintainable will the technology be when it is developed and how much will maintenance cost; how flexible will the technology be for accepting upgrading and how much will upgrades cost?
    a. Time
    b. Technological risk
    c. Flexibility/adaptability

4. System performance -- will the system have the speed, accuracy, and capacity (random access memory, throughput, secondary memory, and so on) required of it as specified system response demands?
    a. Speed
    b. Accuracy
    c. Capacity

These DIFs are not necessarily of equal importance. If they are not of equal importance, they need to be assigned differential weights that will be used in assigning the values to each design concept.

The differential weights are obtained by ranking the factors and assigning ratings to them. The rankings and the ratings should be made by stakeholders from each of the areas with which the DIFs are concerned. Again, a group method which mixes these two kinds of specialists in interactive groups for obtaining the rankings and ratings would be preferable.

The procedure for obtaining DIF weights is as follows:

1. Rank the factors at each level of the hierarchy and in each cluster in order of their importance to the design problem under consideration. First, rank the four major factors (personnel, training, system development, and system performance) in order of importance. Next, rank the clusters of subordinate factors under each major factor. For instance, rank the two factors (quantity and quality) under the personnel factor. Then rank the four subordinate factors (development, delivery, time, and risk) under the training factor. Continue in this way until the members in each cluster have been ranked.

2. Assign ratings within each level and cluster in the hierarchy as in the ranking procedure above.
    a. Assign the least important factor a rating of 10.
    b. Consider the next-least-important factor. How much more important is it than the least important? Assign it a number that reflects that ratio. Continue rating in this manner until all factors in each cluster (including the cluster made up of the four major factors) have been rated. Check each set of ratios as each new judgment is made.
    c. Review your ratings to insure that they reflect the importance of each of the factors and subordinate factors. Are the ratios of distances between factors correct? Make any necessary adjustments to your ratings.
    d. Normalize the values within each cluster (including the cluster made up of the four major factors) by summing the ratings and dividing the individual values by the result.

3. Obtain an aggregate value for each subordinate factor by multiplying its value within the cluster by the value of the major factor to which it belongs.

Step 6. Obtain ratings for each information processing activity for each design concept on each DIF

At this state in the analysis, a trade-off matrix having dimensions defined by FATDS design concepts, information processing activities, and design impact factors has been defined. Figure 5 illustrates the form of this trade-off matrox. The objective of Step 6 is to obtain merit ratings for each design concept for each information processing activity on each DIF.

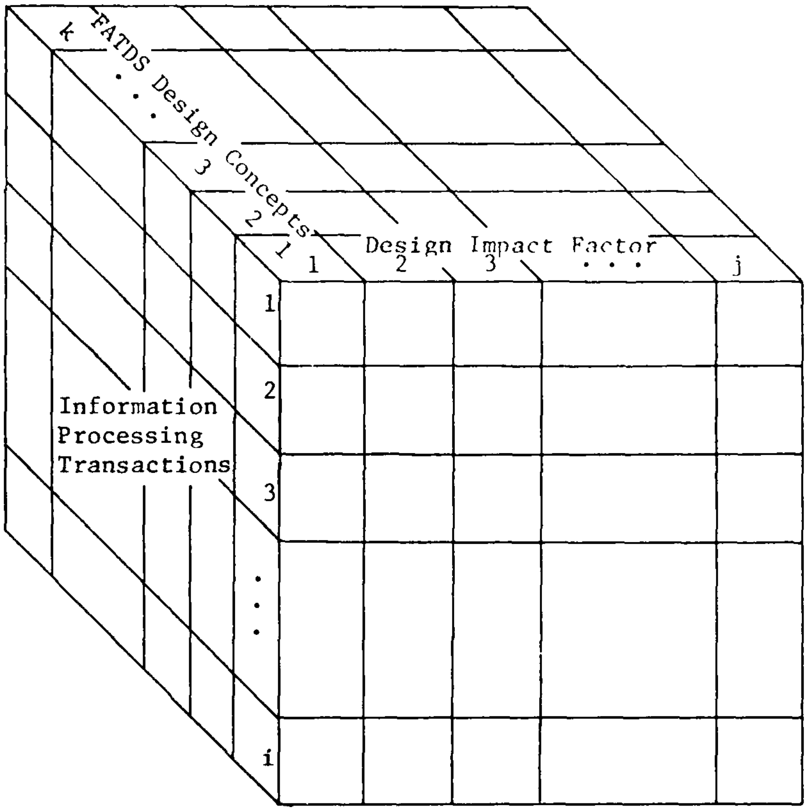


Figure 5. FATDS Concept-Level Trade-Off Matrix

The merit ratings should be made by technical experts in each impact factor area and technical experts in the respective technologies involved in each design concept. Since it is unlikely that individuals can be found who possess both kinds of expertise, the ratings should be obtained by using a small group approach in which each group is made up of different kinds of experts as required for the particular information processing activities and design concept technologies that are to be rated.

For this first level of analysis, merit ratings can be made on a 1-to-3 scale, with the points on the scale defined as shown in Table 1. The unit of the system that is rated could be different for each impact factor, but it appears that system component may constitute the most useful and efficient unit. Each individual system component usually accounts for just a few information processing activities. Oftentimes, there will be a one-to-one match between components and activities. Providing ratings at the component level may, however, require that some amount of preliminary systems organization (i.e., identifying information processing activities with distinct system elements) be carried out.

Step 7. Obtain partial FOM on each DIF for each design concept

In this step, calculate a partial FOM for each design concept for each primary DIF. A partial FOM is obtained by, first, aggregating merit ratings acrosss information processing activities within each subordinate DIF:

$$PM_{\ell k(j)} = \sum_i W_i \, R_{\ell ik(j)}. \qquad (1)$$

In (1), $PM_{\ell k(j)}$ denotes the partial merit (PM) of the ℓ^{th} concept alternative on the k^{th} subordinate DIF (nested under the j^{th} primary DIF); W_i represents the importance, or criticality, of the i^{th} information processing activity; and $R_{\ell ik(j)}$ is the merit rating (1-to-3) assigned the ℓ^{th} concept alternative on the i^{th} activity for the k^{th} subordinate DIF (under the j^{th} primary factor).

Partial FOMs for the primary DIFs on each alternative are obtained by aggregating merit indices across subordinate DIFs. That is,

$$PM_{\ell j} = \sum_k D_{k(j)} \, PM_{\ell k(j)}, \qquad (2)$$

where $D_{k(j)}$ represents the importance of the k^{th} subordinate DIF nested under the j^{th} primary factor. All other terms are as defined previously.

Table 1

Concept-Level Rating Anchor Points

A. Personnel
- a.1. Quantity:
  - 1 - The number of personnel required to operate and maintain this alternative will be high, relative to the antecedent (or baseline) system.
  - 2 - Personnel requirements will be approximately the same as the antecedent system.
  - 3 - Personnel requirements will be less than the antecedent system.
- a.2. Quality:
  - 1 - The personnel required to operate and maintain this alternative must be of higher quality than the antecedent system.
  - 2 - Personnel quality requirements will be approximately the same as the antecedent system.
  - 3 - Personnel quality requirements will be less than those of the antecedent system.

B. Training
- b.1. Development:
  - 1 - Training development on this alternative will be a complex undertaking. Extensive and detailed front end analyses will be required.
  - 2 - Training development for this alternative will not be appreciably more complex than for similar systems of this type.
  - 3 - Training development will be a relatively easy process. The new system is very similar to its predecessor, or conceptually similar systems exist elsewhere.
- b.2. Delivery:
  - 1 - The training delivery system will be complex and extensive. It will require the construction of many new facilities.
  - 2 - The training delivery system for this alternative will not be appreciably more complex or extensive than for similar or antecedent systems.
  - 3 - The training delivery system for the antecedent can be used almost "as is".
- b.3. Time:
  - 1 - The time required to train personnel to operate/maintain this alternative will be considerably longer than the antecedent system.
  - 2 - The time required to train personnel to operate/maintain this alternative will be approximately the same as the antecedent system.
  - 3 - Less time will be required for training this system than is required on the antecedent system.

Table 1 (Cont'd)

- b.4. Risk:
  - 1 - Given the anticipated personnel input to the training program and the allocated training time, there is considerable risk that training objectives will not be met.
  - 2 - Training risk, measured in terms of the likelihood of meeting training objectives, is approximately the same for this alternative as on other systems that are similar in concept.
  - 3 - There is a high likelihood of being able to meet training objectives.

C. System Development

- c.1. Time:
  - 1 - The alternative under consideration represents a considerable departure from the antecedent system. Hence, there is a high likelihood that the system development process will be long and possibly error-prone.
  - 2 - The alternative is relatively complex, but does not represent a significant departure from the antecedent system. No real problems in the system development process are anticipated.
  - 3 - The technology involved in this alternative is "off-the-shelf." System development time should be shorter than usual.
- c.2. Technological Risk:
  - 1 - The technology employed in this alternative is beyond the current state of the art. There is considerable risk involved in taking this approach.
  - 2 - The technology employed in this alternative represents the state of the art. Some modifications may be in order, but no real problems are foreseen.
  - 3 - The technology employed in this alternative is off-the-shelf. It has been proven in a variety of similar applications.
- c.3. Flexibility/Adaptability:
  - 1 - It will not be possible, beyond a very limited scope, to modify this alternative to meet changing threat/technological situations.
  - 2 - The technology used in this alternative will not be particularly amenable to change. PIPs will require significant hardware modifications.
  - 3 - The technology used in this alternative will result in a very flexible and adaptative system; it will be possible to accomplish system upgrades (i.e., PIPs) without completely redesigning or reconfiguring the system.

Table 1 (Cont'd)

D. Performance--likelihood of meeting system response demands

- d.1. Speed:
  - 1 - System response demands will not be met..
  - 2 - System response demands will be met, but not exceeded.
  - 3 - System response demands will be exceeded.
- d.2. Accuracy:
  - 1 - System requirements will not be met.
  - 2 - System response demands will be met, but not exceeded.
  - 3 - System response demands will be exceeded; alternative is not error-prone.
- d.3. Capacity:
  - 1 - The capacity of this alternative is not sufficient to meet the present and the near-term future threat.
  - 2 - The capacity of this alternative is adequate to meet the present and near-term future threat.
  - 3 - The capacity of this alternative (e.g., random access memory, throughput, secondary memory, etc.) exceeds that required to meet the current and near-term future threat.

Users also can compute partial FOMs for each of the $\underline{m}$ system components by aggregating merit ratings across DIFs within components. This would be done by, first, aggregating across transactions within components and then aggregating across subordinate and primary DIFs:

$$PM_m = \sum_j \{ \sum_k D_{k(j)} [\sum_i W_{i(m)} R_{\ell i(m)k(j)}] \} \qquad (3)$$

In (3), $W_{i(m)}$ indicates the criticality of the i^{th} IP activity within the m^{th} system component, and $D_{k(j)}$ again represents the importance of the k^{th} subordinate DIF nested under the j^{th} primary factor.

Step 8. Obtain aggregate FOM for each design concept

An aggregate FOM for each concept-level alternative is obtained by aggregating partial FOMs across DIFs:

$$M_\ell = \sum_j PM_{\ell j}. \qquad (4)$$

The concept alternative having the highest aggregate FOM is preferred. Hence, it is the alternative to select for additonal development. If no single design concept yields a FOM significantly higher than the rest, then the two highest scoring alternatives should be carried forward into the next step.

Step 9. Review the results of the two previous steps in an attempt to improve the highest rated design concept

The design concept with the most favorable FOM is selected for review and improvement. First of all, users should identify its least favorable components and DIFs. Compare these ratings with similar ratings obtained for the other design concepts. Can parts of other design concepts be substituted into the preferred design, thus increasing the FOM for the selected design? If so, make the substitutions and calculate new FOMs.

If two design concepts were carried into this step, then perform the above procedure on both of them to determine whether substantially different FOMs result. If so, then carry the one with the higher value into the next phase. However, if the two design concepts still do not yield substantially different FOMs, then carry both of them forward into the next phase.

Finally, revise the parallel flowcharts for the selected design concepts as they were developed in Step 3 of Phase 3 of the front-end analysis. Revised flowcharts are necessary in the next phase.

PHASE TWO: DEVELOP ALTERNATIVE INTERFACE CONCEPTS FOR THE SELECTED AND REVISED DESIGN CONCEPT

Phase 2 develops several alternative interface concepts for the selected and revised design concept, evaluates each interface concept, and revises the best of the interface concepts in an effort to improve it. The interfaces between human and machine exist to facilitate transactions of information from one to the other. The critical aspect in designing interfaces for C^3 systems is to insure that the interfaces select, organize, display, and accept information in such a manner as to facilitate the natural information processing activities of the commanders/operators of the system. With regard to control room operators for large industrial processes, Rasmussen and Lind (1981) observe:

> The operator's symbolic data processing...depends upon an internal or mental model of the causal structure of the system, and...humans have a number of ingenious ways to circumvent complexity by transfer of the problem to a representation suited to treat the present problem... The major tools are hierarchical aggregation/decomposition to change the resolution of the attention applied to the problem--which is very often coupled to a change in level of abstraction used for the causal representation... Hierarchical decomposition/aggregation is related to the span of attention of the operator (and) to the level of detail or resolution applied for data processing.

With regard to the general cognitive model for monitoring remote systems described in Phase 3 of the front-end analysis, aggregation occurs primarily on the input branch and decomposition occurs primarily on the output branch. The level of abstraction to which aggregation is carried and from which decomposition begins is determined by the operator's processing of the information to arrive at a response alternative. However, there may well be many fluctuations in the level of abstraction in the commander/operator's internal information processing between the initial aggregation branch and the final decomposition branch. The commander/operator may first scan a broadscale internal representation of the situation, examine one or two more detailed levels of representation of parts of the situation, recall a menu of broad options and principles for selecting from them, make a selection, and then recall specific details at two or three lower levels to implement the selected option. If the displays which he receives from the interfaces do not match his internal processing, he may be momentarily confused and may have to undertake several additional mental actions either to transform the display representations to match his own or transform his own to match the display. In either case, he loses time and may also lose continuity in his own internal processing. Transforming representations to make them fit each other may well be too complex a task within the overall context of the other activities he has to perform. Rasmussen and Lind (1981) observe:

> The way to assist operators to avoid complexity is...to make a repertoire of display formats available to him, structured in a hierarchy with a small number at the high levels of abstraction/aggregation, and a larger number at the low detailed levels, together with an orderly and structured way to seek through the hierarchy to "zoom-in" on the relevant display. The properties of the individual displays and the quality of cross-references to related displays at higher and lower levels of abstraction are, however, important for the perception of complexity.

The symbols used for displaying information also are critical. If the commander/operator's internal representation is primarily spatial and the interface displays are alphanumeric, the display information will have to be transformed before it can be related to the individual's internal spatial representation. In such an instance, graphic displays at the appropriate level of detail might be much more readily usable by the commander/operator. Both the speed and the accuracy of response might be enhanced by graphic displays.

Equal attention must be paid to the design of the information representation in the controls as is paid to the design of the displays. The problems of obtaining an adequate fit between the commander/operator's internal representations and the representations in the controls are similar. If the commander/operator's internal representations of response alternatives are abstract and spatial but the control representations are detailed and alphanumeric, then the individual must engage in a series of potentially disruptive transformations.

Wherever possible, the interface designs should minimize the perception of complexity and the transformations required of commander/operators. It may be necessary to add new information processing activities to the machine components of the system to develop the appropriate levels and symbols for presenting information to commander/operators and for accepting information from them.

Phase 2 consists of ten steps, as follows:

1. Identify all human/machine and machine/human transactions in the revised flowcharts for the selected design concept.

2. Identify and describe the commander/operator's general cognitive context for each transaction.

3. Develop the machine technology focus for each interface concept.

4. Develop alternative interface concepts for each commander/operator position.

5. Determine the importance of each transaction to the attainment of field artillery objectives (missions).

6. Review the DIFs and weight them according to their importance.

7. Obtain ratings for each transaction (T) in each interface concept on each DIF.

8. Obtain partial FOMs on each DIF for each interface concept.

9. Obtain aggregate FOM for each interface concept.

10. Review the results of the two previous steps in an attempt to improve the highest rated interface concept.

The outcome of this phase is a specification of those technologies that provide the best information representations at each interface for accomplishing each transaction.

<u>Step 1. Identify all human/machine and machine/human transactions in the revised flowcharts for the selected design concept</u>

The design concept is specified in part by one or more parallel flowcharts in which each system component (including the human subsystem) is represented by one row in the flowchart. Human/machine and machine/human transactions are represented as flow lines which cross the boundaries of the human subsystem row, either originating from or terminating in an information processing activity in the human subsystem row. Each such transaction should be identified and designated in one of two lists, one for human/machine transactions (for interface controls) and one for machine/human transactions (for interface displays). The designation of each transaction should specify the originating IP activity, the terminating IP activity, the system component that performs each activity, and the mission context within which each activity occurs.

<u>Step 2. Identify and briefly describe the commander/operator's general cognitive context for each transaction</u>

In this step, the cognitive processes of the commander/operator surrounding each transaction are briefly described. What kinds of cues are presented to indicate to the commander/operator that he needs to perform a given transaction? What kinds of cues shape his performance of each transaction? What kinds of cues serve as feedback regarding the adequacy of a given transaction? What kinds of decisions are to be made either directly before or directly after each transaction, if any? What kind of information must be presented to the commander/operator? What short and long term memory requirements are imposed on the commander/operator? How large a cognitive load must he be able to handle? What is the rate at which transactions must occur? At what level of abstraction and in what symbols are relevant information and applicable principles represented in the commander/operator's internal information processing? These descriptions should be developed by personnel who have had the most extensive experience in commanding and operating existing FATDS in combat or near-combat-like situations. However, they will need more than just their experience as a basis for generating the descriptions. They should also be provided with a summary of the system response demands and a summary of the selected episode descriptions from the front-end analysis and time in which to review them thoroughly. Use a group process to develop the descriptions.

Sort the transactions into categories according to the commander/operator position at which they are to be performed. Prepare a summary of the transaction descriptions in each category. These summaries identify the cognitive contexts relevant to each interface and constitute the basic performance requirements for each interface.

Step 3. Develop the machine technology focus for each interface concept

The same approach is used in this step as was used in the first step of the previous phase for developing alternative design concepts. However, in this case the interface technologies must be compatible with the machine technologies selected for information processing in the selected design concept. Again, alternative interface concepts for the selected design concepts are developed to address at least three different levels of interface technology:

1. Existing technologies. The interface concept at this level will draw only from those compatible interface technologies that are fully developed and on the commercial market at this time.

2. State-of-the-art technologies. The interface concept at this level will draw not only from existing interface technologies but also from those technologies whose potential has been proven in research applications and perhaps in some prototype applications, but they are not yet widely available commercially.

3. Foreseeable technologies. The interface concept at this level will draw not only from existing and state-of-the-art technologies, but also from technologies that are theoretically feasible but which have not been tested in any applications.

Using these definitions as a guide, examine the transaction description summaries for each commander/operator interface position and identify the interface technologies that will provide the closest match to the cognitive context in the summaries at each level of focus. There may well be several technologies at the same level of focus that apply to the same characteristics in a given summary. At this point, list them all. Again, the persons who make these judgments should be the most knowledgeable available with regard to the various interface technologies. As before, if the experts can be assembled in small groups, then a group process should be used to obtain their judgments. If they cannot be assembled at one place at one time, then a Delphi approach would be useful.

Step 4. Develop alternative interface concepts for each commander/operator position

Before interface arrangements can be conceived, it is necessary to decide which performance characteristics are important for each interface. In some instances, the speed and accuracy with which the operator extracts information from the displays or enters decisions into the controls may be critical. In other instances, his speed and accuracy in searching through an aggregation/decomposition hierarchy may be critical. Speed and accuracy standards specify how well the operator must perform. It is also necessary to specify what the interface can do to support the operator, and the interface characteristics that are most directly responsible for providing that support; for example, level of abstraction and symbols used for presenting information, minimum information clutter, interface response time to inputs or requests for other information. A specification of these kinds of characteristics should be prepared for each interface.

An interface concept consists of a tentative arrangement of displays and controls; a specification of the information content, levels of abstraction, and symbols which characterize the displays and controls; a specification of the hardware and/or software technologies to be used in the interface; a specification of the speed of response available in display changes and in controls. Other characteristics may well become apparent once a few interface concepts are prepared. The alternative interface concepts should provide sufficient specification to prepare full scale two dimensional mock-ups of the various interface panels and to prepare input displays and control feedback displays involved in actually performing the transactions involved in a particular episode.

Step 5. Determine the importance of each transaction to the attainment of field artillery objectives (missions)

Some transactions are more important for accomplishing the objectives of the field artillery system than are others. Consequently, it is necessary to assign each transaction a value that reflects its criticality for accomplishing field artillery missions, as was done in Step 5 of Phase 1 of this stage.

The mission criticality judgments should be made by those available personnel who have had the most intensive experience in commanding and operating existing FATDS in the most combat-like situations possible. However, raters will need more than just their experience in judging criticality. They should be provided with a summary of the transaction performance requirements and a summary of the selected episode descriptions from the front-end analysis and time in which to review them thoroughly. Again, if possible, use a group process.

There are two different procedures that can be used in obtaining the criticality judgments. They were previously described in Step 4 of the first phase of the design process. The ratings for IP activities assigned in Phase 1 might also be useful in providing importance ratings for IP transactions.

Step 6. Review the DIFs and weight them according to their importance

The DIFs used to value the interface concepts are essentially the same as those used to value the design concepts as described in Step 5 of the first phase of this stage. However, the weights assigned to the DIFs need not be the same as the weights assigned to them in the previous phase. In fact, it may be desirable to revise the DIFs or their definitions. Some DIFs might be eliminated as not relevant for valuing the alternative interface concepts. For instance, it seems reasonable that the weights obtained previously for personnel and training factors may still be appropriate, but that new weights might be desired for the development and performance factors.

Step 7. Obtain ratings for each transaction (T) on each interface concept on each DIF

The next step in the procedure concerns obtaining merit ratings for the interface alternatives for each transaction and on each DIF. These ratings should be made by technical experts in each impact factor area, by technical experts in the respective technologies involved in each interface concept, and by the most experienced personnel available in commanding or operating FATDS. Since it is unlikely that individuals can be found who possess all three kinds of expertise, the ratings should be obtained by using a small group approach in which each group is made up of different kinds of experts as required for the particular interface concept that is to be rated. During these ratings, the raters should have available to them the specifications for the interface concept being rated, full-scale tentative mock-ups of the interface panels, and complete sets of examples of the information characteristics of the displays and controls required for performing the transactions in the selected episodes from the front-end analysis. They should also have the summaries of the episodes from the front-end analysis. Part of their judgment process may well involve walking-through and talking-through many of the transactions.

Since interface characteristics per se are less ambiguous than the properties of the concept-level alternatives, the experts are asked to provide merit ratings on a 0-to-100 scale. The following scale anchors can be used as a guide in assigning interface merit ratings:

0 - the alternative is completely unacceptable for this application.

25 - the alternative is marginally acceptable for this application.

50 - the alternative is judged adequate for this application.

75 - the alternative is judged to be an above average choice for this application.

100 - the alternative is the best possible, given the current and anticipated state-of-the-art.

The unit of the system that is judged this time consists of an entire interface for a position, or of the different parts of an interface if they are used for totally separate transactions. Step 7 results in an interface trade-off matrix of order i transactions by j DIFs by ℓ interface alternatives. The objective of the remaining steps is to integrate the information in the trade-off matrix so that a decision can be made concerning a preferred interface configuration.

Step 8. Obtain partial FOMs on each DIF for each interface concept

In Step 8, partial FOMs for each alternative on each subordinate and primary DIF and for each system component are computed. The procedures used to obtain the various FOMs are nearly identical to those used in Step 7 of the previous phase. These are recapped briefly as follows.

1. Obtain a partial FOM for each interface alternative on each subordinate DIF:

$$PM_{\ell k(j)} = \sum_i W_i R_{\ell ik(j)}, \qquad (5)$$

where W_i is the importance of the i^{th} information processing transaction, and all other terms are analogous to those defined previously.

2. Obtain a partial FOM for each alternative on each of the k primary DIFs:

$$PM_{\ell j} = \sum_k D_{k(j)} PM_{\ell k(j)}. \qquad (6)$$

3. Obtain a partial FOM for each of the m system components:

$$PM_m = \sum_j \{\sum_k D_{k(j)} [\sum_i W_{i(m)} R_{\ell i(m)k(j)}] \}. \qquad (7)$$

Step 9. Obtain aggregate FOM for each alternative interface concept

In Step 9, aggregate FOMs for each interface alternative are obtained by summing partial FOMs across primary DIFs:

$$M_\ell = \sum_j PM_{\ell j}. \qquad (8)$$

The interface alternative with the highest aggregate FOM is preferred; it is the interface configuration to select for development. If no single interface alternative yields a substantially higher value than the others, then the two highest ones should be carried forward into the next step where a final determination will be made.

Step 10. Review the results of the two previous steps in an attempt to improve the highest rated interface concept

The interface alternative with the highest aggregate FOM is selected for review and improvement. Again, identify its least favorable transactions or transaction sets, components, and DIFs. Compare these ratings with similar ratings obtained for the competing interface concepts. Can parts of other interface concepts be substituted into the selected concept thus increasing the FOM for the selected interface? If so, make the substitutions and calculate new figures of merit.

If several alternative interface concepts are carried into this step, then perform the above procedure on both to determine whether substantially different aggregate FOMs result. If so, then select the one with the highest value for implementation. However, if the alternative interface concepts still do not yield substantially different overall values, then the selection will have to be made at a higher level using additional and perhaps more subjective decision factors.

GENERAL CHARACTERISTICS AND BENEFITS OF THE CDMA

The Concept Design Management Approach (CDMA) provides the developmental context and procedures for conducting trade-off analyses of alternative concept designs for a C^3 system and for integrating the better features of the non-selected alternatives into the selected alternative. The approach is characterized by eleven significant features:

1. It is a rational approach for developing the design concept for a FATDS. It consists of two major processes:

    a. A front end analysis process (1) which collects or generates information about the environments and situations in which the FATDS will operate, (2) which identifies the response demands which must be met by the FATDS, and (3) which specifies the minimum human role which must be supported by the system.

    b. A design concept process (1) which allocates information processing activities in the emerging system concept to human or machine components and (2) which specifies the interface characteristics required to support mental information processing of commanders and operators of the FATDS.

2. It conceives of a FATDS (or any C^3 system) as being an information processing system performed both by machine and human components.

3. It provides a general cognitive model for insuring at least a minimum role for humans as commander/monitor of the system. This model provides guidance for analyzing the activities which make up this role.

4. It encourages the consideration of established technologies, state-of-the-art technologies, and foreseeable technologies to insure that the resulting system concept is not outmoded by the time the system is fielded.

5. It identifies the various kinds of human judgments that need to be made in developing a design concept for a FATDS.

6. It identifies the characteristics of personnel best suited for making each kind of judgment.

7. It specifies particular group process techniques for obtaining the best possible judgments from the appropriate personnel. These techniques provide for the mixing of personnel with different qualifications in each group so that each can bring his or her own special qualifications to bear on the judgments in an optimum manner.

8. It specifies techniques for assigning numeric values to judgments and for aggregating judgments from different raters. The aggregation procedures allow for the introduction of differential weights which reflect management interests and criteria.

9. It specifies trade-off techniques for using the numberic values assigned to judgments regarding the impact of alternative concepts on critical factors for selecting the best of several alternative design or interface concepts.

10. It specifies techniques for using the numeric values assigned to judgments regarding the impact of a design or interface concept on critical factors for improving the concept.

11. It provides a basis for developing a detailed audit trail of the entire design concept process.

The approach described in this report offers the design management team a number of attractive benefits:

1. It provides a rational and fully described approach which can either be incorporated into the project intact or used as a first approximation in developing their own fully explicated approach. The CDMA is very flexible and can be readily adapted to meet specialized needs and interests.

2. It provides a division of activities that can be used for measuring progress and making assignments.

3. It provides a basis for project stability even through major personnel changes. New personnel can readily review the audit trail of past activities and the projection of future activities.

4. It provides assurance that the design concept that evolves from the application of the approach is the best that could be developed at that time with the personnel and resources available.

At this time, the CDMA exists more as a very detailed proposal since it has not actually been tried out as an intact process. A tryout would help develop or firm up details in the process. However, all of its features are drawn from established behavioral science technology. There is no doubt about it being a workable process, but adjustments will be needed during its early applications.

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