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ON THE DESIGN OF SIMULATIONS OF COMMAND AND CONTROL PROCESSES

Roland V. Tiede, Roger A. Burt, and Theodore T. Dean

Science Applications, Incorporated

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No. 20 (cont'd)

processes employed by the command group/staff. All relevant aspects of human performance except the higher-level decision making operations can be realistically simulated. A trade-off is found to exist in the alternative configurations between the realism of staff play, the ability to make behavioral measurements, and the cost of personnel and computer hardware/software.

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ON THE DESIGN OF SIMULATIONS OF COMMAND AND CONTROL PROCESSES

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ON THE DESIGN OF SIMULATIONS OF COMMAND AND CONTROL PROCESSES

BRIEF

This volume reports on the follow-on, Phase 2, research effort on the design of an Integrated Division-Level Battle Simulation for Research, Development, and Training. It develops the logical framework for simulated staff processing so that the model design can accommodate variant human performance from the team players in populated staff modules as well as simulated variant performance in simulated modules. It also examines the staff processing structure to determine whether alternative interface locations (between live players and the simulation) are feasible, considering task realism, performance measurement requirements, and model implementation. The material covered in this and a companion volume, "Some Guidelines for Effective Task Design in Command and Control Simulations," is essentially identical except for Section 5.

Requirement:

Prepare a report detailing the critical dimensions and parameters of human performance in command and control, and providing a design for simulations of command and control processes.

In the light of the design problems in Phase 1 which gave rise to this task, it may be thought of as finding answers to the following questions:

1. Can the simulated staff modules be designed so that they will accommodate variant human performance on the part of one or more populated staff modules? This will allow behavioral scientists to examine the effect of human staff errors on battle outcome.
2. Can the simulated staff modules themselves be made to generate common staff errors? This will allow examination for corrective responses that might be instituted by the populated modules.
3. Is it feasible, in the interest of economy of operations and player motivation, to vary the interface boundaries of the staff modules? This will allow the controller/investigator, in some experiments, to eliminate certain repetitive, low skill procedural tasks from the live staff procedures.

This research effort was carried out in parallel with a second effort whose purpose was to develop principles of task design for interactive simulations. The successful accomplishment of both tasks required search of largely common data sources and both required development of the detailed logical information flow structure within the staff

modules that comprise the decision making node in military command control systems. Therefore, the technical approach to both consisted of five steps of which the first four were common to both efforts. The five steps for the effort which is the subject of this report were:

1. A literature search covering human behavior in command control decision nodes and of extant games and simulations was conducted.
2. A detailed formulation of the staff processing required to process all message traffic postulated in the Phase 1 design was developed. This analysis began by defining the elementary operations performed by a single man--the basic building blocks of staff procedures. The sequence in which these elementary operations need be performed to process the message types selected in Phase 1 was established in the form of event thread charts.
3. The points of occurrence of variant human performance, i.e., of the error classes identified in Step 1 were identified. The frequency of occurrence was estimated since no hard data on error frequency were available.
4. A logical framework was then established for the design of simulated staff modules to permit such simulated modules to accommodate variations in human behavior in populated modules and reflect the effects of human errors in battle outcomes. Similarly, the framework was established to insert variant performance (errors) into the processing performed in simulated modules so that the reaction to such performance by populated modules could be observed and measured.
5. Finally, the staff processing structure was examined to determine whether alternative interface locations between man and the simulation are feasible considering task realism, performance measurement requirements, and model implementation.

Conclusion:

1. Simulated staff modules can be structured so that they can accommodate variant human performance.
2. Software can be developed that will simulate staff processing in an event thread framework and that will provide: (1) investigator control of the simulated human staff performance, and (2) investigator control of the simulated staff response times.

3. For emulating manual staffs the realism of the staff processing will get progressively worse as the level of interactive play is increased.
4. The ability to measure player performance and to control the information flow in experiments will generally improve as the level of interactive play is increased.
5. The cost of experiments, in terms of the total number of personnel required, will go down as the level of interactive play is increased.
6. The investment cost of computer hardware/software will increase as the level of interactive play goes up.

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SECTION 1

INTRODUCTION

1.0 PURPOSE AND SCOPE

The results of the follow-on, Phase 2 effort on the design of an Integrated Division-Level Battle Simulation for Research, Development, and Training are contained in two companion volumes:

- On the Design of Simulations of Command and Control Processes
- Some Guidelines for Effective Task Design in Command and Control Simulations

Although based on the logic of the original Phase 1 top-down design¹, they transcend the original work in that they develop basic considerations that apply to the design of any simulation of command and control and to the design of player tasks in such simulations when used as experimental tools.

The Phase 2 effort has centered on two additional design requirements that were acknowledged, but not fully addressed, during the Phase 1 design work. These requirements can be stated as follows:

TASKS (KEY WORDS)

BASIS

1. Prepare a report:

- | | |
|--|---|
| ● Detailing the critical dimensions and parameters of human performance in command and control | ● Search of behavioral science and gaming literature |
| ● Providing a design for simulations of command and control processes | ● Analysis of existing interactive simulations (to include design developed in Phase 1) |

2. Prepare a report:

- | | |
|--|--|
| ● Discussing principles of task design for interactive simulations | ● Search of behavioral science and gaming literature |
|--|--|

¹ Tiede, R. V., Burt, R. A. and Bean, T. T., Design of an Integrated Division-Level Battle Simulation for Research, Development, and Training, (Army Research Institute Draft Technical Report, August 1979)

- including trade-offs among task realism, credibility, and impact upon performance measurement
- Analysis of existing interactive simulations (to include design developed in Phase 1)
- Providing guidelines for effective task design

In the light of the design problems in Phase 1 which gave rise to these tasks, they may be thought of as finding answers to the following questions:

- Variant (Non-Standard) Human Staff Performance
 - Can the simulated staff modules be designed so that they will accommodate variant human performance on the part of one or more populated staff modules? This will allow behavioral scientists-investigators to examine the effect of human staff errors on battle outcome.
 - Can the simulated staff modules themselves be made to generate common staff errors? This will allow examination for corrective responses that might be instituted by the populated modules.
- Controllable Interface Boundaries
 - Is it feasible, in the interest of economy of operations and player motivation, to vary the interface boundaries of the staff modules? This will allow the controller/investigator, in some experiments, to eliminate certain repetitive, low-skill procedural tasks (e.g., answering radios or telephones, transmitting messages, routine filing, etc.) from the live staff procedures.
- Task Design for Interactive Simulations
 - What are the principles of task design for interactive simulations? What are the trade-offs among task realism, credibility, and impact on performance measurement, and do they provide guidelines for effective task design?

These problems require the detailing of the relevant dimensions and parameters of human performance in command and control as well as a

more detailed design of the staff procedures to be established for the players in populated modules or, correspondingly, to be represented in simulated modules.

The report identifies three classifications of human errors that can occur during the processing of staff actions and therefore lead to the Blue force failing to accomplish its assigned mission. The human error types are based on a search of behavioral science and war gaming literature and an analysis of the event sequence relationships in the Phase 1 design. The latter analysis included the definitions of 27 "elementary operations" (for live staff players) or Class 1 events (for simulated modules). All staff procedures are composed from these basic procedural steps.

In this framework, the report addresses the basic design problems described above. With respect to the first problem, it shows that simulated staff processing can be designed in such a manner that simulated modules "accept and pass on" faulty or substandard staff actions generated by one or more populated staff sections, thereby allowing the substandard performance to be reflected in the battle outcome. The simulated modules can also be made to exhibit staff errors themselves, based on stochastic or fixed switches preset by the experimenter(s).

The second and third problems, that of controllable interface boundaries, and the discussion on the principles of task design under the enhanced basic design concept, are added as Section 5 of the two respective reports on this effort.

1.1 RELATIONSHIP TO THE PHASE 1 DESIGN

The Phase 1 design consisted of two parts: (1) the basic design concept for the Integrated Division-Level Battle Simulation and (2) a proposed initial implementation of the concept. The basic design concept was for a general interactive simulation model with sufficient scope and flexibility that it could be applied alternatively to behavioral research, to the development and evaluation of new tactics, or to the training of staff personnel. The system contained six "plug-in" modules, each of which could either be "played" by human players or else be simulated by means of rules imposed by the computer and/or controllers. Five of these modules represented the Blue Command Group and its four principal staff sections; the sixth module was the Red Command. The system provided for the play of a division-level (alternatively corps-level) war game in which the "configuration of play" could be selected beforehand. The configuration of play is the particular combination of populated modules and simulated modules chosen among the six. The play itself involved not only the simulated combat between the opposing forces but also the varying states of knowledge the opposing commanders use as the basis

for their tactical decisions. The system handled the information flow of approximately seventy-five standard tactical messages, and was based on an event-oriented simulation using approximately 350 separately defined events. These events covered staff actions, staff coordination, staff output, and staff input as well as the simulated battle occurrences.

The second part, the proposed implementation of the concept, developed a physical layout, the system architecture, the software requirements, and precise specification of the controller functions for the initial implementation. These key elements imposed three specific constraints on the scope of the full concept:

- One or two human controllers, aided by computerized preprocessing capabilities and an interactive executive control routine, would control the play of the game.
- Configurations of play would be limited to no more than two populated staff modules (any two out of six modules).
- Blue staff modules would operate under a manual staff system only.

This report now addresses the two additional design requirements in a manner that is consistent in all respects with the structural concept of Part 1. The enhanced basic design concept presented here, on the other hand, requires that the proposed initial implementation in Part 2 be modified.

1.2 TECHNICAL APPROACH

The technical approach used in the Phase 2 design work was based on a common point of departure for the two separate design requirements. The common basis consisted of a literature search for relevant background information and an analysis of existing interactive simulations, including the Phase 1 design itself. The approach consisted of the following six steps in which the first four were the common prerequisites to the last two:

- Step 1 - Literature search covering human behavior in command and control and interactive war game simulations.
- Step 2 - Detailed formulation of the staff processing required in the framework of the tactical message specified in the Phase 1 design.

- Step 3 - Identification of the points of occurrence and frequency of occurrence of variant human performance in the staff processing.
- Step 4 - Development of the logical framework for simulated staff processing so that the model design can accommodate variant human performance from the team players in populated modules as well as simulated variant performance in simulated modules.
- Step 5 - Examination of the staff processing structure to determine whether alternative interface locations are feasible, considering task realism, performance measurement requirements, and model implementation.
- Step 6 - Consideration of the special requirements for task design imposed by the use of such simulations as experimental tools.

1.3 ORGANIZATION OF THE REPORT

Section 2 presents the results of the review of the behavioral science and war gaming literature. The review was conducted in order to identify: the critical dimensions of human performance in command and control, the parameters describing the variance in such human performance, and the way existing simulations reflect the variance. Based upon the review, the essential operations that must be performed in information processing and decision-making were identified, although measurements of variance were sparse. Error analyses were found to be highly situation-oriented and consequently did not lend themselves to this effort. As a result three classes of errors were defined solely for the purposes of relating variant staff performance to battle outcome in the model.

Section 3 then defines the elementary staff operations that must be performed in command and control systems. These operations are based in part on the material identified in Section 2. The required staff processes, categorized solely from the tactical information messages set forth in the Phase 1 design, are then developed using event thread charts to link the elementary staff operations in appropriate event sequences. The section is concluded with a matrix showing the procedural step points at which the three classes of human error can occur.

Section 4 addresses the first design requirement by providing a logical design framework for accommodating variant human performance in the overall model design. The discussion begins by tracing the

tactical information flow in the model as a whole, then refines this flow by incorporating details of the staff procedures developed in Section 3 and by showing where human errors are involved in the flow cycle. The logical design for simulated staff processing is then developed from this framework. The implied system overhead associated with the enhanced design is also discussed.

Section 5 of the volume entitled On the Design or Simulations of Command and Control Processes discusses the feasibility of varying the interface boundaries of the staff modules to include trade-offs among task realism, credibility, and impact upon performance measurement.

Section 5 of the volume entitled Some Guidelines for Effective Task Design in Command and Control Simulations concludes with the principles of task design based on the overall model design with the new extensions.

SECTION 2

HUMAN PERFORMANCE IN COMMAND AND CONTROL

2.0 INTRODUCTION

This section reports on:

- The review of the behavioral science literature to determine:
 - The critical dimensions of human performance in command and control, i.e., the kinds of errors, omissions, delays, and invalidities introduced by human information processing and decision making.
 - The parameters describing the frequency, range, and distribution of such human performance as a function of environment, stress, form of data presentation, etc.
- The analysis of existing interactive and non-interactive simulations to determine how they:
 - Reflect variations in human performance in simulation outcomes.
 - Design tasks and procedures for information processing on a selective basis.

To assist in this determination, SAI reviewed an extensive quantity of behavioral science and gaming literature to ascertain the critical dimensions and parameters of human performance in command and control. The sought-after dimensions would describe the kinds of behavior (errors, omissions, delays, and invalidities) introduced by human information processing and decision making; these parameters would provide an initial basis for modeling the frequency, range, and distribution of these dimensions as a function of environment, stress, training, form of data presentation, etc. It was hoped that the review of existing interactive and non-interactive war gaming simulations would provide insight as to how previous models have reflected variance in human performance in simulation outcomes, and how tasks and procedures for information processing were designed on a selective basis.

2.1 REVIEW OF EXISTING WAR GAMING SIMULATIONS

Two primary sources ^{3,4} were reviewed to obtain a listing of all war gaming simulation models which might, even remotely, address C³I functions. Table 2-1 contains a listing of each of these models, a summary description of each model's purpose and the model's proponent. Although each of the models have interesting aspects that would be of interest in the design of the battle outcome generator, only three - ADVICE II, FOURCE, and NETMAN - provide any real advancement in the modeling of human performance in combat simulation outcomes.

2.1.1 ADVICE-II⁵

The ADVICE-II model is a force-on-force, computer-assisted, division-level war game. The computer is used only to perform the time-consuming clerical, filing, computational and data retrieval tasks. Specifically, the computer keeps all records, maintains the data base, performs the numerical assessment, and generates all standard format reports to players.

The reports are delayed and the numerical content of the reports is degraded by means of stochastic routines with variable parameters that can reflect different information processing performance levels. In addition, information about enemy activity is stochastically degraded to reflect the performance of the intelligence system extension to the command and control elements.

-
- 3 Catalog of War Gaming and Military Simulation Models, Studies, Analysis, and Gaming Agency, Joint Chiefs of Staff, 8th Edition, January 1980
 - 4 Tabulation of Models of Interest to CAA, Methodology, Resources and Computation Directorate, U.S. Army Concepts Analysis Agency, July 1979
 - 5 Tiede, R. V., Leake, L. A., and Whipple, S. Jr., Information Flow and Combat Effectiveness, (Research Analysis Corporation, Report RAC-R-100, April 1970)

TABLE 2-1
CURRENT SIMULATION MODELS PERTINENT TO C³I

<u>MODEL (PROPONENT)</u>	<u>PURPOSE</u>
Advice II (CACDA)	A computer-assisted division-level force-on-force war game which models the flow of tactical information in ground combat with realistic feedback to staff.
CAMMS (CATRADA)	A computer-assisted brigade-level training simulation used to train battalion and brigade command groups in the exercise of command and control.
CARMONETE/ATHELO (CAA)	A computerized, battalion level Monte Carlo, time-sequenced critical event simulation of a combined arms air/ground war game.
CEM IV (CAA)	A two-sided, fully automated, deterministic model capable of aggregating conventional warfare results as a series of four day theater level cycles.
COMMEL II.5 (CAA)	A computerized, analytical, general war battle model designed to process input data to develop a battle between division-sized forces.
CRM (DCA)	A computer-assisted, general war, analytical model which examines residual communications assets and the ability to restore interrupted users.

TABLE 2-1 (CONT'D)
CURRENT SIMULATION MODELS PERTINENT TO C³I

<u>MODEL (PROPONENT)</u>	<u>PURPOSE</u>
CREST (CNO)	A computerized, analytical model that evaluates the effectiveness of one unit successfully evading one or more adversaries.
DADENS-C2 (ADS/DCD)	A computerized, analytical, general war and damage assessment/weapons effectiveness model designed to simulate either one- or two-sided war games.
DIVSIFT (SAI)	A computer model that measures the action handling effectiveness of a command post staff when the staff is loaded by the events of a combat scenario.
DIWAG (CACDA)	A player-assisted, analytical, general division war model which performs the firepower, mobility, target acquisition, and combat service support functions.
FIRST BATTLE (CAC)	A low resolution battlefield simulation system designed to exercise division and corps staffs.
FOURCE (TRANSANA)	A division-level non-interactive force-on-force combat model with emphasis on the simulation of staff performance and combat information/intelligence flow.

TABLE 2-1 (CONT'D)
CURRENT SIMULATION MODELS PERTINENT TO C³I

<u>MODEL (PROPONENT)</u>	<u>PURPOSE</u>
IDAHEX (OSD)	A computer-assisted, limited war, analytical and training model representing maneuver and its consequences.
MANMODEL (ARI)	A computer simulation of the data entry processes that focuses on system tasks and procedures in an effort to estimate performance as it pertains to data entry. By varying input parameters, MANMODEL permits system designers to explore the effects on the data entry process of changes in manning levels, training, personnel selection and other factors. It provides an evaluative vehicle for comparison of alternative system configurations, operational procedures and personnel characteristics (e.g., training, aptitude, motivation).
MATSS (SAI)	A dynamic computer simulation of target acquisition, attack decision, and attack processes against deeper targets that incorporates multi-sensor fusion and time delays.
NETMAN (ARI)	A computer model for simulating the information processing actions of army staff during field exercises using a computer-based message handling system.

TABLE 2-1 (CONT'D)
CURRENT SIMULATION MODELS PERTINENT TO C³I

<u>MODEL (PROPONENT)</u>	<u>PURPOSE</u>
NNWS (CNO)	A computer-assisted, analytical, limited war model of the interaction and results of US/NATO Naval forces versus Soviet forces on a theater-wide basis.
NEWAIR (SHAPE)	A computer-assisted theater-level air battle simulation model which addresses the outcome of a conflict between air forces employing conventional weapons.
QUICK (SAGA)	A general war gaming system designed to assist the military war gaming analyst at the JCS level with the generation of detailed strategic nuclear war plans.
SIM II (CNO)	A computerized, analytical, limited war model of detailed and rigid naval warfare situations.
SIMTOS (ARI)	A computer-assisted simulation which permits laboratory research on tactical military decision making behavior, particularly with respect to information flow and display variables.
STAB II (NASC)	A computerized, analytical general war model used to analyze the effectiveness of airborne weapon systems.
STATE III (SHAPE)	A critical event, stochastic, computer-assisted land combat model for simulating armor/anti-armor engagements.

TABLE 2-1 (CONT'D)
CURRENT SIMULATION MODELS PERTINENT TO C³I

<u>MODEL (PROONENT)</u>	<u>PURPOSE</u>
STRAT MSG (USAF/SA)	A computerized analytical general war model which simulates the two-way flow of multi-priority messages between the NCA and forces.
TACOS II (ADS/DCD)	A computerized, analytical model designed to consider the effectiveness of ground/air defense and penetrating air forces.
WARRAMP-WCEM (CAA)	A computerized, analytical, limited war model of two forces while considering the effects of command and control, logistics and close air support.
WASGRAM (CNO)	An interactive, computer-assisted graphics model of naval warfare used for analysis and training.

The game is interactive with two players per side and three persons in the control group. The players are at division and brigade levels. Player-generated requests and orders are delayed but not degraded.

This model was the first to link command and control performance to battle outcome and is the basic concept which has been extended to fulfill the Phase 1 design effort. Variant human behavior is however simulated in highly aggregated form with insufficient resolution for the current purpose.

2.1.2 FOURCE⁶

FOURCE, or Command, Control, Communications, and Combat Effectiveness, is a division level force-on-force combat model with resolution to battalion. The simulation is a two-sided deterministic mathematical model which executes without player intervention. The purpose of the simulation is to evaluate and compare manual vs. ADP-assisted information processing within the division in terms of the battle outcome.

All of the operations and intelligence staffs within the division are simulated as either manual- or ADP-assisted. In the manual mode, time delays are introduced to reflect successive routing of messages through manual nodes. These time delays are eliminated, for the most part in simulated ADP-assisted staffs although querying times are considered. Time delays are computed as a function of processing times, workload for each staff element and communication delays. Processing times are dependent upon report type not report content. Errors are not introduced into the report content but occasionally a report is lost. Through this delay process, FOURCE has been able to distinguish between the actual battlefield and the battlefield as the staffs at various echelons perceive it.

Accordingly, FOURCE provides a significant contribution to the state-of-the-art in the modeling of command and control in combat simulations. However, the current effort extends the concepts developed for FOURCE in that it is interactive, provides for higher resolution and will model variant human behavior in aggregate form. FOURCE may be used to validate times, etc, but that is its only practical value.

6 Command, Control, Communications and Combat Effectiveness
Model Documentation, Technical Report Vol. II, TRASANA
TM 3-78, October, 1978

2.1.3 NETMAN⁷

NETMAN is a non-interactive digital computer model which simulates the information processing actions of Army personnel during field exercises using a computer-based message handling system. The model does not link message handling effectiveness with battle outcome. However, it does place particular emphasis on certain human performance features considered to be important, e.g., operator stress, speed, precision, and level of aspiration. In simulating each operator, the model requires as input an estimation of time related data for various operator tasks to be accomplished. The overall man-machine performance measure, effectiveness, is calculated for a simulated exercise and summarized over the total exercise. It is composed of four independent factors -- thoroughness, completeness, accuracy, and responsiveness.

The relationships⁸ that have been examined using NETMAN have particular relevance to this effort in the modeling of lower-order information processing, in that various message handling parameters are related to operator speed, and operator precision. These relationships will be particularly useful in defining and validating the parameters for lower-order processing functions.

2.2 REVIEW OF HUMAN PERFORMANCE IN COMMAND AND CONTROL

The review of the literature on human performance in command and control tasks or functions was essentially non-productive. Even though there is a prodigious amount of literature which addresses the many and varied ramifications of human performance, only a small segment of it is directly related to and in a form suitable for use in the design of simulations of command and control processes. Most of the relevant error analyses were highly specific studies of human performance in visual detections and graphic display applications, and

7 Siegel, A. I., Leaky, W. R., and Wolf, J. J., A Computer Model for Simulation of Message Processing in Military Exercise Control and Evaluation Systems, ARI Technical Report TR-77-A22, October 1977

8 Ibid.

during operation of input/output devices. The control factors being examined during these analyses were essentially related to the environment, stimuli or psychomotor skills. In addition, the data from these studies do not facilitate linkage to show interactions, sequential, or combined effects on combat outcomes. Another relevant discovery during the literature review was that error analyses were clustered around the lower skill level tasks in information processing functions while few research efforts focused on variance in the cognition or decision making processes. Accordingly, the literature did not provide detailed data on the critical dimensions of human performance in command and control nor did it provide appropriate parameters describing the frequency, etc, of such performance.

However, Gagne⁹ did provide significant insight and assistance in developing the models for staff processing, whether simulated or populated. As shown in Phase 1, each staff process will be modeled via a sequence of exclusive events, each representing a discrete task or function that must be performed to complete the staff process.

Figure 2-1¹⁰, provides a simplistic but very intuitive model of human functioning which has been used to extend our Phase 1 efforts to provide a clear and logical framework to link staff actions with the ongoing "battle" within the simulation. Gagne reviews human functions, within a system, as a sequence of transformations which the human being performs upon inputs to produce outputs. His model is directly relevant to our modeling efforts and can be extended to reflect the sequence of actions that occur within each staff module.

9 Gagne, Robert M. and others, Psychological Principles in System Development, (New York: Holt, Rinehart and Winston, 1962).

10 Ibid, pg. 54.

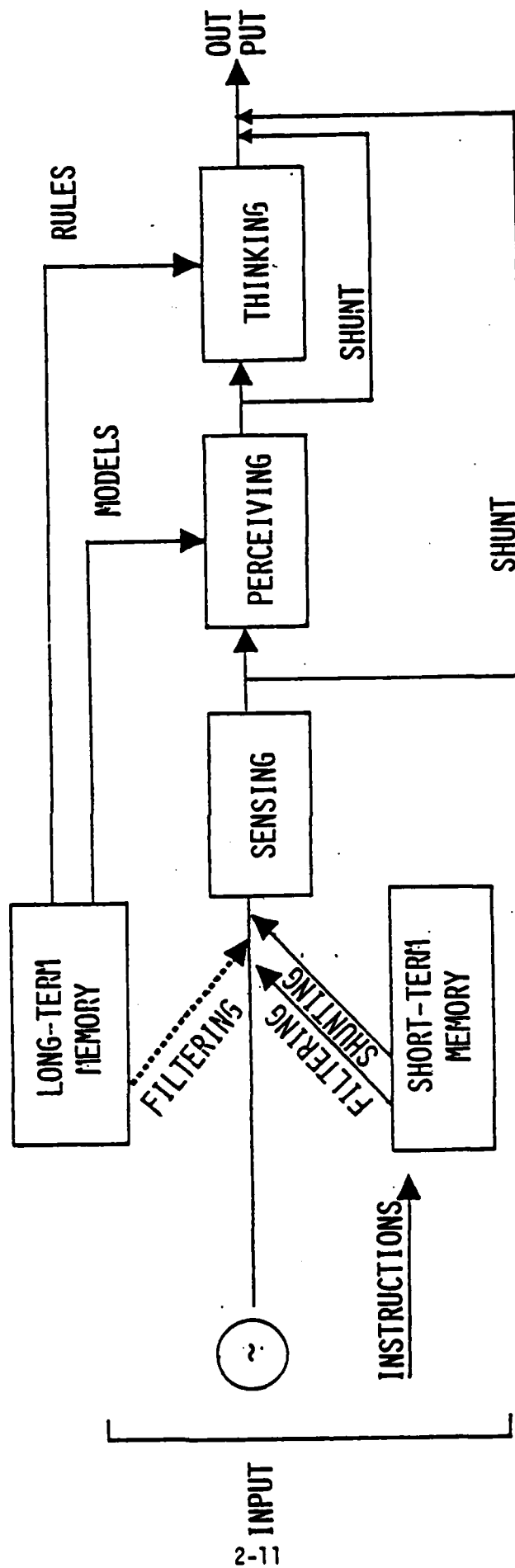


FIGURE 2-1. MODEL OF HUMAN FUNCTIONS*

* This figure appears in Gagne' (see footnote 9)

The input shown on the figure corresponds to the messages received by an individual section from all sources, while the instructions relate to the current operating procedure for that specific module. As described by Gagne, these instructions establish sets in short term memory which determine the shunting conditions and thus the level of functioning at which the individual operates in the situation. In addition, they establish the filtering conditions, which determine what the operator senses or attends to. As may be readily observed, this process is very similar to the lower order information processing tasks inherently required of a division staff section. Finally, there are inputs to this process from long-term memory, the most important of which are the models, which make possible comparisons with inputs to produce perception, and the rules, which represent courses of action to be compared in the thinking process. The sequences in which these actions are accomplished are also stored in long-term memory.

The fundamental actions which are of primary interest are the sensing, perceiving, and thinking functions. According to Gagne,¹¹ sensing is a function which "indicates the presence or absence of a difference in physical energies". For our purpose this translates to the recognition of an incoming tactical message, whether delivered via voice, radio, telephone, hand, teletype or data link. Filtering conditions establish attention to the method of receipt, while shunting conditions act to prevent the performance of higher-level functions by the human operator. Lower level tasks usually require operators to receive the information but not to interpret its meaning. Perceiving represents the next level in the sequence of actions. Here the individual operator produces outputs which, in effect, place inputs into categories whose basis is their effect rather than their appearance. In other words, perceiving is a matter of identifying the meaning of inputs. As before, instructions play their role as inputs for the establishment of shunting and filtering conditions. The most important inputs, however, are the models from long-term memory which provide standards against which inputs are compared. The last in the sequence of actions is thinking, the highest level of human functioning. To accomplish this function, an individual uses rules that are stored in long term memory to generate and select alternative courses of action in order to generate output or decisions. In many instances, the individual must transform the existing information or extrapolate beyond the boundaries of the existing information to produce an output, again based upon these models stored in long-term memory.

11 Ibid, pg. 45.

Gagne, through this intuitive mechanism, has represented a basic set of inferences that must be considered when observing the variety of behavior possible in a human being. We find this model interesting in that it provides a basic framework for examining and isolating the human activities in the system environment.

2.2.1 Critical Dimensions in Human Performance

J. S. Kidd's contribution¹² to Gagne's book provides additional definition to the model in terms of those critical dimensions that affect system effectiveness. Kidd has examined the operator in complex systems for the purpose of identifying which of his characteristics are germane to the system performance. The framework he used also involved the specification of the operator's role or function in the system. In a complex information-processing system, Kidd has portioned these functions into two categories --information-processing and decision-making. The latter category should be conceived as being highly dependent upon the first; that is, the quality of the decision-making is dependent upon the quality of the information processes. Kidd has defined functions that belong to each category and these definitions have been used to fully define each elementary operation required in the simulation of the division staff sections. These functions are arbitrary and are not intended to describe completely all tasks assigned to human operations within an information-processing system.

A summary definition of each category and the functions included with each is presented below:

- Information-Processing. A series of actions or operations involving the communication or reception of data.
 - Signal Detection and Classification. Detection is a matter of distinguishing signal inputs, while classification is a matter of distinguishing among inputs.
 - Recoding. The translation from signals in one format to signals in another.
 - Accumulating and Summarizing. The collection and manipulation of quantitative and qualitative data to keep abreast of the status of subordinate units.

12 Ibid, pgs 159-183

- Output-Processing. The classifying, encoding, and accumulation of generated signals or information.
- Value Weighting and Destination Routing. The determination of the importance and destination of information to be disseminated.
- Decision-Making. The action of producing a choice or judgement from one or more alternatives based upon available information.
 - Selection and Synthesis. The interpretation of the content of the input to include the operator's experience with respect to the consistency and veracity of alternative sources.
 - Pattern Construction. Creating a coherent whole out of discrete fragments.
 - Cause-and-Effect Attribution. The assumption or determination of why the situation is at it appears.
 - Time-line Analysis and Prediction. The correlation of cause-attribution with the evaluation of time-contingent processes in the environment to extrapolate to possible outcomes.
 - Critical-Cause Selection. The determination of what factors in the environment can be manipulated and the prioritization of these factors. This leads to the critical factor that must be manipulated to most directly achieve desired goals.
 - Action Selection. The selection of a course of action from available alternatives to achieve desired goals.

- Effect Evaluation. The assessment of action selection upon the environment based upon feedback subsequent to action initiation.

The above functions, then, define the critical dimensions associated with human performance in a command and control or information-processing system. These critical dimensions and Gagne's model provide the basic framework from which elementary operations have been defined and sequentially linked to encompass all those categories of action that must be completed within a staff section. Section 3.1 fully addresses this modeling effort.

2.2.2 Classes of Human Errors in Information Processing Systems

During the review of the literature, there was one reoccurring theme - to err is human. Errors are an expected human phenomenon and the research emphasis is on studying error causing factors in various combinations to determine ways in which to minimize their occurrence or effects.

For the purposes of this effort, the factors and the frequency with which they adversely impact human performance was of interest. The literature revealed that errors may be introduced by any number of factors, but the frequency with which they occurred was usually related to specific situations. The net result was that the factors that caused errors and the frequency with which they occurred were not available in a form relevant to the modeling of variant human behavior.*

This result led to an examination of how errors impact upon the division outcome. This impact can be partitioned into three categories:

- The body of information on which the commander and his staff base their execution of the assigned mission, is, or becomes, wrong or misleading.
- The commander and his staff fail to issue the correct orders in a timely manner even with adequate resources and an adequate body of information.

* However, a significant portion of these data will be helpful in the design implementation, e.g., ADP formats, data base entry, etc.

- The commander and his staff issue incorrect orders even with adequate resources and an adequate body of information.

These three categories can be directly attributed to human errors on the part of the commander and his staff and readily lend themselves to correlation with three fundamental reasons for their occurrence. Specifically, the first category is brought about in part by the cumulative human errors in the way in which the body of knowledge is achieved and maintained, i.e., errors that cause the body of information on which decision-makers base their execution to become wrong or misleading. The second is mostly attributable to human errors in management; i.e., errors that lead to untimely execution of decisions, even if the body of information is correct. The latter category is solely attributable to human errors on the part of the decision-maker, i.e., errors that lead to the wrong decisions, even if the decisions are timely and based upon correct information.

This reasoning has led to the definition of three classes of human error in information processing systems:

- Data errors - those errors that introduce erroneous or misleading data into the data stream and/or the staff files/displays, e.g., the location of the 2/84 Mech Inf is plotted incorrectly on the G3 SITMAP on the wrong side of the Weser River.
- Procedural errors - those errors that delay the completion of the staff action by making a false start or an error in performance of an elementary operation, e.g., G2 fails to coordinate with G3 and assigns a recce mission to the cavalry squadron unaware that the squadron has been assigned a screening mission in another sector, thereby delaying arrival of cavalry squadron.
- Cognition errors - those errors that cause a faulty tactical decision because of false or incomplete perception of the available data or because of inadequate action-selection criteria, e.g., the commander misinterprets an enemy feint as the main effort and commits his reserve prematurely.

As defined above, data and procedure errors are directly observable and measurable. This is true since the information stream/body of knowledge contains a reference standard from which to observe or measure deviations from ground truth or standard operating procedures. Cognition errors, on the other hand, are not directly observable and measurable because cognitive processes either alter existing information or generate new information, hence, there is no reference standard for comparison. This is discussed in detail in Tiede's¹³ discussion of performance measurement in military information systems.

It is readily observed that these three classes of errors are defined to be mutually exclusive. This is a desired characteristic which allows the distribution of error phenomena over staff processing of information but this does not imply that each class of error has unique impact on the battle outcome. On the contrary, they may have similar impacts within a very wide range. For example, either a transposition of UTM coordinates (data error) or a faulty pattern recognition (cognition error) may lead to an erroneous prediction of an enemy breakthrough. The point is that the impact of these errors is highly situation dependent and the impact upon the battle outcome may not be traceable to the originating class except under highly controlled experimental conditions.

2.3 CONCLUSIONS ON HUMAN PERFORMANCE

2.3.1 Existing War Gaming Simulations

Surprisingly, there was only one war gaming simulation (FOURCE) which explicitly simulated human performance in command and control and then linked the performance with the battle outcome. However, computerized decision rules within FOURCE are simplistic. Another model (NETMAN) transformed the effects of fatigue, stress, proficiency, etc, into time-delays in the decision-making process, but these delays were not related to the battle outcome nor were the

¹³ Tiede, R. V. On the Analysis of Ground Combat, p. 62 (Military Affairs/Aerospace Historian Publishing, 1979)

various effects related to the quality of the decision. The one remaining model that has applicability was ADVICE II. This simulation models human performance for the lower level information processes in highly aggregated form and employs live players to make the higher level decisions. Since it is an interactive system, the battle outcome reflects both the timeliness and quality of the decision process.

Each of these models provides insight into the design of the integrated division-level battle simulation. However, the actual design will be extending the state-of-the-art of command and control and war gaming simulations by providing for interactive populated and simulated staff models and by linking and measuring the effects of variant human performance on the battle outcome.

2.3.2 Human Performance in Command and Control

Although the review of the behavioral science literature was essentially non-productive in terms of the objectives, it did provide a basic model for indicating the sequence and interaction of events within an information processing system and helped to specify the critical dimensions in information processing and decision making.

The lack of substantive data on the type and frequency of errors led to a determination of kinds of errors which impact upon the battle outcome. This in turn led to the definition of three classes of error--data, procedural, and cognition--which may be overlaid on the division-staff information processing functions to allow behavioral scientists to examine the effect of human staff errors on battle outcome.

SECTION 3

DELINEATION OF STAFF PROCEDURES

3.0 INTRODUCTION

This section presents an analysis of interactive simulations that focuses on the detailing of division staff procedures and identification of the procedural step points at which one or more human errors might occur. The analysis begins with the basic building blocks of the staff procedures, the elementary staff operations performed by one man. These fundamental procedural steps are identified, based in part on a suggested approach from another study. The detailing of the procedures, that is, the development of event thread charts composed from the basic building blocks, is, on the other hand, based solely on the set of tactical information messages already defined in the Phase 1 design. Seven such charts are presented showing the staff actions either as the Standing Operations Procedures (SOPs) to be followed by players in live staff modules or as the Class 1 event sequence in the simulated modules. The seven charts cover the 420 different staff processes stemming from the standard tactical messages. The section is concluded with a matrix showing the procedural step points at which the various classifications of human errors can occur. The error classifications are those from Section 2.

The analytical framework developed in this section is applied to the design of simulated staff modules in Section 4 which in turn forms the basis for variable interface boundary design in Section 5.

3.1 ELEMENTARY STAFF OPERATIONS

The Phase 1 design combined, for the first time, command and control processes executed by human players in live staff modules with the simultaneous simulation of the same processes in other, but now simulated, staff modules. Depending on the selected configuration of play, simulation represented an interactive war game from the point of view of the populated modules and a simulation of decision-making processes from the point of view of the simulated staff modules. However, no documents were found in the literature which treated these more-or-less separate areas jointly. Earlier efforts and other

studies have provided ideas and approaches for the design of an interactive war game. Similarly, but in a different vein, alternative approaches to the simulation of decision-making processes have yielded some insights into the problem of simulating human staff performance. Consequently, the material here, which identifies the elementary staff operations common to both the live staff procedures and the computer logic for simulating staff processes, is largely unexplored territory.

The concept of elementary operations originated in an earlier study¹ of staff processes. This study used an event-oriented simulation of the staff actions to determine the sequence of operations, the time required for each step, the time spent in queue, the staff member who performed each operation, and the station at which each operation was performed. The approach involved breaking staff processes down into a series of elementary operations such as those listed in Table 3-1. The study itself provided some insights into human staff performance, but the simulation did not address the actual tactical information content of the staff actions being processed.

A similar approach has been adopted here but this time it has been extended to include the information content. The staff processes invoked by the standard tactical messages in the Phase 1 design have been broken down into a series of elementary staff operations, where each such operation is performed by one man. Furthermore, in order to provide a basis for the task design for interactive simulations, each elementary operation identified has an associated process/skill level required of the man who performs the operation. These levels were affixed by the following argument:

1 Tiede, R.V., Walker, M. E., Stenstrom, D. J., and Sweeny, S. O. The Integrated Battlefield Control System (IBCS) Third Refinement Study, (McLean, Va., Science Applications, Inc.: Final Report, March 1975)

TABLE 3-1. ELEMENTARY OPERATIONS

THROUGHPUT OPERATIONS

Receive Radio (Rcv Rad): All action steps required to produce a written copy of an incoming message via radio to include required radio operating procedures.

Receive Telephone (Rcv TP): All action steps required to produce a written copy of an incoming message via telephone to include required telephone operating procedures.

Receive RATT (Rcv RATT): All action steps required to produce a written copy of an incoming message via RATT to include required RATT operating procedures.

Receive Aurally (Rcv Aur): Reduction of an oral transmission to a written form.

Transmit Orally (Xmit Oral): All action steps required to convey a written message by unaided, human voice to a pre-designated addressee(s).

Plot on Map (Plot): Post or update symbols on map.

Enter in Journal (Enter): Physical process of recording in journal, workbook or list.

Retrieve (Rtrv): (Must be associated with a specific file or display.) Locating and extracting from a particular file or display.

Compose: Prepare a draft of a product or portion of a product.

Make Overlay (Overlay): Physical preparation of map overlay.

Post Display (Post): Enter or update data on visual display.

BRANCHING OPERATIONS

Determine Internal Routing (DIR): Read for content and select addressee/station routing within element for further processing of that product.

TABLE 3-1. ELEMENTARY OPERATIONS (CONT'D)

Determine External Routing (DER): Read for content and select external addressee(s).

Reproduce, Manual (Repro, Man): Production of an exact handwritten copy (may be multiple copies using carbon paper).

Reproduce, Machine (Repro, Mach): Production of an exact copy (or copies) utilizing copy machine.

Type: Production of an exact copy using a typewriter. (May be multiple copies using carbon paper.)

COLLECTION OPERATIONS

Consolidate and Approve (C&A): Accept, integrate, edit portions of a product produced by more than one source and release final product for distribution (normally to external addressees). The same operation is used for approval only in which case there is a single input.

TERMINATING OPERATIONS

File: (Must be associated with a specific station.) To place a product or extract therefrom in a designated, closed (non-display) storage place or to update a permanent (nondisplay) record.

Terminate (Term): This copy goes no further and is placed in File 13 or convenience file.

Transmit Radio (Xmit Rad): All action steps required to convey a written message via radio to a predesignated addressee to include required radio operating procedures.

Transmit Telephone (Xmit TP): All action steps required to convey a written message via telephone to a predesignated addressee to include required telephone operating procedures.

Transmit RATT (Xmit RATT): All action steps required to convey a written message via RATT to a predesignated addressee to include required RATT operating procedures.

Transmit Courier (Xmit Cour): Picking up an action from an outbox, courier, other staff member, or self and delivering it to a predetermined addressee/station or his inbox.

"Figure 3-1 is a representation of a series of processes such as a decision node carries out on information flowing through the node. At the bottom of the figure is an external information stream--the communications network--which the node taps and to which it contributes. Six progressively more complex processing levels are depicted. The information that flows up from the external stream must first be received, a Level I or communications process. The received information in a tactical military system is in the form of orders (plans), summaries, reports, queries, or requests. These must be tagged, sorted, recorded (think of the large number of telephone and voice radio inputs), and used to update files; much of it is also displayed on situation maps or totes. The composite of these processes may be called Level II or message center and filing processes. The Level II processes produce a data base, some part of which is in the form of visible displays for ready reference. It is pertinent to comment in passing that the graphical representation of certain kinds of information on a situation map is the substitute for the hill overlooking the battlefield and for helicopters when the latter cannot fly or see."²

"The next four process levels use the files in successively more complex ways. Note that they, too, update the files, but these updates are more in the nature of manipulations on the basic data added by Level II. These utilization processes begin with Level III, selective retrieval of information from the files. At Level IV, such data are aggregated by means of a priori rules, which may vary from simple arithmetic combinations to more sophisticated rules of combination such as the appearance of three or four maneuver battalions operating in the same area triggers the search for their associated fire and service support elements. The important consideration is that the rules for aggregation have been determined in advance and are stored. Process Level V also aggregates data, but the rules for aggregation are devised by the user in real time--that is, he hypothesizes, through pattern recognition, new and higher level interpretations of the data being presented. For example, the rapid increase in density of artillery in a given sector is interpreted as an indicator of enemy intent to attempt a breakthrough in that sector. Process Level V may also be accomplished in a succession of stages

² Tiede, R. V., On The Analysis Of Ground Combat, (Military Affairs/ Aerospace Historian Publishing, 1978).

LEVEL VI

Decision

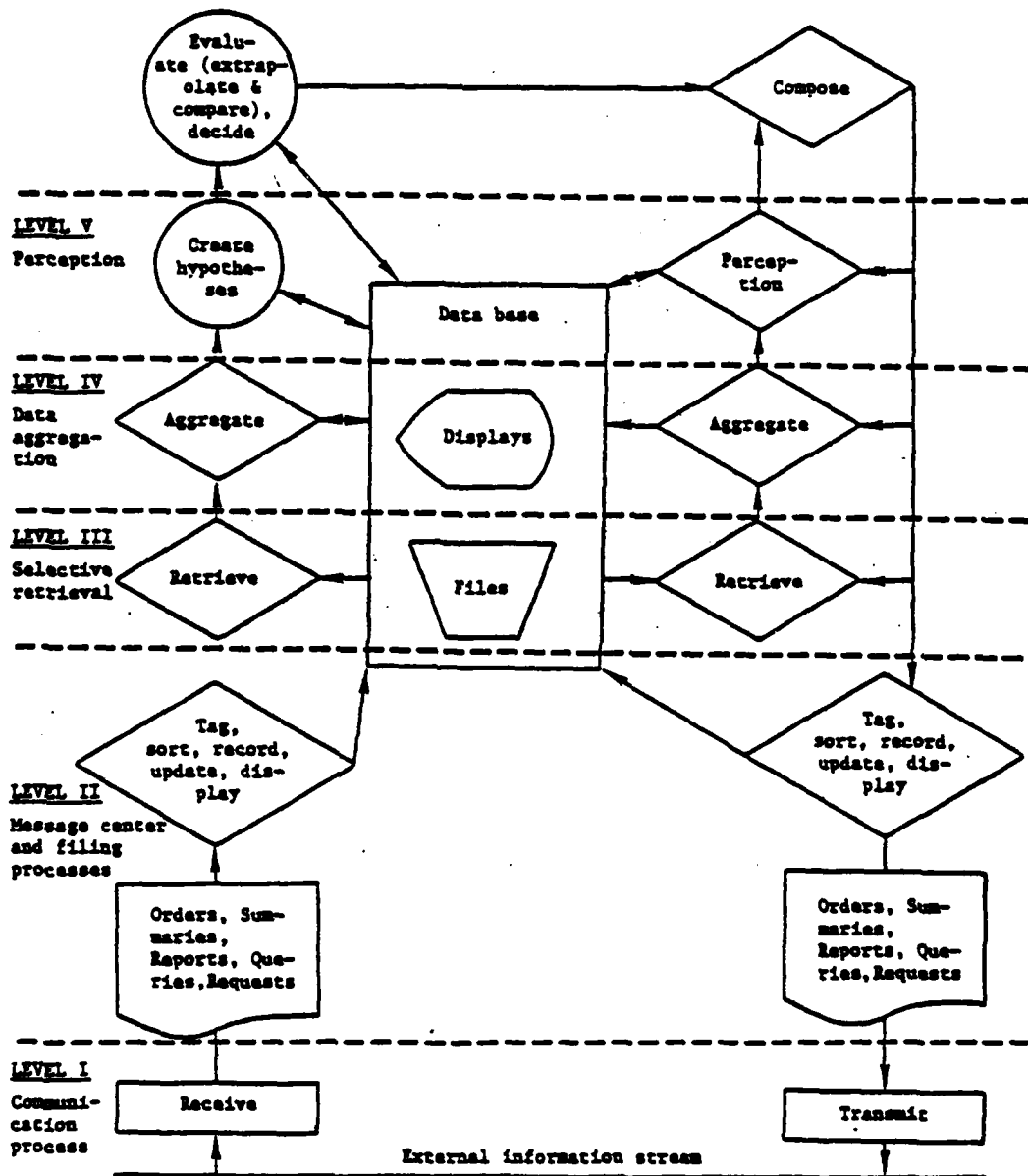


FIGURE 3-1. PROCESS LEVELS IN A TACTICAL DECISION-MAKING NODE.

* Taken from Tiede (see footnote 2)

that amounts to piling hypotheses one on top of another. Furthermore, data aggregations may be extrapolated forward in time. This amounts to yet another hypothesis formulation of a different type; assumptions are made about observed rates and/or accelerations. For example, examination of present positions and rates of advance for both sides leads to a prediction that the main battle will occur at point Y at time T. Level V produces what is commonly called perception. At the highest level, Level VI, data aggregations are compared and evaluated, and one or more are selected. This last is the culmination of the decision process."³

3.1.1 Definitions of the Elementary Operations

The elementary staff operations for the division-level battle simulation are presented in Table 3-2. The staff procedures to be followed by players in populated modules are structured out of these 27 basic procedural steps. Correspondingly, the event threads in the computer simulation of staff processes are composed from these Class 1 events.

The elementary operations fall into two broad groups in a manner suggest by J. S. Kidd⁴. According to Kidd, the tasks allocated to human operators within a general man-machine system fall into the two categories of information-processing and decision-making. While the line of demarcation between the two categories is somewhat obscure and arbitrary, the table groups the elementary operations of Levels I, II, III and IV in the information-processing category and those at the higher levels under decision-making. Furthermore, under these categories, the individual definitions contain italicized references to Kidd's task descriptions, where applicable.*

In this table and the discussion following, the short word "chops" is used to mean request for concurrence.

One point should be made about the dual purpose table. The elementary operations defined are ordinarily understood to be one-man

3 Ibid.

4 Gagne Robert H., and others, Psychological Principles in System Development (New York: Holt, Rinehart, and Winston, 1962.)

* Kidd's task descriptions were oriented to radar man-machine systems. It is remarkable that the same task descriptions are applicable to corpo- or division-level command and control systems.

TABLE 3-2

DEFINITIONS OF THE ELEMENTARY OPERATIONS

E.O. DESCRIPTOR	PROCESS//SKILL LEVEL	DEFINITION
<u>Information-Processing</u>		
INITIATE BY CLOCK	I	Start a staff action whose output is due at a prescribed clock time by SOP. <i>Signal Detection and Classification.</i>
RECEIVE (or ACCEPT)	I	RECEIVE: transform oral communications received by radio or telephone into a hand written message, making one or more copies at the time. ACCEPT (subsumed under RECEIVE): accept a hand written/printed message delivered by a courier. <i>Signal Detection and Classification.</i>
TRANSMIT (or DELIVER)	I	TRANSMIT: transform a hand written message into oral communications on a radio or telephone. DELIVER (subsumed under TRANSMIT): hand over a written message to a courier or hand carry the message to its addressee. <i>Output-Processing.</i>
DER1	II	Determine the external routing of a received message. "External" means outside the staff section including other staff sections, Corps and adjacent headquarters, but not subordinate units in the BOG. <i>Value Weighting and Destination Routing.</i>
DER2	II	Determine the external routing for information copies of a message generated/processed in the staff section. In this case "external" means outside the staff section, including other

TABLE 3-2 (CONT'D)

		staff sections, Corps and adjacent headquarters as well as subordinate units in the BOG. <i>Output-Processing.</i>
DIR1	II	Determine the precedence for message processing and the internal routing for the purpose of updating the staff files/displays. <i>Value Weighting and Destination Routing.</i>
DIR2	II	Determine the internal routing for generated/processed messages for the purpose of filing/posting output reports. <i>Output-Processing.</i>
ENTER	II	Log in the receipt/transmittal of a message. <i>Accumulating and Summarizing.</i>
FILE	II	Place a received/generated message, or elements thereof, in the appropriate staff file. <i>Accumulating and Summarizing.</i>
MAKE COPIES	II	Reproduce copies of a written message, as required.
COMPOSE	III	Prepare in draft or final form an output query, report, or frag order based on the action selection made by the decision-maker. <i>Output-Processing.</i>
DECOMPOSE	III	Extract from a received message data elements relevant to the functions of the staff section. <i>Recoding.</i>
DETERMINE COGNIZANCE	III	Determine the area of responsibility for the action selection made by the decision-maker. The subsequent processing of the action should be switched if the area of responsibility is outside the purview of the staff section. <i>Output-Processing.</i>

TABLE 3-2 (CONT'D)

POST (or PLOT)	III	POST: transfer oral or written data onto a graphic display or status board. PLOT (subsumed under POST): transfer onto a scaled situation map. <i>Recoding.</i>
RETRIEVE	III	Withdraw a received/generated message from its appropriate staff file. <i>Output-Processing.</i>
COORDINATE W. STAFF	IV	Determine whether the action selection made by the decision-maker should be approved by the Commander and/or coordinated with other staff sections prior to its release. Subsequent processing of the action should be switched if approval or coordination is determined to be required. <i>Action Selection.</i>
COORDINATION COMPLETE?	IV	Determine whether concurring responses have been received from all sections to which chops requests were submitted. <i>Effect Evaluation.</i>

Decision-Making

EVALUATE IN CONTEXT	V	Determine whether the received message generates the requirement for formal staff action at this time. The determination may be based on the message content alone or on a trigger criteria existing for certain type messages. If formal staff action is determined not to be required at this time, the action processing terminates. <i>Selection and Synthesis.</i>
INITIATE BY SELF	V	Initiate formal staff action based on perception of situation or problem held in the mind of the initiator. <i>Selection and Synthesis.</i>

TABLE 3-2 (CONT'D)

SYNTHESIZE DATA	V	Generate from the available data a picture or perception of the situation or problem. <i>Selection and Synthesis.</i>
EVALUATE DATA	V	Determine whether: (1) the uncertainties of the perception warrant the pursuit of more information before proceeding with the action; (2) the perception warrants immediate action; or (3) the perception warrants both of the above. <i>Effect Evaluation.</i>
CONSTRUCT PATTERN	V	Complete the picture or pattern by hypothesizing the missing or unknown elements. <i>Pattern Construction.</i>
EXTRAPOLATE SITUATION	V	Interpret the situation by extrapolating the time relationships inherent in the perception. <i>Time-line Analysis and Prediction.</i>
GENERATE ALTERNATIVES	V	Postulate two or more alternative courses of action which address the analyzed situation or pattern. <i>Cause-and-effect attribution and Time-line Analysis and Prediction.</i>
ESTABLISH CRITERIA	VI	Formulate the weighting factors to be used in comparing the alternative courses of action. <i>Critical Cause Selection.</i>
EVALUATE ALTERNATIVES	VI	Rank the alternative courses of action by applying the weighting factors. <i>Critical Cause Selection.</i>
SELECT ACTION	VI	Select the best course of action from the postulated alternatives. If no more than one alternative has been generated, the selection is entirely automatic. <i>Action Selection.</i>

tasks whether they are interpreted as procedural steps in a live staff module or as Class 1 events in a computer simulation of the staff processing. The strict interpretation as one-man tasks, however, breaks down in the case of two Level V operations: EVALUATE IN CONTEXT and SYNTHESIZE DATA. In a live staff module, these procedural steps will ordinarily be performed by the senior staff officer himself. But both operations call for accessing tactical information from the staff section files/displays in order to evaluate the received message in context or to generate a picture or perception of the situation. The senior officer in a live module may request assistance in these accessing subtasks from other subordinate staff players. Consequently, the one-man task rule breaks down in the live staff procedures.

Consider as an example the staff processing that would take place if the G3 were to receive a chop request from G2 regarding the proposed use of air cavalry helicopters for a post-strike damage survey. It will be shown in the next subsection that the G3, under these circumstances, would perform the following sequence of operations preparatory to responding to G2: SYNTHESIZE DATA, EVALUATE DATA, CONSTRUCT PATTERN, EXTRAPOLATE SITUATION, GENERATE ALTERNATIVES, EVALUATE ALTERNATIVES, and SELECT ACTION. The G3 would emerge from the last of these operations with the basic decision whether or not he concurred with the modified mission for the air cavalry elements. The sequence of operations, however, would begin with one of the Level V steps mentioned above. In a live G3 module, the senior operations officer might very well request the help of the assistant operations officer or the operations sergeant in assembling the information about the current status and missions of the air cavalry troop prior to his analyzing the situation. In this instance, it is clear that the SYNTHESIZE DATA step is not, strictly speaking, a one-man operation.

In a simulated staff module, on the other hand, the interpretation of the one-man operations will be followed in the strictest sense. The computer will simulate the staff processing of the receipt of a chops request like that above as though the elementary operations involved were each performed by a single individual. It will be shown in Section 4 that this rigid rule provides the basis for simulating the chance occurrences of human error phenomena in the staff processing.

3.1.2 Class 1 Events

The definitions of the elementary operations given in Table 3-2 provide a basis for completing the list of Class 1 events specified in the Phase 1 design. In the general event-oriented

simulation structure, Class 1 events were defined as the staff processing events the structured sequences of which gave the basic logic for simulated staff modules. The report stated that all the different event threads reflecting the staff processing would contain "an internal trigger, or starting, Class 1 event, and one or more terminating, or ending, Class 1 events. The number of events simulated between the trigger and terminating actions steps will depend on the individual action SOPs and on the level of detail used in simulating the staff action." The definition of the elementary operations now fix the level of detail, and the intermediate Class 1 events can be added to the original table (Table 4-3 in the Phase 1 report).

Table 3-3 shows the now complete list of Class 1 events in the basic design concept for the battle simulation. The event numbers shown in the Table are based on the convention adopted for that design. The following points should be noted about the Class 1 events:

- Event No. 100 corresponds to the elementary operation INITIATE BY CLOCK.
- Event Nos. 101 thru 112 are all variations of one elementary operation RECEIVE.
- Event Nos. 189 thru 199 are all variations of one elementary operation TRANSMIT.
- The remainder of the events in the table are, with one exception, in one-to-one correspondence with the remaining elementary operations in Table 3-2*.
- The one elementary operation for which no Class 1 event has been defined is INITIATE BY SELF. This exception is discussed further in Section 4.

It should be noted further that these Class 1 event definitions may be modified when the question of variable interface boundaries is addressed. As will be seen in the next subsection, one

* The event numbers for these Class 1 Events are so chosen that they provide ready identification of the process/skill level associated with the elementary operation. Thus Event Nos. 121 thru 127 are Level II, Event Nos. 130 thru 134 Level I, etc.

TABLE 3-3. CLASS 1 EVENTS

EVENT NUMBER	DEFINITION OF THE EVENT
<u>Internal Triggers</u>	
100	Clock indicates that it is time to initiate staff action.
101	Receive a tactical information message from BOG or higher HQ.
102	Receive a retransmitted copy of input to another staff section.
103	Receive an info copy of output by another staff section.
104	Receive a query from another staff section.
105	Receive a request for concurrence from another staff section.
106	Receive a request for consideration from another staff section.
107	Receive a concurring response to a request for concurrence.
108	Receive a non-concurring response to a request for concurrence.
109	Receive a decision from the Commander.
110	Receive a non-concurring response to a request for consideration.
111	Receive a response to its query to another staff section.
112	Receive information from another staff section.
<u>Action Steps</u>	
121	Determine external routing of retransmittal copies (DER1).
122	Determine external routing of information copies of output (DER2).
123	Determine precedence for processing and internal routing for files/displays update (DIR1).
124	Determine internal routing for section copy update (DIR2).
125	Log in receipt/transmittal of all input/output messages. (ENTER).
126	Place received/generated message, or elements thereof, in appropriate section files (FILE).
127	Reproduce copies of a message (MAKE COPIES).

TABLE 3-3. (CONT'D)

Action Steps (Cont'd)

- | | |
|-----|--|
| 130 | Prepare output message in draft or final form (COMPOSE). |
| 131 | Extract from received message selected data elements relevant to staff section function (DECOMPOSE). |
| 132 | Determine area of responsibility for the selected action (DETERMINE COGNIZANCE). |
| 133 | Transfer data onto a status board or graphic display (POST or PLOT). |
| 134 | Withdraw received/generated message from appropriate section files (RETRIEVE). |
| 140 | Determine requirements for Commander's approval or staff coordination (COORDINATE W. STAFF). |
| 141 | Determine whether concurring responses cover all staff sections solicited (COORDINATION COMPLETE?). |
| 150 | Determine if formal staff action required at this time (EVALUATE IN CONTEXT). |
| 151 | Generate perception. (SYNTHESIZE DATA). |
| 152 | Determine if more information required (EVALUATE DATA). |
| 153 | Complete pattern by hypothesizing the missing or unknown elements (CONSTRUCT PATTERN). |
| 154 | Interpret the situation by time-line extrapolation (EXTRAPOLATE SITUATION). |
| 155 | Postulate two or more courses of action (GENERATE ALTERNATIVES). |
| 163 | Formulate weighting factors for comparing alternatives (ESTABLISH CRITERIA). |
| 164 | Rank the alternatives by applying the weighting factors (EVALUATE ALTERNATIVES). |
| 165 | Select the course of action (SELECT ACTION) |

Terminators

- | | |
|-----|---|
| 189 | Send to selected staff elements. |
| 190 | Issue frag order or warning order. |
| 191 | Initiate query. |
| 192 | Initiate a request for concurrence. |
| 193 | Initiate a request for consideration. |
| 194 | Initiate a report for higher headquarters. |
| 195 | Aggregate information on file for a response. |

TABLE 3-3. (CONT'D)

Terminators (Cont'd)

196	Issue a concurring response to a request for concurrence.
197	Issue a non-concurring response to a request for concurrence.
198	Issue a non-concurring response to a request.
199	Retransmit copies of input.

approach to eliminating the low-level, repetitive staff operations is simply to combine the Level II, III and IV tasks in a staff action under the Level I trigger event or under the Level I terminating event associated with the action. This would mean that the live modules and simulated modules alike would be implemented by means of Class 1 Event Nos. 100 thru 112 as triggers and Event Nos. 189 thru 199 as terminators, but that these events would have broader definitions covering the Level II, III and IV steps involved. The sequences of Class 1 events spelling out the low-level events that could thus be eliminated are presented in the next subsection. The logical design implications are developed in Section 5.

3.2 EVENT THREAD CHARTS FOR STAFF PROCESSING

The logical sequences of events that make up the simulated battle were presented in Design Note J of the Phase 1 design. Separate event thread charts were given for each standard tactical information message that was involved in the command and control of the Blue division-level forces. The charts were composed from the six classes of events that formed the basic structure of the model.

The event thread charts were necessarily incomplete in one respect. Although they showed the Class 1 trigger events that started the staff processing associated with a tactical information message and the Class 1 terminating events that ended the staff actions, they did not reflect the internal action steps between the starters and the terminators.

The elementary operations and/or Class 1 events set forth in the previous subsection now provide a basis for developing the complete event thread charts for the staff processing represented in simulated staff modules as well as the corresponding SOPs to be established for players in live staff modules. The charts serving these two parallel purposes are presented here.

3.2.1 Categorization of Staff Procedures

Within the spectrum of the standard tactical messages specified in the Phase 1 design, there are 405 different staff procedures involving unique input/output messages and unique staff sections. There are also 15 additional staff actions in which the

senior officer in a staff section initiates formal staff action because he spontaneously perceives that it is required forthwith (INITIATE BY SELF). The resulting 420 staff procedures provide the basis for the categorization of staff procedures and the event thread charts for staff processing.

The seven (7) categories of staff actions to which this family of 420 procedures reduced are shown in Table 3-4. The table shows that for each of seven (7) different kinds of actions--each identifiable by the manner with which it is triggered--there is a separate sequence of procedural steps (or Class 1 events) characterizing the staff processing. The trigger events are those listed in Table 3-3.

The event thread charts for the seven categories are presented in the following paragraphs.

3.2.1.1 Category 1 Actions

The first category of staff procedures covers all actions triggered by the receipt of a Class 4 input message from the BOG, or higher or adjacent headquarters. The event thread chart is shown in Figure 3-2.

This chart and the ones to follow are based on the event thread method of specifying the sequence of events and/or procedural steps involved in the simulation. The circles represent defined events. The arrows connecting successive events represent the passage of time. Here the events themselves contain the following identifying information:

- The Class 1 event number (from Table 3-3).
- The elementary operations descriptor from (Table 3-2).
- The process/skill level of the operation (also Table 3-2).

All charts are intended to serve two separate purposes. First, they specify the basic logical structure to be used in the simulated staff modules. Second, they give the staff action SOPs for player roles in

TABLE 3-4

STAFF ACTION CATEGORIES

Intersection of Tactical Information Messages and the Staff Modules

Category	Triggered By	No. Actions from Phase 1 Design
1	Receipt of external tactical message from BOG/Corps (Event No. 101)	33
2	Receipt of retransmitted copy of another section input (Event No. 102)	78
3	Receipt of action copy, info copy, query answer, and any response except a concurring chops response (Event Nos. 103, 106, 108, 110, or 111)	192
4	Internally initiated (INITIATE BY SELF)	15
5	Receipt of directive from Commander or concurring chops response (Event Nos. 107 or 109)	20
6	Initiated by clock/SOP (Event No. 100)	6
7	Receipt of staff query or request for chops (Event Nos. 104 or 105)	76
TOTAL		420

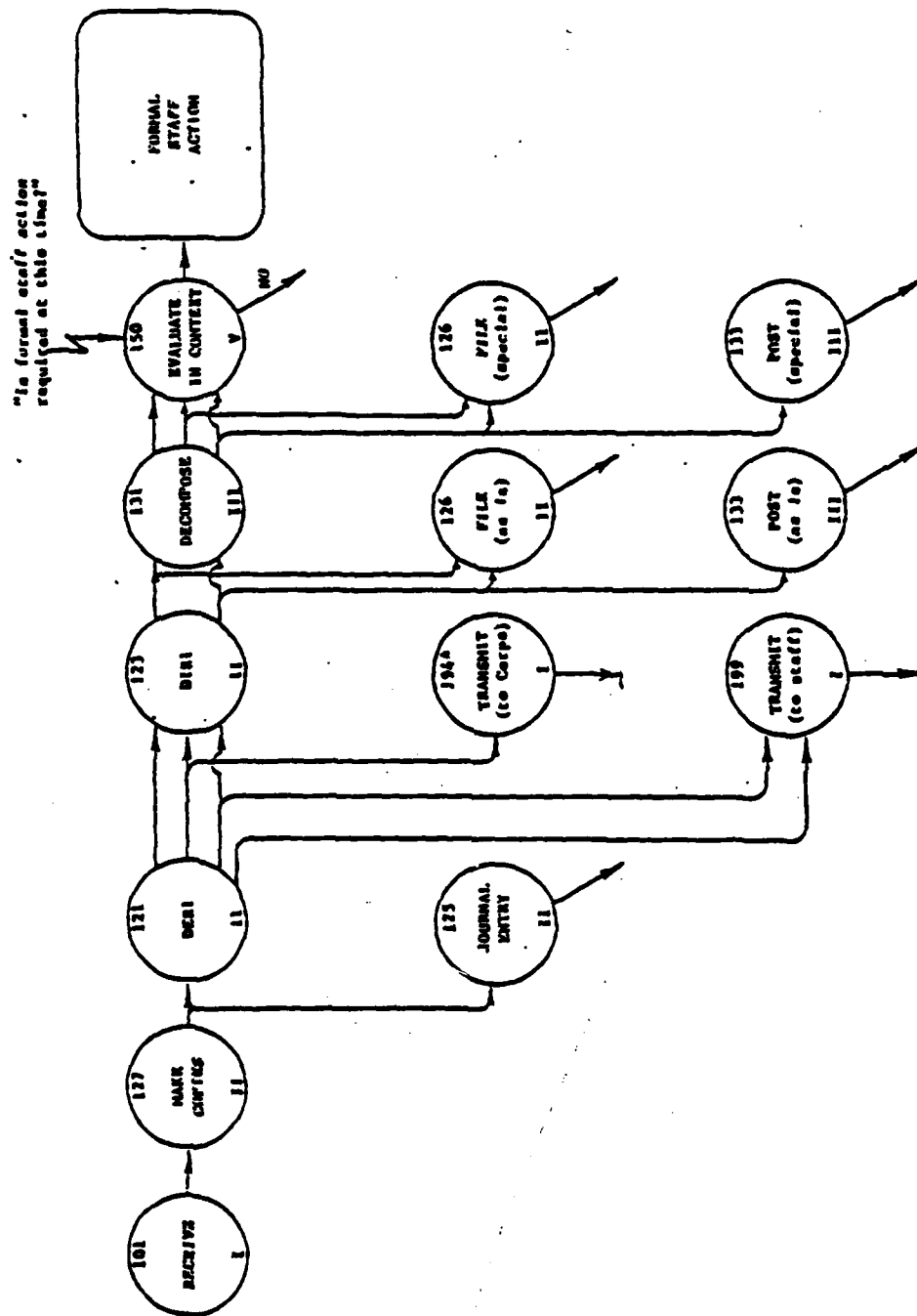


FIGURE 3-2. CATEGORY 1 ACTIONS

Triggered by Receipt of External Tactical Messages from BGC/CORPS

the populated modules. In the latter case the individual events are to be interpreted as individual procedural steps, i.e., elementary operations ordinarily performed by one member of the player team.

Figure 3-2 shows that Category 1 actions always culminate in a box labeled FORMAL STAFF ACTION. This box denotes a continued sequence of staff processing events whose thread chart is shown in Figure 3-3. The formal staff action segment is shown in a separate chart because it is common to several other staff procedure categories.

Formal staff action involves a number of elementary operations with Process/Skill Levels V, and VI. The segment can be thought of as the culminating staff processing that focuses on the tactical decision-making required of the staff element. In contrast to this, it should be noted from Figure 3-2 that the front half of Category 1 actions consist almost entirely of lower level operations associated with the maintenance and update of the section files and displays. The single exception is the procedural decision choice EVALUATE IN CONTEXT in which the senior staff officer determines whether formal staff action is required at this point in time.

3.2.1.2 Category 2 Actions

The second category of staff procedures covers all actions triggered by receipt of retransmitted copies of another staff element's input. The retransmission copies will always stem from the front end processing of Category 1 actions by another staff section. The Category 2 event thread chart is shown in Figure 3-4.

The front end processing of Category 2 actions clearly shows a different structure from that of the previous category. Special mention should be made, moreover, of the sequence of events stemming from the procedural decision choice EVALUATE IN CONTEXT shown in the chart. The added logical structure is included in order to accommodate one tactical information message among all those specified in the Phase 1 design. This message is the Post-Strike Analysis Report. Formal damage analysis is performed by the Fire Support Element following a strike, but the FSE is supplied with the raw data for his analysis through the receipt of retransmitted copies of Post-Strike Damage Reports sent to G2. Consequently, whenever FSE receives a (retransmitted) Post-Strike Damage Report, he must decide (in EVALUATE IN CONTEXT) whether the individual report provides the trigger criteria to begin the formal analysis. Furthermore, after he has

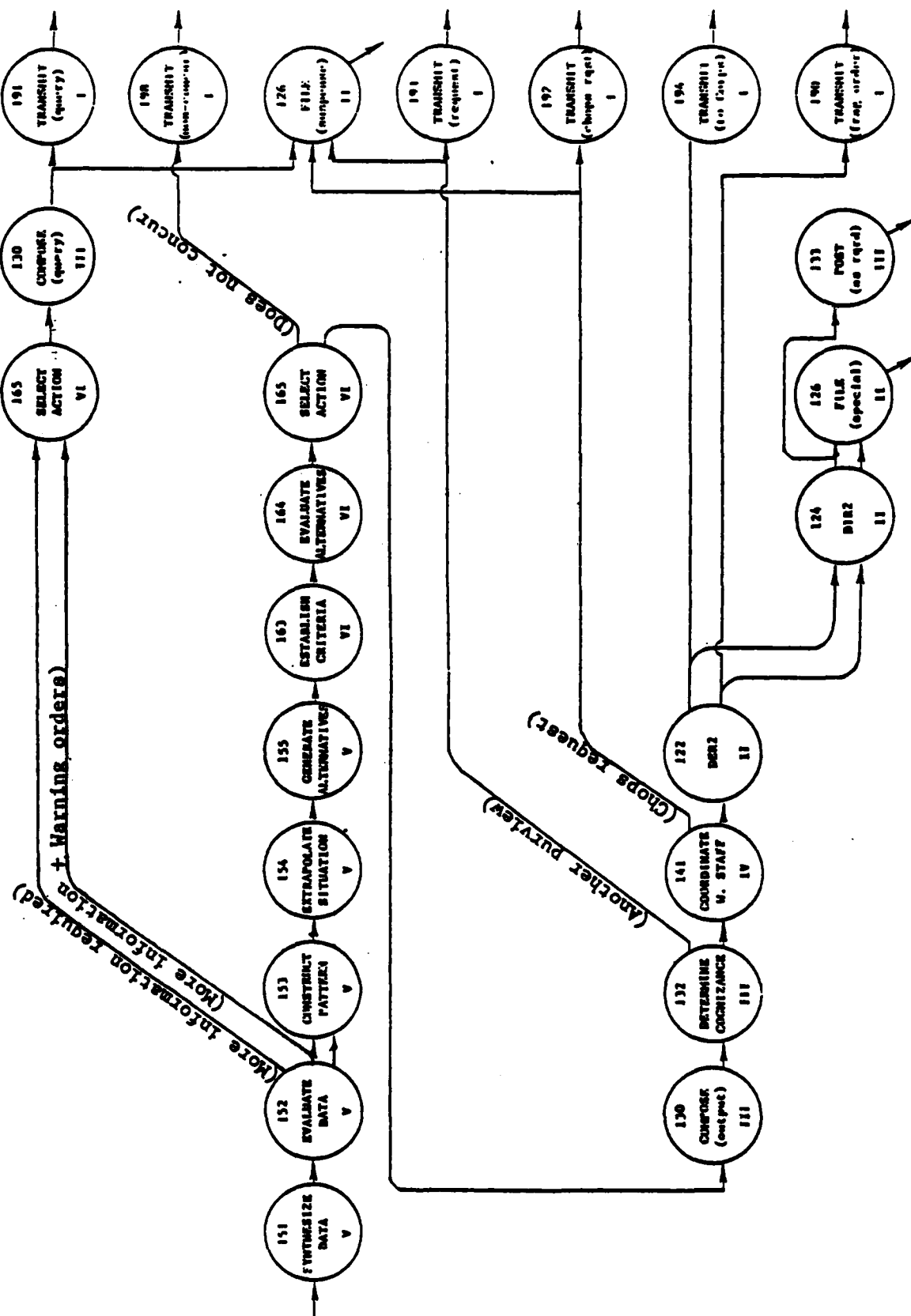


FIGURE 3-3. FORMAL STAFF ACTION SEGMENT

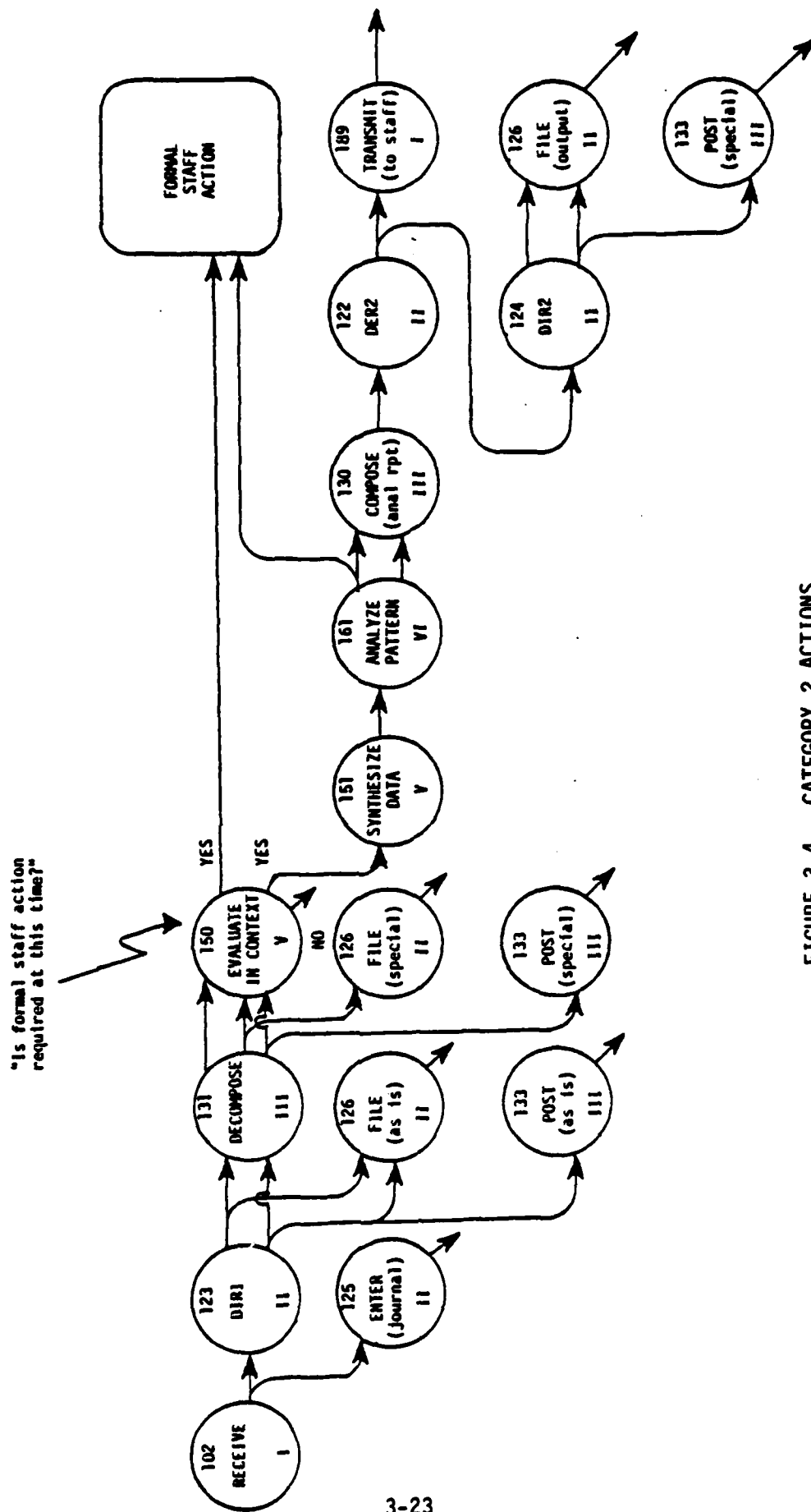


FIGURE 3-4. CATEGORY 2 ACTIONS
Triggered by Receipt of Retransmitted Copy of Another Staff Section Input

embarked on the formal analysis, he may perceive that the results of the analysis not only must be sent to CG, G2 and G3, but also provide the basis for formal staff action with respect to the division artillery units. The added logical structure here in the Category 2 event thread chart is devoted solely to these processing requirements of the Post-Strike Analysis Report.

3.2.1.3 Category 3 Actions

The third category of staff procedures covers the largest group of actions identified in the Phase 1 design (see Table 3-4). The actions are those triggered by receipt of action copies, information copies, staff query responses, or responses to all requests except concurring chops responses. Category 3 actions cover the majority of staff coordination processes in the battle simulation. The event thread chart is shown in Figure 3-5.

The front end processing of Category 3 actions is somewhat simpler than that in the previous categories. Furthermore, it is anticipated that the frequency with which these actions will terminate in EVALUATE IN CONTEXT (hence, not continue on into formal staff action) will be higher than for Categories 1 and 2. The vast majority of these actions will simply be "paper mill" processing in which the staff section receives information copies of another section's output and no further disposition is indicated beyond the filing of the subject report.

3.2.1.4 Category 4 Actions

The fourth category of staff procedures cover those actions that are initiated by the senior staff officer because he holds a perception of the situation or problem in his mind and has determined that formal staff action should be instituted forthwith. The event thread chart is shown in Figure 3-6.

The interpretation of Category 4 staff procedures is clear enough for live staff modules. During the course of a division-level

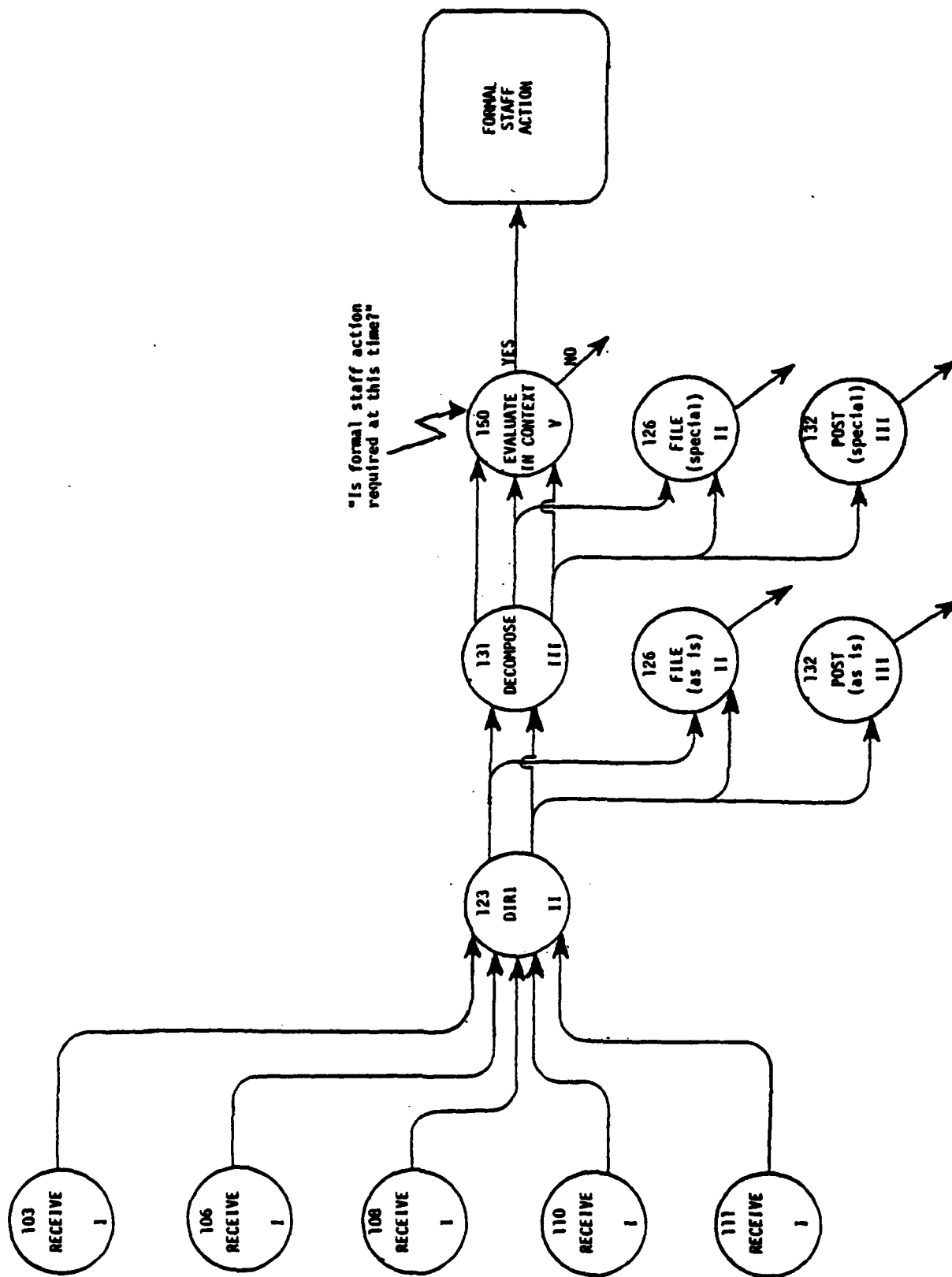


FIGURE 3-5. CATEGORY 3 ACTIONS

Triggered by receipt of staff action copies, info copies, query answers, and any responses except concurring chops responses.

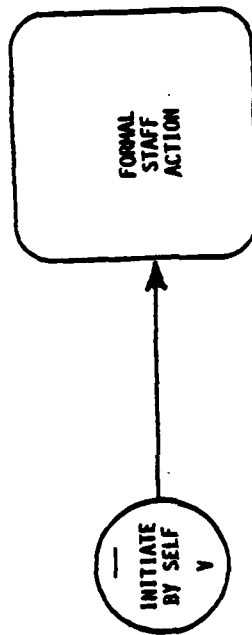


FIGURE 3-6. CATEGORY 4 ACTIONS
Internally Initiated Actions

combat, the Commander or any of his principal staff officers may spontaneously initiate formal staff action pertinent to the successful execution of the division's assigned mission. However, the computer simulation of internally initiated actions will necessarily fall short of modeling the human brain "when the light comes on." As stated in paragraph 3.1.2, the elementary operation INITIATE BY SELF has no corresponding Class 1 event definition. Class 1 events, as staff processing steps, were originally thought to be task performance steps carried out by a simulated staff person in response to some kind of external stimulus. In this case, "when the light comes on," the stimulus is internal. The Phase 1 concepts of Class 1 events and special "release" events (intervention by the controller(s)) do not, by themselves, provide sufficient framework for simulating internally initiated actions. The actions will have to be simulated by programming them as externally triggered events.

The additional logical framework required for simulating Category 4 actions is presented in Section 4. There may very well be behavioral research experiments in which the simulated staff modules will be triggered to reflect internally initiated actions as part of the dynamic setting that is presented to the live player team.

3.2.1.5 Category 5 Actions

The fifth category of staff procedures covers those actions triggered by receipt of a directive from the Commander or a concurring chops response. The actions involve only a small number of output-processing tasks since the basic decisions on which their output frag orders or Corps requests are based will have been made in other, earlier staff actions. The event thread chart is shown in Figure 3-7.

For the processing of concurring chops responses, Category 5 staff procedures employ the decision-making step: COORDINATION COMPLETE? The procedural rule established by this elementary operation is that no frag order or Corps request for which chops requests have been sent out shall be released until concurring responses have been received from all sections solicited. If one or more chops requests are returned as non-concurring (and consequently processed as Category 3 actions), then it should be clear that the Category 5 processing of the concurring responses will terminate at the procedural choice: COORDINATION COMPLETE? and not culminate in the issuance of a frag order or Corps request.

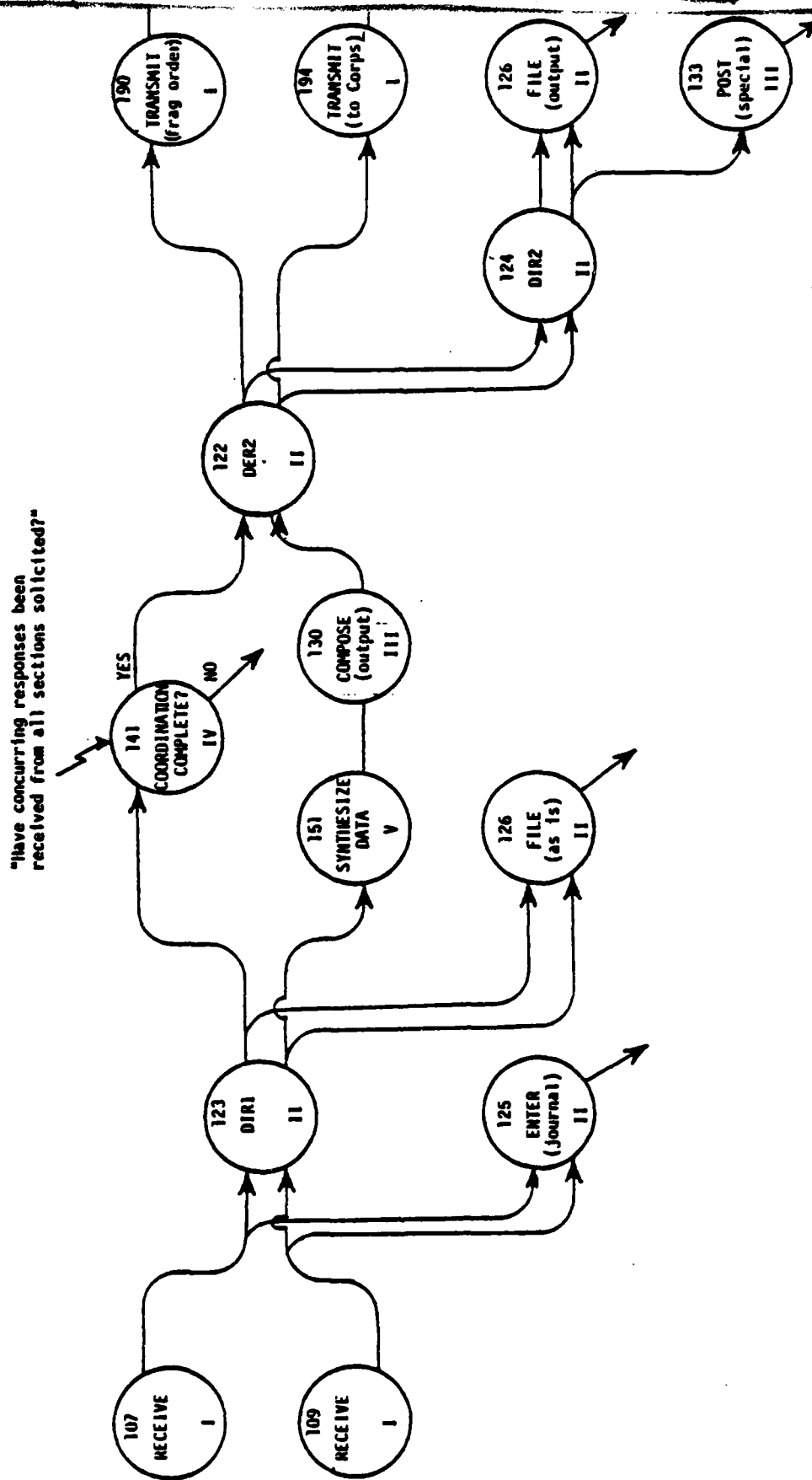


FIGURE 3-7. CATEGORY 5 ACTIONS
Triggered by Receipt of a Directive from the Commander or a Concurring Chops Response

It should be added that this feature of the Category 3 and Category 5 procedures provides the senior staff officer with several recourses if a proposed course of action "bounces" with one or more non-concurrences. Under the Category 3 procedures, he may reformulate the proposed course of action taking into account the objections raised by the other staff officers, or he may resubmit the original output but this time route it for the Commander's approval, notwithstanding the non-concurrences from the other sections.

3.2.1.6 Category 6 Actions

The sixth category of staff procedures pertains to the periodic reports to higher headquarters that must be prepared by the division staff. These actions are always triggered by the clock. At the appropriate time in advance of the due time, the staff section must embark on the report preparation tasks. The event thread chart is shown in Figure 3-8.

Category 6 procedures are applicable to the following six reports identified in the Phase 1 design:

- Division Situation Report, prepared by G3
- Division Intelligence Summary, prepared by G2
- Intelligence Paragraph of the Division SITREP, prepared by G2
- Preplanned Request For Fire Support, prepared by FSE
- Division Personnel Daily Summary, prepared by G1/G4
- Division Logistics Report, prepared by G1/G4

It can be seen in the figure that the first step in Category 6 procedures is the operation SYNTHESIZE DATA in which the senior staff officer assembles the tactical information necessary for the composition of the report. The data are compiled from the section files/displays. In accordance with the definition of this elementary operation (Table 3-2), if the required information is found to be

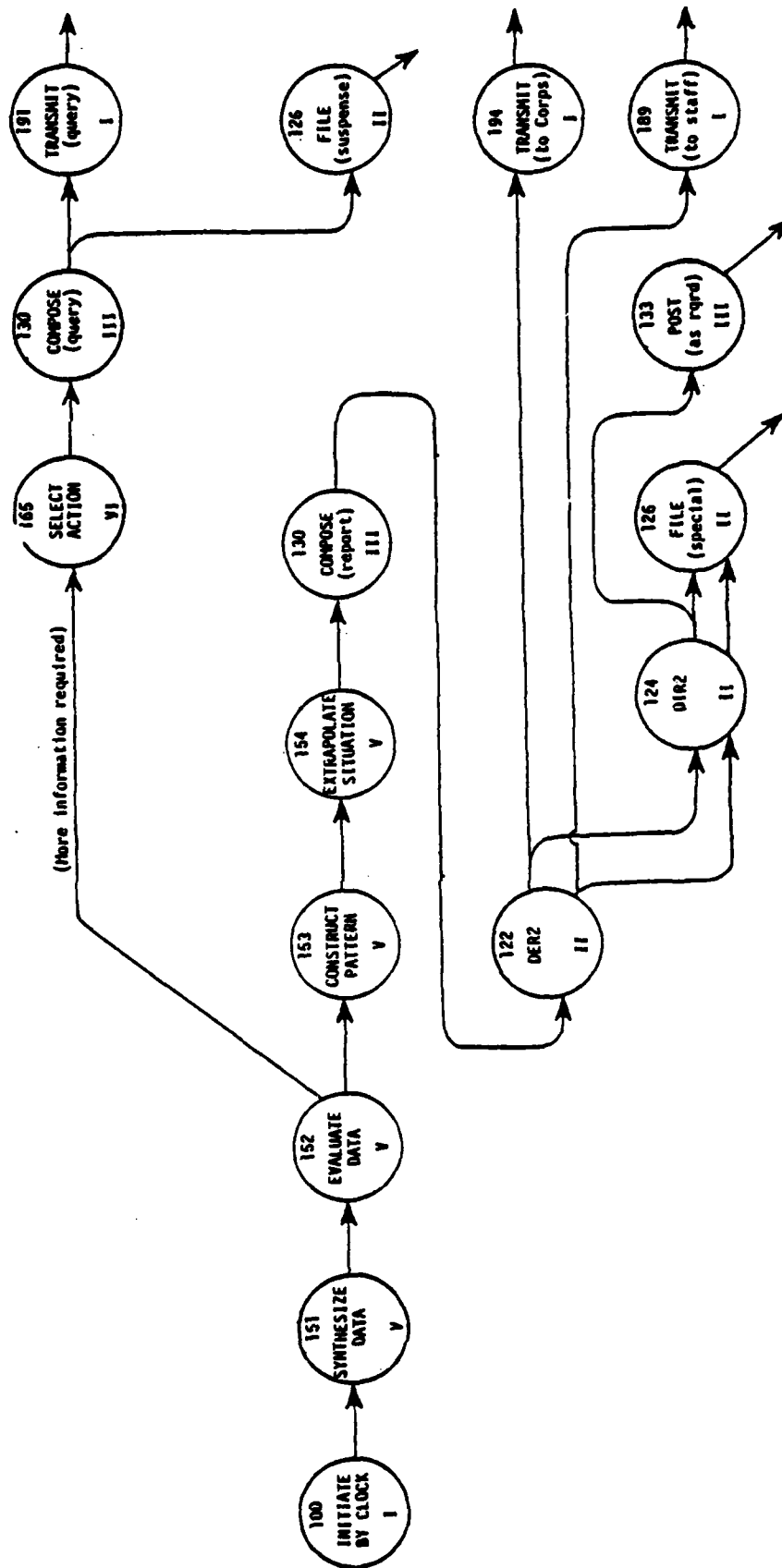


FIGURE 3-8. CATEGORY 6 ACTIONS
Initiated by the Clock and SOP

incomplete, the subsequent processing of the report preparation must be switched in the same manner as that shown in the formal staff action segment (Figure 3-3). For example, if the G3 finds, in preparing the Division SITREP, that the G2 has failed to submit the Intelligence Paragraph, then he (the G3) cannot proceed with his analysis and report composition but instead must first send off a staff query to G2. This type of "contingent procedural switching" will be shown to be a significant aspect of aberrant human performance in Section 4.

3.2.1.7 Category 7 Actions

The last category of staff procedures covers the staff actions attendant upon receipt of a query from another section or a request for concurrence on a proposed course of action. The event thread chart is shown in Figure 3-9.

In the staff processing of queries, the Category 7 procedures exhibit another example of contingent procedural switching as discussed above. According to the Phase 1 design, staff queries are limited to requests for the latest version of certain Class 3 or Class 4 reports, copies of which are kept on file in the section having cognizance for the type report. The G2, for example, will keep on file the latest copies of the Wx Forecast, Bde Intsums, Estimate of Enemy Strength, Composite Target List (Intel), Division Intsum, and the Intel Paragraph of the Division SITREP that he has received or generated. At any time he may receive a staff query from another staff section. The query will specify one of these reports, and in order to respond to the query, the G2 must withdraw the appropriate copy from his files (RETRIEVE) and send it off to the section who submitted the query.

Now, in the framework of the example described above, suppose the G2 receives a query from G3 specifying the current Intelligence Paragraph. The G3 submitted the query because he had found (in the Category 6 procedure) that he could not compile the Division SITREP because the G2 had failed to supply the Intelligence Paragraph. The G2 (now in the Category 7 procedure) would discover upon attempting to retrieve the aforesaid report from his files that the material was not there because he had failed to generate it in the first place. As a consequence of this discovery, the G2 would be required to switch away from the normal query response sequence and to start immediately on the compilation and composition of the overdue report. This second example of contingency procedural switching suggests even more

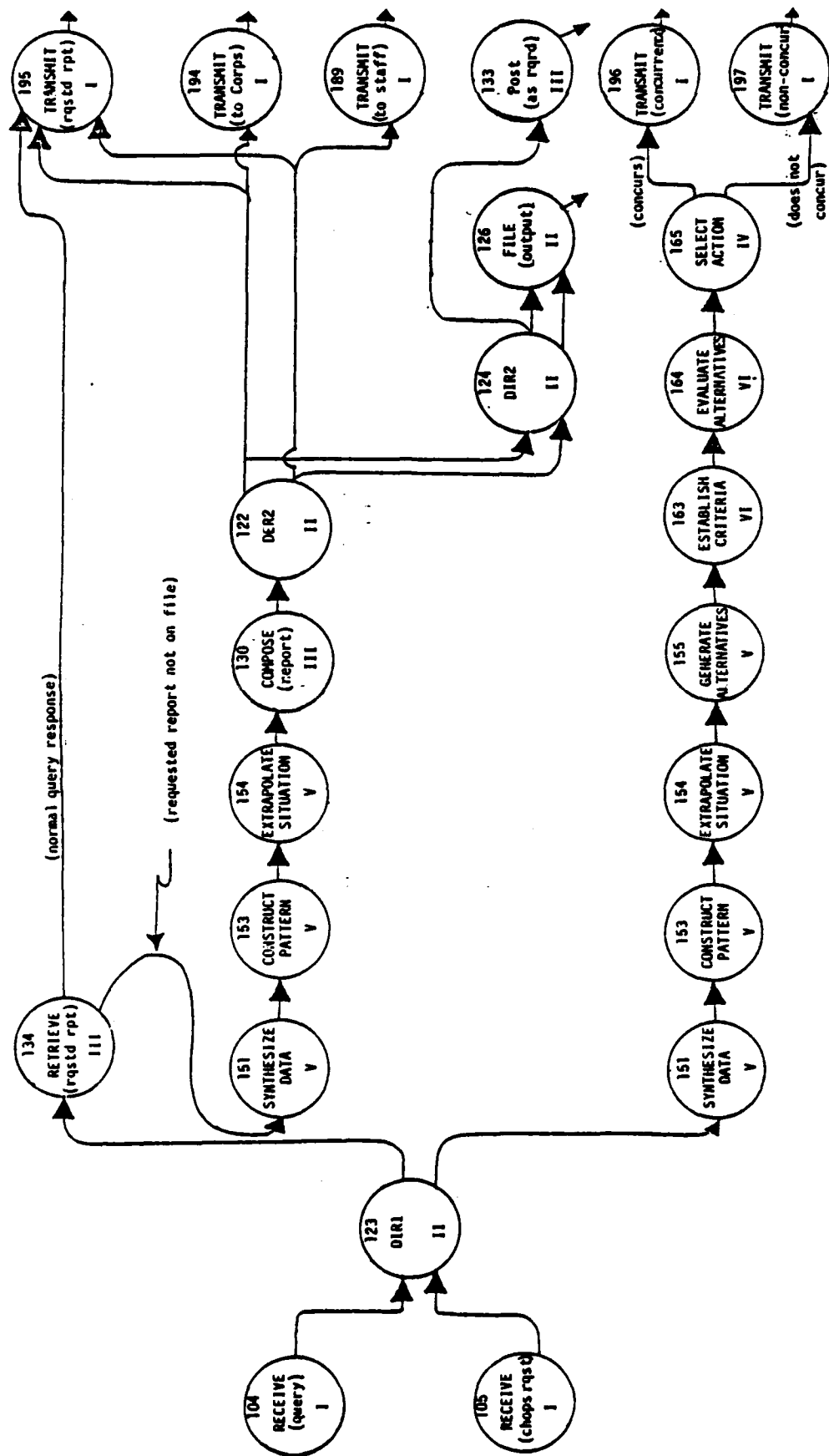


FIGURE 3-9. CATEGORY 7 ACTIONS
Triggered by Receipt of a Staff Query or a Request for Concurrence

strongly the significance of substandard human staff performance in behavioral research experiments.

3.2.2 Preliminary Discussion of Variable Interface Boundaries

The seven event thread charts presented above provide the second tier of building blocks with which the logical structuring of simulated modules may be approached. The charts also provide a visible basis for addressing the second design requirement, which is the elimination of some of the low-level, repetitive processing tasks for the live modules. One approach to this requirement is to build in the capability for changing the interface boundaries between the staff modules and the rest of the computer simulation. A conceptual picture of these boundaries is shown in Figure 3-10, which is taken from the Phase 1 design⁵. The annular ring in the figure represents the five Blue staff modules. The unshaded module (G2) is populated with human players; the remaining, shaded modules are, under the illustrated configuration of play, simulated modules. Within this annular ring, the staff processing of the tactical information will be governed by the staff procedures specified by the seven event thread charts. The populated module, in this case G2, will perform its "play" according to the action SOPs given by the charts. The simulated modules will represent the staff processing by means of the sequence of Class 1 events given in the charts.

In this framework, the input interface, which is denoted by the arrows pointing into the annular ring, corresponds to the left hand margins of each of the seven staff processing charts. The data transfer into the staff modules is always followed by the elementary operation RECEIVE. Similarly, the output interface, which is denoted by the arrows coming out of the annular ring, corresponds to the implicit data transfer following the elementary operation TRANSMIT. Although there are several isolated occurrences where the terminating TRANSMIT operation appears in the middle of the charts, most TRANSMIT events appear at the right hand margins.

5 Tiede, R. V., Burt, R. A. and Bean, T. T., Design of an Integrated Division-Level Battle Simulation for Research, Development, and Training, (Army Research Institute Draft Technical Report, August 1979).

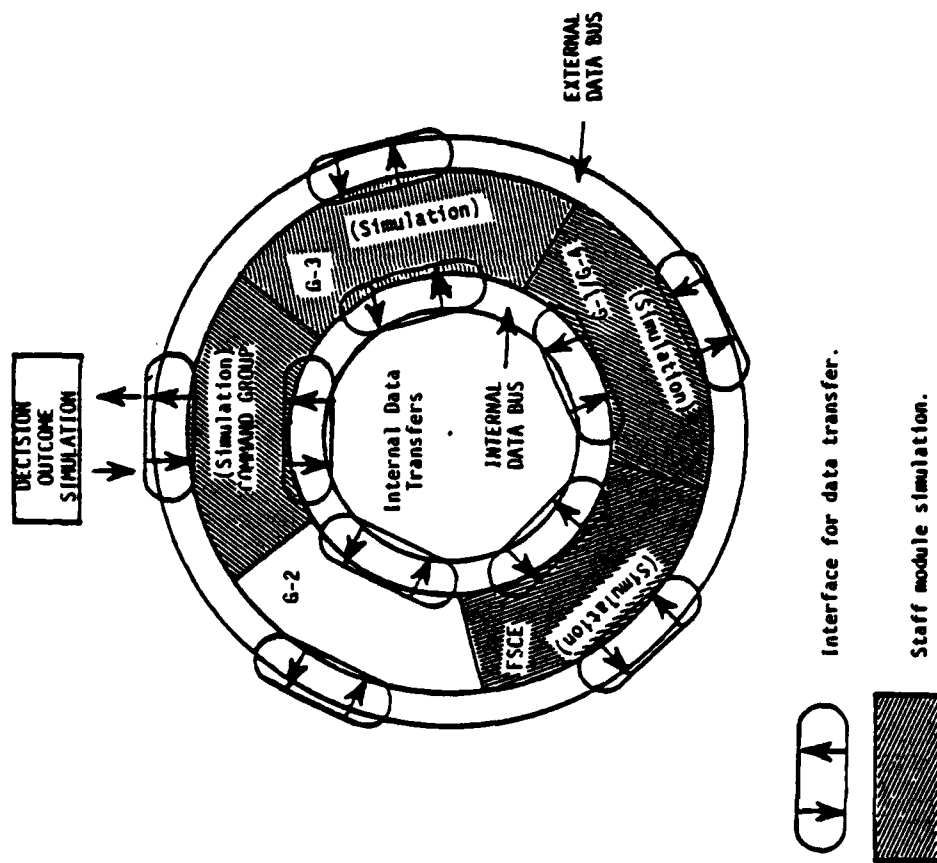


FIGURE 3-10. DATA FLOW IN MODULAR STAFF SIMULATION

The interface boundaries, specified in this manner, spell out the full range of procedural steps or Class 1 events that is required in the staff processing by a division-level staff. The steps include all the low-level, repetitive information processing tasks that, for some behavioral research investigations, may represent so much excess baggage in terms of the objectives of the experiments.

The discussion that follows introduces the idea of changing the interface boundaries. In order to show the implications of a relocated boundary, an extreme position has been selected for the relocation. The selected position is oriented to a live staff module consisting of only one player: the senior staff officer and decision-maker. If the battle simulation can be developed so that it can allow the play of one-man live staff modules based on this extreme boundary location, then other, intermediate boundary positions between the two extremes appear entirely feasible.

The proposed boundary for a one-man populated module is now illustrated using the charts for Category 1 Actions. Figures 3-11 and 3-12 show the input interface and the output interface locations if the staff processing for a live module were to begin at the point where the decision-maker determines whether formal staff action is required at this time (in EVALUATE IN CONTEXT) and end at the point where he effects the implementation of his selected course of action (in COMPOSE, SELECT ACTION, or COORDINATE W. STAFF). The data transfer from computer to player or from the player back to the computer would take place at these points.

Similar interface boundary locations can be generated in the remaining event thread charts. However, it can be seen from these figures by themselves that the new, extreme positions eliminate nearly all the Level I, II, III and IV elementary operations from the procedures to be followed by the one-man live staff modules. In this conceptual framework, all the information processing at the beginning of the staff action and all output processing following the tactical decision will be simulated in the computer. The lone player in the live staff module must address only the fundamental decision-making procedural steps which, with one or two exceptions, are all Level V or VI operations.

This approach to providing variable interface boundaries brings out the central design problem that is addressed later in Section 5. The original Phase 1 concept included the Blue perceived data base as the primary computer storage medium for the body of

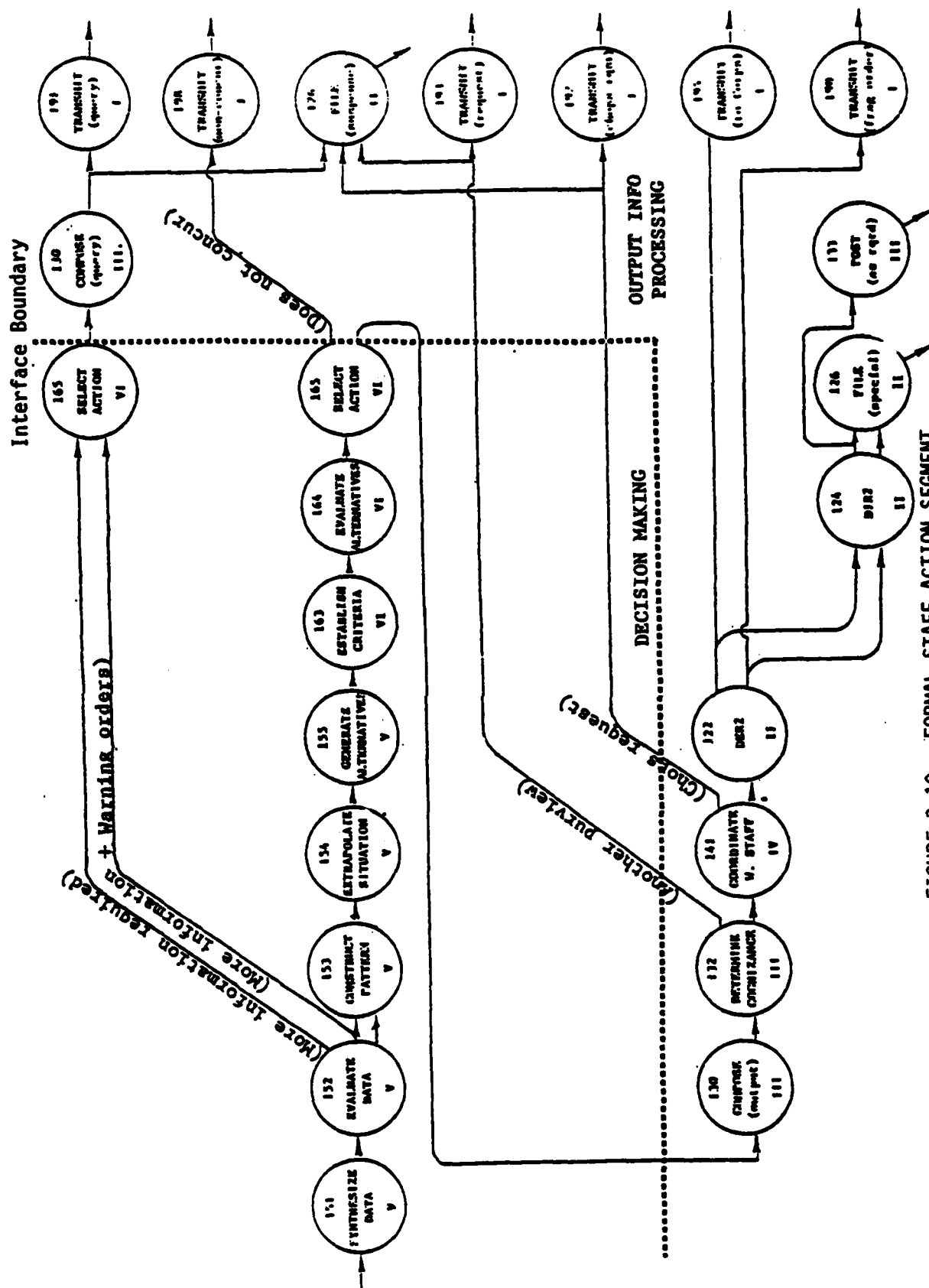


FIGURE 3-12. FORMAL STAFF ACTION SEGMENT

information regarding the "state of the battle" held by the Blue side. The transfer of data from the perceived data base to the live players was visualized as being limited to about seventy-five standardized tactical message formats whose printing or cathode ray tube display was presented one-at-a-time to the players. The populated modules, in turn, had the responsibility for maintaining and updating their own section files, status boards, and situation maps so that the tactical decisions they made were based, among other things, on how well they organized, aggregated, and sifted their own data. Now, under the new boundary location described above, it is clear that the computer will take over the input information processing tasks heretofore assigned to the players. But how is this section data base information to be presented to the lone decision-maker when he embarks on the elementary operations EVALUATE IN CONTEXT or SYNTHESIZE DATA? Is he provided with a fully automated situation map display? Can he access any of his section files by means of keyboard queries? With either the extreme boundary position or even an intermediate location closer to the boundaries implied by left and right hand margins of the charts, the computer assistance aspects of the Phase 1 design will have to be enlarged. One part of this expanded requirement, the question of the computer storage of the staff files and displays, is addressed in the next section. The remainder of the questions, such as the added data presentation formats and the software switching, is developed in considerable detail in the Section 5.

3.3 POINTS OF OCCURRENCE OF VARIANT HUMAN PERFORMANCE

This subsection now merges the human performance material developed in Section 2 with the staff processing structures discussed earlier in this section. The objective here is to determine where, in the execution of the staff actions, relevant human errors are likely to occur. The points of occurrence of aberrant performance will provide, with respect to populated staff modules, basic guidelines for the instrumentation of the player team. The determination will also provide, with respect to simulated staff processing, the embryonic logical framework by which the computer/controller(s) may accommodate two different aspects of human error phenomena: first, the simulated processing attendant on substandard performance coming from the live player team, and second, the injection of simulated errors in order to observe the compensating responses, if any, by the live team.

The points of occurrence of human errors in staff processing that are derived here become central to the logical design of the simulated staff modules as presented in Section 4.

3.3.1 Three Classes of Human Error

In Section 2 human errors in staff processing were classified according to their elemental effect on the information processes. Three such classes were identified. This classification is repeated here in order to illuminate the basic relationships with the procedural steps in the staff actions:

- Data Error: Introduction of erroneous or misleading data into the staff section files/displays.
- Procedure Error: Delaying the completion of the staff action by making a false start or an error in performance of an elementary operation.
- Cognition Error: Making the wrong tactical decision because of false or incomplete perception or inadequate selection criteria.

The caveat that went with these effects should also be repeated. It should be clear that while the errors may be observed as discrete occurrences in a live staff module, the consequences of such occurrences, stemming from the cause-and-effect relationships among them, are difficult to predict. A staff section, for example, could issue an incorrect frag order because of at least three different manifestations of human errors. First of all, because of one or more data errors, the decision-maker might construct an erroneous perception of the situation or problem at hand and end up with an inappropriate tactical decision. Second, because of cumulative delays from procedural errors, the decision-maker might come forth with an invalid decision since the decision was based on a situation now three to six hours old. Finally, even though he is confronted with a timely and accurate picture of the situation, the decision-maker himself might fail, as a result of cognition errors, to generate the full spectrum of alternatives or to develop adequate evaluation criteria and therefore end up with the wrong tactical decision. Beyond these three simple sequences there are undoubtedly numerous combinations of the three error classes that could lead to a wide variety of alternative outcomes. Indeed, it can be argued that an ironic "comedy of errors" in command and control is possible under the classifications. A situation could exist where data errors lead to a wholly erroneous picture of the tactical problem. Thereafter the

decision-maker makes a number of cognition errors which fortuitously compensate for the wholly erroneous perception. In this unlikely circumstance the staff section might come forth with the correct tactical response derived entirely for the wrong reasons.

As discussed in paragraph 2.4.4 of the Phase 1 design report⁶ not all of these error classes are either observable or measureable directly in the information stream. Data errors and procedural errors can be observed, hence measured, directly because the data stream and/or data base contains a reference standard. Cognition errors, on the other hand, involve the generation of new information not previously contained in the information stream; hence, their effect can be observed only indirectly, i.e., in the outcome of combat. As pointed out above, data errors and procedural errors can also affect combat outcomes. One must, therefore, carefully control the non-cognition errors if the effects of cognition errors are to be isolated.

3.3.2 Frequency of Occurrence

The points of occurrence of the human error effects are identified with respect to the 27 elementary operations in Table 3-5.

The table shows the elementary operations and/or Class 1 events as they are listed in Tables 3-2 and 3-3. The estimated relative frequency of occurrence of the three error effects is shown in the labeled columns. As indicated in Section 2, no adequate data were found in the literature to support the relative frequencies. The estimates shown are based on three broad factors that influence the likelihood of occurrence and that will be used in the computer logic for simulated staff modules. The factors are as follows:

- The nature of the elementary operation itself.
- The redundancy of the information content in the sense of information theory.
- The stress or fatigue experienced by the staff person at the time.

6 Ibid.

TABLE 3-5

ESTIMATED RELATIVE FREQUENCY OF OCCURRENCE OF ABERRANT
PERFORMANCE EFFECTS IN THE ELEMENTARY OPERATIONS

Event No.	E. O. Descriptor Cognition	Data	Procedure
		Error	Error
100	INITIATE BY CLOCK		2
101-112	RECEIVE OR ACCEPT	3	2
121	DER1	1	2
122	DER2	1	2
123	DIR1	1	2
124	DIR2	1	2
125	ENTER	2	2
126	FILE		2
127	MAKE COPIES		1
130	COMPOSE	2	1
131	DECOMPOSE	1	1
132	DETERMINE COGNIZANCE	1	1
133	POST or PLOT	2	2
134	RETRIEVE		2
140	COORDINATE W. STAFF	1	2
141	COORDINATION COMPLETE?	2	1
150	EVALUATE IN CONTEXT	2	1
	INITIATE BY SELF	1	1
151	SYNTHESIZE DATA	2	1
152	EVALUATE DATA	1	1
153	CONSTRUCT PATTERN	1	1
154	EXTRAPOLATE SITUATION	1	1
155	GENERATE ALTERNATIVES	1	1
163	ESTABLISH CRITERIA	1	1
164	EVALUATE ALTERNATIVES	1	1
165	SELECT ACTION	1	1
189-199	TRANSMIT or DELIVER	3	2

Blank - Never occurs

- 1 - Occurs with relatively low frequency
- 2 - Occurs with relatively medium frequency
- 3 - Occurs with relatively high frequency

Thus, it can be seen that data errors are expected to occur with highest frequency in the RECEIVE and TRANSMIT operations and not to occur at all in the FILE and MAKE COPIES operations. Similarly, the procedure errors (slip of the tongue, data entry errors, slips of the pencil, computational errors, etc.; corrected but delaying the execution of the operation) are expected to occur with different frequencies in all procedural steps. Finally, the cognition errors are expected to show up only in the higher level elementary operations.

SECTION 4

LOGICAL DESIGN FOR SIMULATED STAFF PROCESSING

4.0 INTRODUCTION

This section presents the logical design framework for the simulated staff modules in the battle simulation. The section focuses on the added design requirement related to the human errors that are known to occur in the command and control of division-level forces and whose occurrences and effects are an important and promising area for behavioral research applications. The requirement may be stated in terms of two questions about the way the simulated staff modules will operate:

- If the players in live staff modules make errors in the course of executing their staff functions, can the simulated staff modules, subject to the control by investigators/controllers, be made to "adapt" to the substandard human performance so that the consequences of the errors will be reflected in the battle outcome?
- Can the simulated staff modules, again subject to the intervention by the investigators/controllers, be made to exhibit errors in their own staff processing, so that the players in live staff modules may be tested to see if they attempt to correct the mistakes before they are reflected in the battle outcome?

Both questions are oriented to the coordination required between principal staff sections for effective command and control of the division. If the battle simulation can be implemented with the

requisite input control parameters and controller's intervention techniques to provide these features, then the model will open the door to a wide variety of behavioral experiments.

The discussion on simulated staff processing begins by tracing the tactical information flow in the model as a whole, as it was originally conceived in the Phase 1 design. This information flow structure is then refined first by incorporating the details of the staff procedures from Section 3 and second by showing where human errors are involved in the flow cycle. The refined structural framework is then used as the basis for describing the logical design of Class 1 events whose structured sequences make up the simulated staff processing in the model. The design features related to input control parameters and to controller's release events--the mechanisms required for the questions cited above--are then explored. The section is concluded by a review and restatement of the functions required of investigators/controllers in organizing and running behavioral research experiments with the enhanced design concept for the battle simulation.

4.1 TACTICAL INFORMATION FLOW IN THE SIMULATION

One of the principal features of the Phase 1 design concept is the explicit treatment of the flow of tactical information messages between the combat units engaged with the opposing forces and the division Command Group and its chief staff sections. Whenever one or more of the Blue staff modules are manned by teams of human players, the tactical information flow is manifested by the players "receiving" messages from the battlefield and their "transmitting" in turn new frag orders or queries back to the subordinate units. The treatment is explicit because the players are confronted with realistic formats and printed content based on about seventy-five selected tactical message formats.

The flow of tactical information in the model is illustrated in Figure 4-1. The figure shows the flow cycle as it was originally conceived in the Phase 1 design. The flow of information can be seen to circulate through three different conceptual entities: the real world data base, the Blue perceived data base, and the Blue staff modules. A similar flow cycle exists for the Red side, but in keeping with the fundamental asymmetry of the design concept, the Red command and control module consists only of the Red Commander by himself.

The flow of tactical information messages is governed in the simulation by the occurrence of events. The ground-truth facts

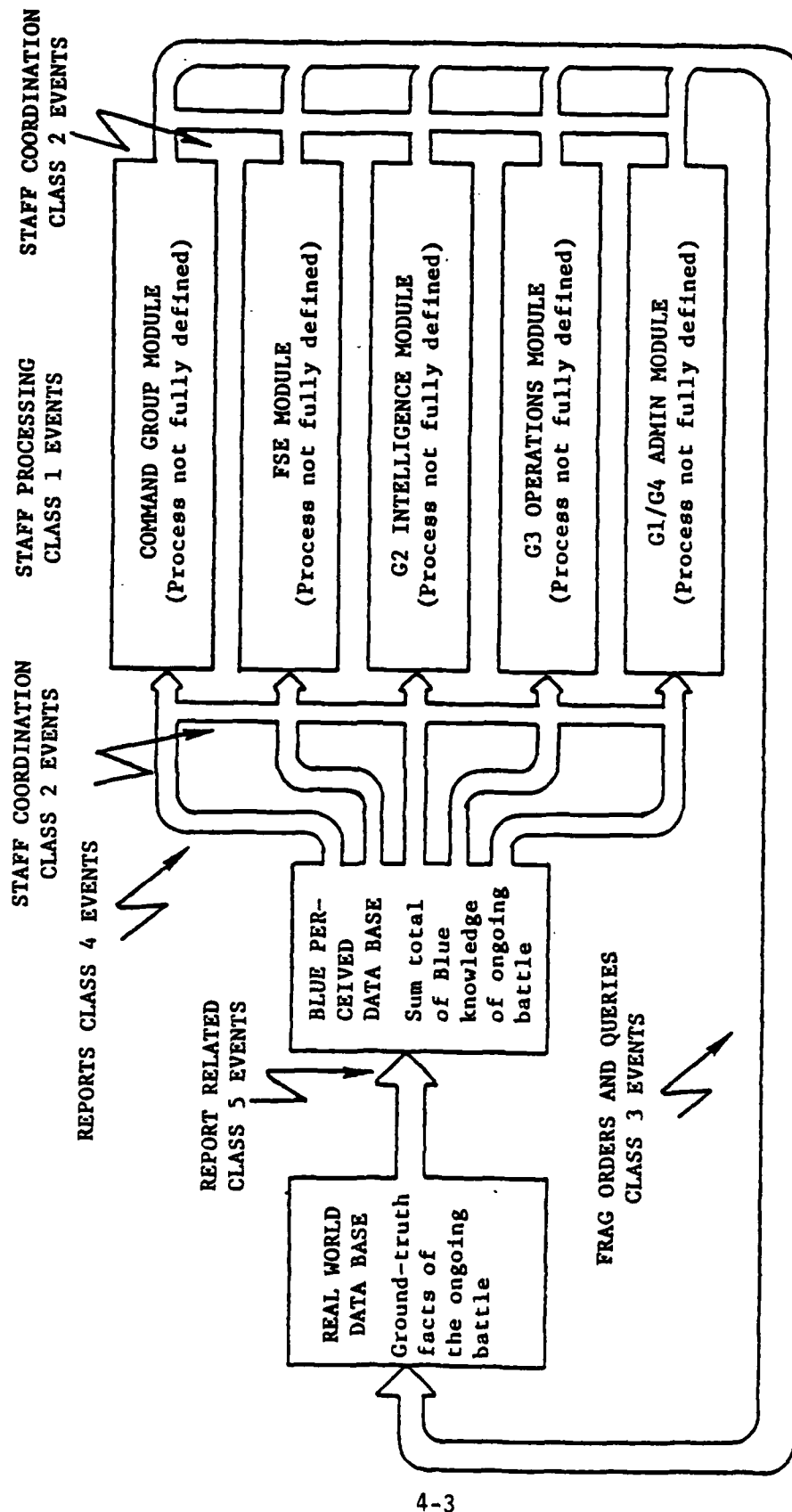


FIGURE 4-1. SIMPLIFIED ILLUSTRATION OF THE TACTICAL INFORMATION FLOW IN THE BATTLE SIMULATION;
ORIGINAL PHASE 1 DESIGN

about the on-going battle are carried from the real world data base to the Blue perceived data base by means of report-related Class 5 events. These events cover the intelligence gathering and status reporting activities taking place in the BOG. The general Blue perceptions of the battle are then carried from the perceived data base to the cognizant staff module by means of the Class 4 interface events. The interface boundary between the perceived data base and the staff modules is not shown in the figure, but it is located just to the right of the perceived data base. Upon receipt of the Class 4 reports, the staff modules then establish the flow of input coordination messages by means of the Class 2 events. The description thus far covers the first half of the flow cycle.

The second part of the cycle begins with the staff processing performed by the staff modules. Acting on the basis of the tactical information it receives, each module performs the required command and control functions within its purview and issues or transmits frag orders or queries pertinent to the successful execution of the division's assigned mission. The formulation and generation of these new messages is effected by Class 1 events. The transmission of the messages, carrying the new orders or queries to the appropriate addressees in the BOG, is governed by means of the Class 3 interface events. Concomittant with the staff outputs are the output coordination messages (information copies) shown by the second bar of Class 2 events. The interface boundary between the staff modules and real world data base is also not shown, but it lies somewhere along the bar at the bottom of the figure. This "closes the loop" for the information flow cycle.

Figure 4-1 highlights the fact that the staff processing internal to the staff modules was not fully defined in the Phase I design. A preliminary discussion of the concept of Class 1 events was given in Design Note I, but the list of defined events was incomplete for the class because the level of procedural detail to be used had not yet been determined.

The completion of the list of defined Class 1 events and the detailing of the staff procedures from the previous section now permit the first refinement to be made on the picture of the tactical information flow.

4.1.1 Staff Processing Details

The role of staff processing in the information flow cycle can be illustrated by grouping the procedural steps in Action Categories 1, 2, and 3 (Figures 3-2, 3-4, and 3-5; also Figure 3-3) into three basic stages: maintenance and update of the section files/displays, generation of the perception and decision-making, and output processing. Upon receipt of a tactical information message, a staff section usually goes through these three stages of staff processing. For the purposes of showing a refined picture of the general information flow, the subtle variations on this simplified framework implied by the remaining action categories can be ignored for the moment. Action Categories 1, 2, and 3 cover the majority of the staff processing requirements.

The first refinement to the information flow diagram is shown in Figure 4-2. The figure shows that the staff processing in each of the five staff modules consists of the same three basic stages. While the specific types of tactical messages it receives and the specific organization of its files/displays both depend on the area of functional responsibility for an individual module, the general pattern of information flow through the module is the same for all staff sections.

At this point, a review of the concept behind the perceived data base is pertinent. In the Phase 1 design¹, the Blue and Red perceived data bases were characterized as follows:

"The perceived data base on each side consists of the side's perception of its own troop list and operations SITMAP as well as the enemy order of battle and dispositions. The real world data base and the separate perceived data bases are conceived as distinct bodies of information because neither side will ever enjoy true and full knowledge of the deployment of the units of the other side nor even up-to-date and precise knowledge of its own troops. Accordingly, the basic design concept includes a Blue and Red perceived data base each containing unaggregated information about its own troops and the enemy forces. During the course of the play, the information in these data bases will be continually modified by the occurrences of the Class 5 report generation events. The occurrences will usually be followed by corresponding Class 4 events at which times the staff modules will receive tactical information messages. The messages will be formatted according to standard message formats and based on data aggregated from the perceived data base. Thus, the state of battle

1 Tiede, R. V., Burt, R. A., and Bean, T. T., Design of an Integrated Division-Level Battle Simulation for Research, Development, and Training (Army Research Institute Draft Technical Report, August 1979).

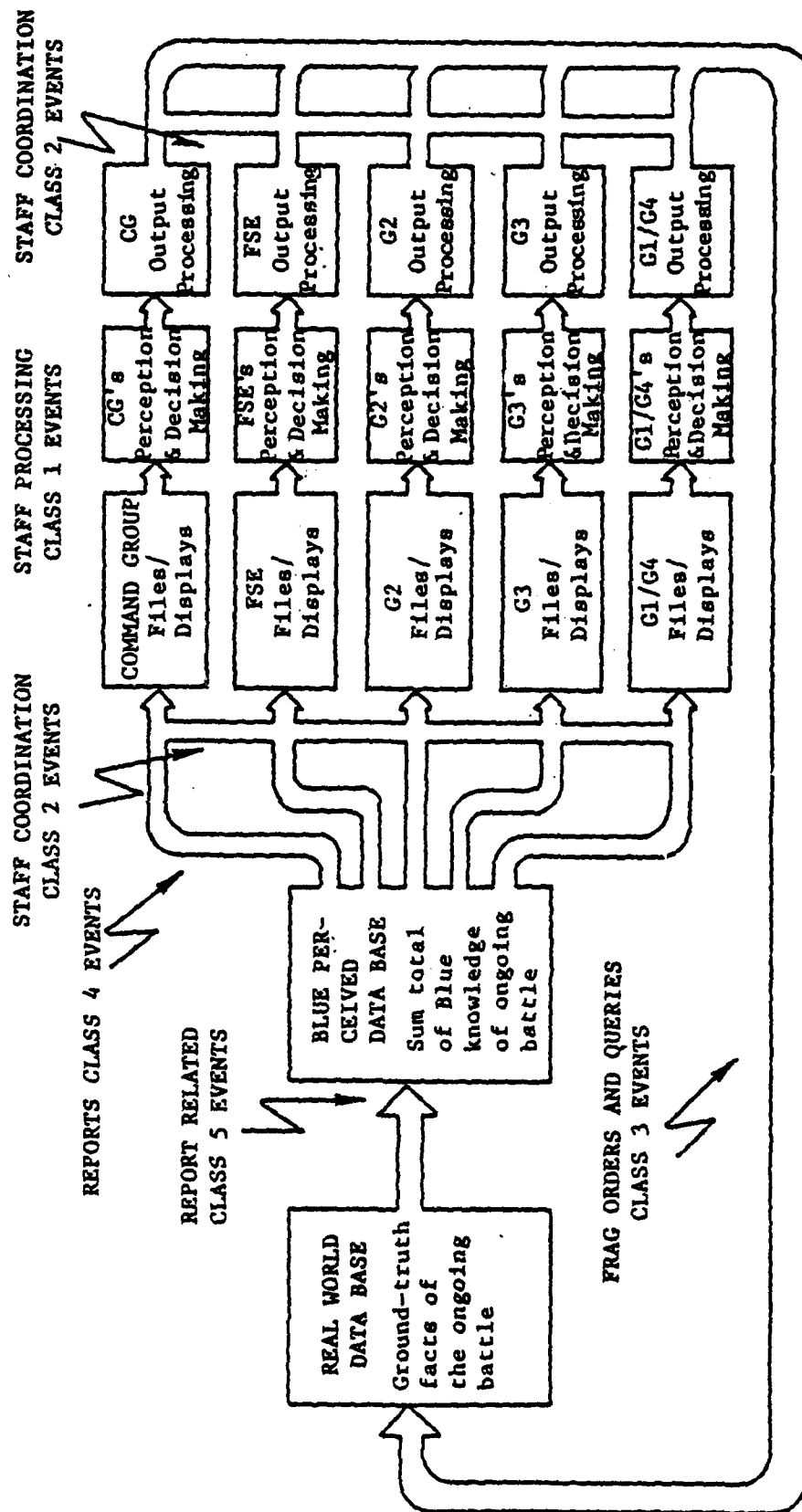


FIGURE 4-2. TACTICAL INFORMATION FLOW IN THE BATTLE SIMULATION, SHOWING THE STAFF PROCESSING

reflected in the information will always be delayed in time and subject to errors and omissions with respect to the true facts in the real world data base."²

"In concept, the perceived data base will always exist in two forms: first as tabular arrays of data available ordinarily only to the controller(s) and/or computer, and second as the series of troop lists, modified organizations for combat, situation map overlays, numerous files, etc., set up and maintained by human players in populated staff modules during an exercise. The first form may be thought of as the body of facts about the conflict marshalled by the Blue or Red sides, while the second form will reflect the way the commander and his staff organize, aggregate, and sift the known facts to facilitate decision making."³

Now the "first form" of the Blue perceived data base is simply the labeled box shown in Figures 4-1 or 4-2. But the "second form", at least with respect to populated staff modules, is the small box shown as the "section files/displays" for an individual module. The section files/displays box is hereafter called the section data base because it represents the body of information from which the decision-maker generates his perception of a problem and on which he bases his tactical decision. The validity of the section data base, that is, the degree to which the second form corresponds to the first form of the perceived data base, is clearly a function of how well the tactical information from successive messages is incorporated into the section data base.

One could summarize the distinction between the data bases as follows:

- Real World Data Base - information about what really happens in the division-level conflict.
- Perceived Data Base - sum total of knowledge one side holds about the conflict potentially available to decision makers of one side; this

2 Ibid.

3 Ibid.

information is generated by the intelligence gathering and status reporting functions employed by the side.

- Section Data Base - information taken from the perceived data base but reorganized and sifted according to the area of functional responsibility of the staff section. This is the information actually available to the decision makers.

Figure 4-2 brings out two points worthy of more detailed discussion. The first is related to the difference between manual staff processing and processing with ADP assistance, as seen from the perspective of the general tactical information flow. The second is concerned more concretely with the implementation of simulated staff processing in a computer. The separate issues are discussed below.

4.1.1.1 ADP - Assisted Staff Processing

The general design concept in the Phase 1 report contained provisions for exercising the staff modules not only under a manual staff system but also under a staff system provided with ADP assistance. The design considerations directed toward the latter mode of operation included the following:

- Requirement for an added sixth class of events and for the specification of the alternative tactical information displays associated with these Class 6 events.
- Requirement for additional hardware to provide a realistic environment for the players in a populated staff module.
- Software techniques for asynchronous data entry from several different player's terminals.
- Software additions for emulating the computerized decision-making aids built into the field ADP facilities.

Although these items were fully identified in the basic design, it was recommended that the initial implementation of the model proceed without them because the terminal hardware specifications and the software emulation routines were not fully defined at the time.

The conceptual picture of tactical information flow (Figure 4-2) nevertheless now provides an interesting perspective for comparing a manual staff system with ADP-assisted staff processing. The obvious disadvantage of a manual system as well as its more subtle shortcomings can be revealed by tracing the information flow through the staff processing boxes. The diagram can also be used to identify the fundamental tactical data management objectives for a field ADP system.

The principal difficulty with a manual staff system lies in the first stage of action processing shown in the figure. Maintenance and update of the section data base attendant on the receipt of a tactical message are performed entirely by hand by subordinate members of the staff section. Management and processing of the vital tactical data are handled by means of complicated staff procedures consisting of a large number of elementary, and sometimes trivial, operations. Since the categories of staff actions in Section 3 are oriented to a manual staff system, the complexity and time-consuming aspect of the input information-processing can be seen by looking at the front end of the event thread charts (e.g., Figures 3-2, 3-4, and 3-5).

The amount of time taken for information-processing before the senior staff officer can begin to formulate his perception of the situation can often spell the difference between effective or inadequate command and control, even if the successive tactical messages were to come in at reasonably spaced time intervals. The time delays are predictably much worse, however, whenever the staff element experiences a "busy hour" when the tactical messages are coming in simultaneously on several different communications channels, one after another. An earlier study⁴ has shown that the time necessary to complete the input processing or the entire staff action

4 Tiede, R. V., Walker, M. E., Stenstrom, D. J., and Sweeny, S. O., The Integrated Battlefield Control System (IBCS) Third Refinement Study (McLean, Va.: Science Applications, Inc., Final Report, March 1975)

can be lengthened as much as 100% or more simply because the E4 or E7 performing the initial input operations has an inordinate number of tasks piled up in his in-basket.

A second, more obscure problem with manual systems can be demonstrated by referring again to Figure 4-2. The basic idea behind the perceived data base and the individual section data bases is that each section data base represents a recasting of the "state of the battle" information from the perceived data base according to the section's area of functional responsibility. This means that the five staff sections are, in principle, looking at the same picture of the conflict but are extracting nuances (i.e., tactical data) from the picture that are relevant to their separate areas of responsibility. This is fine just so long as the coordination between the staff sections is sufficient to assure that they continue to look at the same overall picture. Staff coordination in fact serves two basic purposes. First it is a mechanism for detecting and correcting gross errors. Secondly it serves to keep the separate section data bases reasonably well coordinated.

In a manual system, the staff coordination procedures are executed entirely by staff personnel. A breakdown or failure of staff coordination due to improper procedures or to human errors will inevitably lead to section data bases that are no longer based uniformly on the same picture of the war. In short, in a manual system, when the five cooks attempt to taste the soup from the same pot on the stove, human errors will serve to sprinkle more salt or sugar into the soup spoon as it passed among them.

These shortcomings within a manual staff system immediately suggest the direction and thrust that one would expect to be taken in the development of ADP facilities to assist in the concentration of forces by a division commander. An ADP system should be overlaid on division structure to provide basic automated processing capability down to the desired echelon. Furthermore, the system should be designed to provide the capability to exchange data both internal and external to the division, to build and maintain data files, to perform analysis support, and to provide a graphic display capability to support division operations.

Implicit in these requirements is the recognition that each of the subordinate units on the battlefield "sees" different aspects of the perceived data base indicated in Figure 4-2. There is a natural tendency for knowledge among and between staffs (derived from

the perceived data base) to diverge if there is not a conscious effort to institute and execute staff coordination procedures. Even with excellent vertical and lateral staff coordination the knowledge on the part of each unit will tend to diverge due to time delays, human errors and the orientation of each unit. Accordingly, it has been seen as a significant problem area on today's dynamic battlefield and ADP systems should provide the battlefield with a common data base, accessible by all units. This concept would provide all commanders with the required level and detail of information which would lead to more timely analysis of the dynamic battlefield and reduce the uncertainty in decision making.

There is also a requirement for section data base within each unit's staff. This feature must provide each staff section the capability to extract information that it needs in order to execute its function on a continual basis. As each staff inputs new information or modifies existing information the common data base is essentially updated for all other users. This concept reduces information processing times, decreases the possibility of compounding human error and increases the effectiveness of staff coordination at all levels.

It is clear then that a battlefield ADP system, if implemented properly, can alleviate most of the problems associated with the vertical and lateral transfers of information among all division units. However, it is conjectured that the ADP system should not only alleviate information processing problems but it should also provide an additional bridge between the information and the ultimate decision made by staffs. That is, decision-aiding techniques could, among others be applied to enemy activity and movement, enemy order of battle, logistical considerations, and the most likely outcome of alternative courses of action.

The Phase 1 design addressed and resolved many of the issues brought out above. For example, the simulation has been designed as a storage and retrieval system for incoming and outgoing messages as they pertain to the division staff. All of the various staff modules, whether populated or simulated had access to a common "perceived" data base. The design of this perceived data base was modeled upon the automatic receipt and distribution of incoming messages based on specific message characteristics. To design the common perceived data base, reporting requirements of the division were ascertained and the data utilization at the division-level was assimilated into the information flow of specific staff modules.

This design concept had the advantage of allowing populated staff modules to structure their own section data base from incoming tactical messages and queries made to the common perceived data base. Players, however, would not directly interact with the computer. This design met the Phase 1 design objectives in that it closely approximated the existing manual system and would therefore allow experimental psychologists to examine human behavior within the desired environment. The introduction of the Phase 2 requirements for modeling variant human behavior and for reducing the populated modular boundaries has forced the examination of the design from a TOS-like perspective. Specification of automatic routing of transmitted as well as received messages within simulated staff modules, as defined in the staff action categories of Section 3, will now permit the reduction of the boundaries around a populated module and thus increase the economy of operations⁵. Under such a mode, the players will now be directly involved with the computer.

This idea has grown out of the Phase 2 requirements and has provided significant insight on how to achieve the objectives of an ADP assisted command and control system. It leads to the following conclusions:

- That a common data base does not, without special processing, provide information in a structure that is of immediate utility to a variety of users such as that represented by a division staff.
- That the information contained in the common data base should be manipulated by the computer and displayed to the functional user in a manner that is of immediate utility to him.

⁵ Although this boundary reduction is technically feasible, the credibility and realism of the simulation may suffer. This trade-off will be addressed further in Section 5.

The "files/display" boxes of Figure 4-2 are a representation of this design philosophy and as such the design will facilitate the simulation of an ADP assisted command and control system. The design and design alternatives presented throughout the remainder of this report will adhere to this section data base concept.

4.1.1.2 Computer Implementation of Simulated Staff Processing

A large part of the Phase 1 report was directed at the cost-benefit trade-offs that were implied if computer assistance were used to implement different elements of the basic design. The discussion began by considering the size and organization of the total body of data on which the exercise of the battle simulation would be based. It was then shown, on the basis of these data structure requirements, that an effective tool for research, development, and training could be developed using the computer (1) to set up the exercise and (2) to assist in the timing and the pursuit of the research objectives while the exercise was running. The first of these functions was embodied in a three-stage preprocessing system which lead to a SCENARIO File. The second function was handled by an interactive executive control routine (IECR) which read the SCENARIO File and then embarked on the dynamic portrayal of the combat situation. The two software packages, as well as the file that bridged between them, were based on the common data structure conceived for the overall system.

The five major data groups contained in the required data structure were as follows:

- Real World Data Base
- Blue Perceived Data Base
- Red Perceived Data Base
- Event Table
- Message Format Specifications and Data Element Dictionary

These data groups were estimated to take up 316,000 bytes of data space in the computer. The data space requirements, along with the instruction space requirements, provided the basis for formulating the cost-benefit judgements.

It should now be clear that the Phase 1 data structure omitted the data space requirements for the section data bases. Prior to this second study, it was tacitly assumed not only that the simulated staff modules would operate like idealized division staff elements but also that they would, where required, make reference, not to their own section pool of information, but to the unaggregated tactical information in the perceived data base. In the original concept, section data bases were defined as the section files/displays used by live staff modules and located entirely outside the computer.

The discussion now turns to the question of computer-stored section data bases. Should the basic data structures of the simulation software be expanded to include a sixth major data group covering section data bases? The software design already contains two data bases: the Real World Data Base and the Perceived Data Base. It will now be shown that the incorporation of a third data base (consisting of five separate section data bases) will provide a more realistic portrayal of the tactical information flow as well as the simulated staff processing, but will require significantly increased software development as well as expanded preprocessing functions devolving on the investigators/controllers. The division-level battle simulation can be built without the third data base, but the simulated information flow and the simulated staff activity in this framework will exhibit subtle discrepancies in the tactical information messages and tactical data displays presented to the live players. Because this development/realism trade-off is ARI's prerogative, the logical design material presented in the next subsection will be found to be approached from two separate points of view: first using the expanded data structure containing the third data base and then using the more limited framework without computer-stored section data bases.

The principal reason the third data base will improve the simulated staff processing and the information flow in the model is that it will represent the "state of the battle" information held at any moment by the division staff. If the model is exercised assuming a manual staff system, the body of information held by the staff will consist of five separate section data bases, each containing tactical data organized and filed according to the particular functional requirements of the staff section. If the model is exercised assuming

an ADP-assisted command and control system, the same body of information will represent the common tactical data base associated with the field computer system. The common tactical data base may be partitioned with respect to the separate staff section functions and will always be accessed and/or updated by the separate sections according to the rules and data organization specified for the field ADP system. When emulating either a manual mode or an ADP-assisted mode, however, the third data base will be subject to changes in its state of the battle information only through discrete occurrences of Class 1 events (staff processing operations) or Class 2 events (staff coordination exchanges). Any individual item of tactical data in the data base will remain at its unmodified value or setting until it is updated or changed by a specific action performed by either man or machine in the division staff system. For example, if the G3 section files the latest SITREP received from the first brigade, the entire tactical data contents of the report will remain unchanged in the data base until superseded by the receipt and filing of the next SITREP from the same brigade.

In contrast to this, the perceived data base will be changing dynamically throughout the simulated combat. With each occurrence of the Class 5 events related to the on-going intelligence gathering and status reporting activity in the BOG, individual data items in this data base will change continually in a manner almost entirely independent of the actions taken by the personnel or machines at division headquarters. In the example above, the tactical data contents of the Brigade SITREP sent to the G3 will correspond to the situation data in the perceived data base only for the moment in time at which the Class 4 event occurs. Ten minutes later, or five hours later, the same situation data items will have changed in the perceived data base while the material in the SITREP on file with the division staff will remain unchanged.

This property of the third data base is important in the realistic simulation of staff processing because several elementary staff operations (e.g., RETRIEVE and SYNTHESIZE DATA) involve the accessing of tactical data already on file in the data base. The added data base can emulate either the section files/displays used by a manual staff system or the common tactical data base contained in a field computer system. The "state of the battle" information held in this body of data will be subject only to the manipulations stemming from staff operations.

There are other, lesser advantages to incorporating the third data base. Under a manual mode of staff operations, one of the

basic problems was shown to be the inevitable divergence that developed between different section files/displays during the course of combat operations. These tactical data discrepancies arise because of human errors that occur in the coordination processes between staff sections. By using suitable software data organization, the third data base can provide a means to measure this divergence as it develops in an exercise of the model.

The third data base can also be used in a special manner wherever one or more of the staff modules are populated as staff sections under a manual system. The actual section data bases of these teams will consist of the filing cabinets, display boards, and situation maps the players will use and maintain during the exercise. The software section data bases, which would ordinarily not be involved in the play, could in fact be maintained in parallel by the computer and provide thereby a comparison standard for the real section files/displays outside the machine. With a live G3 module, for example, the Front Line Trace could be compared at the end of the run against a printout from the third data base.

Under an ADP-assisted staff system, the third data base will facilitate the generation and formatting of the alternative tactical data displays used by live staff modules. It will also facilitate the use, by either populated modules or simulated modules, of alternative sets of access and update rules that might be specified for the automated command and control system. These implications of the added data structure are developed further in Section 5.

The cost of third data base, in terms of the added software development and the extended preprocessing functions, can be summarized as follows:

- The added data space requirement for the sixth major data group is estimated to be 100,000 bytes. This makes the overall requirement 416,000 bytes.
- The software data organization of the new data base will have to be hardwired in the computer programs. For manual mode applications, the section data base subdivisions will have to be tailored to the separate

areas of responsibility of the different sections. For ADP-assisted mode applications, the rules for accessing/updating the common tactical data base will have to be based on the software design of the field computer system.

- The preprocessing functions in preparation for an exercise of the battle simulation will have to include the added task of initializing the third data base. This task is visualized as being incorporated in the Phase II Preprocessing Program. The initialization would ordinarily be made consistent with the Blue Special Situation and the research objectives set forth for the exercise.

4.1.2 Human Errors in the Staff Processing

A second refinement is now made to the picture of the tactical information flow in the battle simulation. This refinement delineates those segments of the flow cycle where the separate classifications of human errors become involved.

The second modification to the information flow diagram is shown in Figure 4-3. The figure now shows that data errors and procedure errors can occur at any point between the receipt of a tactical information message by the staff module and the end of the staff processing when the module transmits its decision to the appropriate addressees on the battlefield. The figure also shows that cognition errors can occur only during the second stage of the processing where the decision-maker himself performs the higher level operations on the tactical information. The segments of human error involvement are based on the points-of-occurrence material from paragraph 3.3.

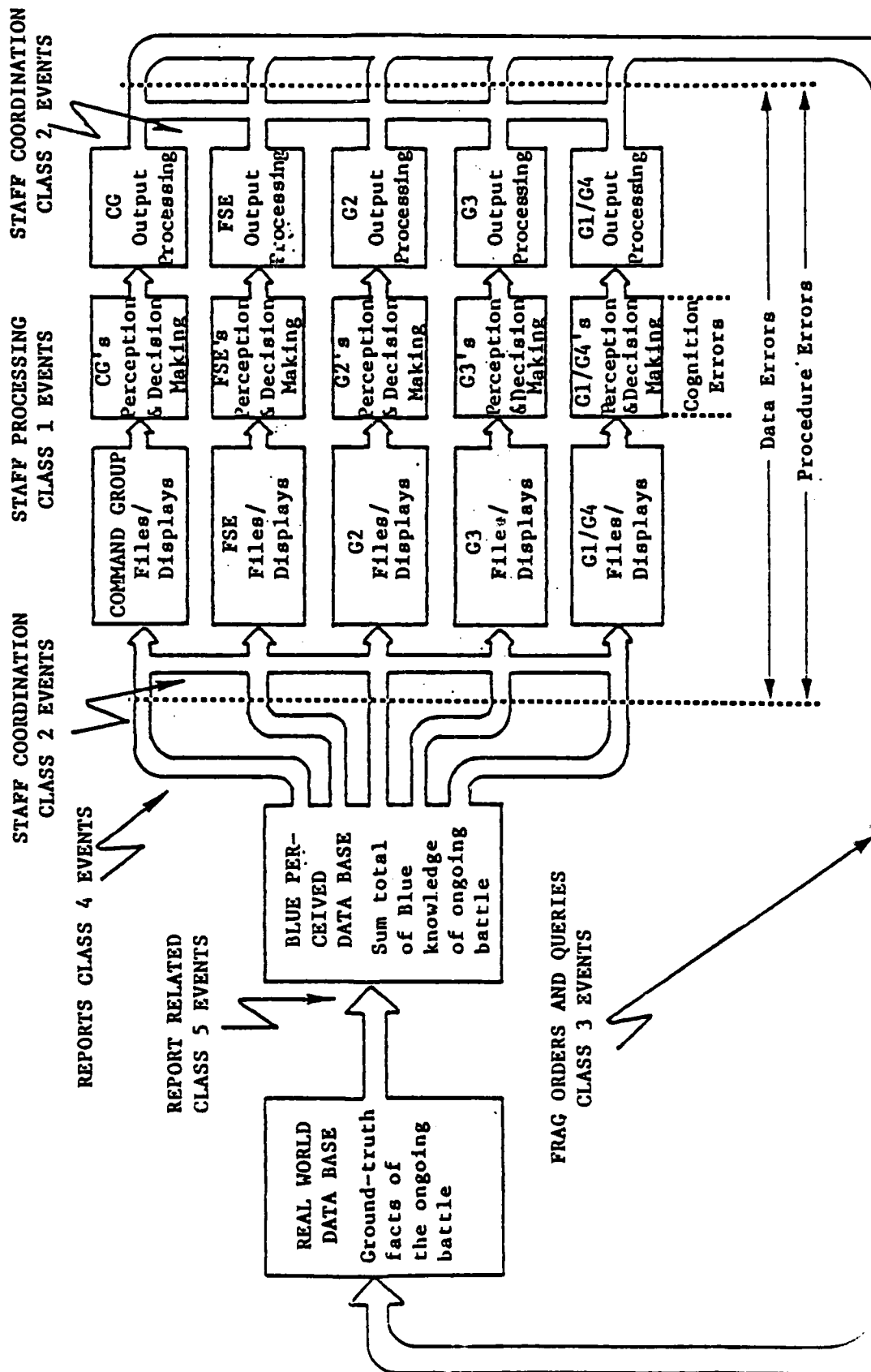


FIGURE 4-3. TACTICAL INFORMATION FLOW SHOWING HUMAN ERROR REGIMES

The areas of error involvement given in the figure should be interpreted as the areas where error effects can occur with some non-zero probability. The arrows should not be taken to mean that the probability is uniform from one end to the other. It will be shown later in this section that the simulated occurrences of human errors to be incorporated in the simulated staff modules will be based insofar as possible on calculated probabilities which change from one processing step to the next in accordance with the three factors given in paragraph 3.3.2. The indicated regimes denote some non-zero probability of occurrence; the actual probabilities will vary from step to step in the simulated staff processing.

It should also be noted that Figure 4-3 exhibits for the first time the interface boundaries of the staff modules. The boundaries are the dotted lines coincident with the beginning and the ending of data and procedure error effects. They represent the base-line boundary locations delineating the entire staff processing event sequence shown in each of the staff procedure categories in Section 3. The ability to relocate the boundary positions so that the live staff modules encompass only a selected portion of the staff procedures is the subject of the next section. Under the base-line locations shown, the live staff procedures now include all the low-level, repetitive operations which may serve to detract from the desired thrust of some behavioral research experiments.

4.2 CLASS 1 EVENT LOGIC

The discussion thus far has taken the two areas: (1) human errors in command and control and (2) the detailed structure of division staff processes, and merged them, in order to focus on the behavioral research experiments that might be run using the Integrated Division-Level Battle Simulation. The preliminary material in this section, furthermore, has served to sharpen the focus by showing where and how substandard human performance perturbs the tactical information flow cycle in a combat situation. This subsection now shows how, in the framework of the complicated structure, the computer can be made to simulate the staff processing in such a manner that the investigators/controllers may control the incidence of substandard staff performance in simulated modules. With a research tool of this kind, where the investigator can manipulate the simulated staff performance that is part of the environment the live players will face, a wide range of behavioral experiments can be run.

The key element in this kind of model is the logical structure of the Class 1 events. Class 1 events were identified in

the original Phase 1 design as the staff processing occurrences within the individual simulated staff modules. The list of such events has now been completed and the structured sequences making up the different categories of staff actions have been specified in Section 3 of this report. The level of detail with which the simulated staff processing will be treated has also been fixed; Class 1 events represent elementary staff operations performed by one person. The discussion now shows how the computer logic for these events should be approached in order to provide the flexibility of control required above.

4.2.1 Principles of the Approach

The proposed general approach to Class 1 event logic is to develop algorithms oriented to the individual information-processing or decision-making operations performed by human beings. The algorithms will make reference to, and operate on, selected items of tactical data from the input message, the section data base, and/or the Blue perceived data base, in accordance with definitions of the elementary operations. The algorithms will also inject human data and procedure errors (but not cognition errors) on a chance basis, governed by sets of computed probabilities that will depend on the nature of the individual operations, the nature of the data, and the workload environment at the time. The probability calculations will contain a control factor that is set by the investigator/controller prior to the exercise. The control factor will allow the user to preset the incidence of occurrence of data and procedure errors, but not to pinpoint the operations or times at which they occur.

This kind of logic in the Class 1 events will serve adequately in simulating the low level staff processing operations and even certain sequences of decision-making operations where the human decision-maker's perception of the problem and his decision alternatives are more-or-less routine. The logic is clearly inadequate and incomplete, however, for simulating the higher level decision-making operations when the decision-maker is faced with a complex command and control problem. The computer, even if it used new artificial intelligence techniques, cannot be programmed to model such processes of the human brain as generation of a perception of the situation, hypothesizing the missing elements in a pattern or picture, synthesizing the weighting factors associated with a set of

alternatives, or selecting the best course of action. The autonomous algorithms described above, at least for some of the higher level staff processing operations, must provide some kind of mechanism for letting the investigator/controller intervene and direct the cerebrations of the simulated staff officer.

The general approach to Class 1 event logic, therefore, will be based on separate, self-contained routines for each defined event, but with the added feature in certain sequences for triggering the interactive participation of the investigator/controller to guide the decision-making operations. Thus the approach will divide the Class 1 events into two subclasses as follows:

- Class 1A Events - those events in which the simulated operation is explicitly represented and includes the chance occurrence of data errors and procedural errors.
- Class 1B Events - those events which will function like Class 1A events unless the tactical importance of the staff action calls for controller intervention. If controller intervention is signalled, then the simulated operation will be effected by interactive input from the controller.

These subclass distinctions provide the basis for the more detailed discussion presented in subsequent paragraphs. The approach, however, involves two basic operational features in the model that bear on its essential cost-effectiveness as a research tool for behavioral experiments. The first is the Monte Carlo technique to be employed in the random occurrence of human errors. The second is the trade-off that exists in using controller intervention as the means to simulate staff processing in the simulated staff modules. These features are discussed before the logical structures of Class 1A and 1B events.

4.2.1.1 Monte Carlo Technique for Human Error Occurrence

The Phase 1 design placed considerable emphasis on the capability of the model to provide "the basis for repeated exercises

of the same experiment, carried out under identical conditions but using different human players." The battle simulation had to present the same division-level combat situation to successive teams of players whether the exercise was oriented to a behavioral research experiment, to a combat developments application, or to a training problem for division staff personnel. This "repeatability" requirement was largely satisfied through the proposed use of the SCENARIO File which was a permanent information storage medium such as a magnetic tape or computer disk and on which was recorded not only the fully initialized real world data base and Blue and Red perceived data bases but also the input control parameters consistent with the specific objectives of the exercise.

The introduction, here in this study, of the idea of Monte Carlo techniques to control the incidence of human errors in the simulated staff processing presents a problem in maintaining the repeatability of experiments. If a random number generator is used to "roll the dice" with respect to the occurrence of human errors, how can the model be made to present the identical occurrences in the same simulated staff actions in successive exercises? Most Monte Carlo simulations are structured so that successive runs of the computer program provide different results, and the overall result must be derived from the statistical ensemble of many separate runs. On the other hand, here in the battle simulation it is required that the pattern of random human errors in the simulated modules be repeated in successive exercises.

According to the general approach described above, each Class 1A algorithm will contain a random number test for possible occurrence of a data or procedural error. The test may be expressed as:

$$R_n \leq P_e$$

where R_n is a random number between 0 and 1, and P_e is the computed probability.

If the test is successful, the algorithm will invoke the appropriate error effect. A data error will inject a selected item of erroneous or misleading tactical data. A procedural error will lengthen the simulated time interval for the completion of the elementary operation.

If the test fails, the algorithm will simply reflect no occurrence of the human error.

The requirement for repeatability of experiments means that the "throw of the dice" given by the random number R_n must be the same in successive exercises so that if the simulated module encounters the same staff processing sequence for the same input tactical message it will reflect the same pattern of errors. Of course, the computed probability P_e can in principle be influenced indirectly by the live players and thereby modify the pattern of errors. For example, a live staff module could stimulate the "paper mill" processing actions of the simulated module and increase its workload. Since the workload experienced by the simulated section is one of the factors governing the calculated probability, the random number tests would reflect a different pattern. But insofar as the random number phasing is concerned, the battle simulation should continue to provide for the repeatability of exercises based on the same SCENARIO File.

4.2.1.2 Controller Intervention

The Phase 1 design introduced the idea of controller intervention by stating that "there will always be certain Class 1 events and Class 5 events in which the controller(s) must intervene in order to supplement the logical rules of the simulation or to influence the onslaught of events on a populated staff module. These Class 1 or Class 5 events are therefore further qualified as release events, because the controller(s) must execute their release, that is, complete the intervention on or before the time of occurrence as measured on the simulated clock."

"Controller intervention by means of release events is one of the key features of the model. Although some types of release events are simply a convenient means for handling certain kinds of staff inputs to populated modules, the basic reasoning behind most release events is as follows:

- Release events provide a means for the investigator/controller to influence the play in order to direct the exercise toward the research objectives.
- Release events provide a means for a human being to provide certain processes such as terrain analysis, identification of routes of advance, etc. which would otherwise call for much larger computer data requirements.

- Release events provide a means for the controller(s) to invoke military judgement in certain parts of the simulated battle.

The implementation of release events will begin by identifying all those occurrences among the Class 1 and Class 5 events where controller intervention is required. Provision must then be made that the progenitors of these events trigger the pending action warning to the terminal operator. Each identified release event must then be provided with its own formatted screen and edit/update routine through which the terminal operator will enter the requisite data for release."⁶

Thus the Phase 1 design anticipated the requirement for controller intervention in the higher level decision-making operations in the simulated staff modules. The Class 1 events in which the controller must intervene are the Class 1B events discussed below.

The central problem with release events, however, lies in the overall burden of control functions that must be carried by the controller(s) during the running of exercises. In order for the basic design to be directed toward a cost-effective research tool, the Phase 1 report stressed the idea of minimizing the control functions so that exercises could always be managed and directed by no more than two qualified personnel. Release events represent a particularly stressful part of the controller's responsibilities because the interactive release of the events is subject to the timing requirements established by the event-oriented computer routine. Under a real-time exercise, for example, the controller would be required to effect the release of the engagement cycle event (no. 508) every 15 minutes for each separate combat engagement on the battlefield. Each such release might require input data reflecting the routes of advance or withdrawal of the opposing forces tailored by the controller's military judgement of the situation.

Now, under this general approach to simulated staff processing, the controller(s) will also have to effect the release of Class 1B events whenever the computer determines that the tactical importance of the action is critical to the simulated outcome. Although the trigger thresholds for determining the decision-making

6 Op cit, Division-Level Battle Simulation, pg. 4-61.

release events will be adjustable through input data, the controller(s), during an exercise, will necessarily rely on the pending action warning associated with release events, because, unlike the cyclic pattern of engagement events described above, the timing of the Class 1B events will not be easily anticipated.

4.2.2 Class 1A Events

Class 1A events are staff processing events that simulate the execution of individual elementary operations. Their logical structures will represent explicitly the information processing and decision making operations performed either by human beings (as in a manual staff system) or by field computer (as in an ADP-assisted system). The separate algorithms will operate on the tactical data associated with the input message, the section data base, and/or the Blue perceived data base, and will simulate the amount of time necessary to complete the operational step. The algorithms will also employ the random number tests for the chance occurrence of data errors or procedure errors as described in paragraph 4.2.1.1.

There will be a separate algorithm for each Class 1 event listed in Table 3-3.

Those algorithms associated with Level V and VI operations will contain additional logical structure which will determine whether the staff action involves a sufficiently significant departure from normal routine to warrant controller intervention. Such events, of course, are Class 1B events. The controller's intervention to substitute for the decision-maker's cognitive processes is discussed further below. But if the logic determines that the Level V or VI operations are more-or-less routine in nature, then the remainder of the algorithm is just like that of a Class 1A event.

The distinction between Class 1A events and Class 1B events is illustrated in Figure 4-4. This figure is a macro logical flow diagram of the algorithm for Event 150 - EVALUATE IN CONTEXT. The elementary operation is a Level V in which the decision-maker determines whether formal staff action is required at the time (i.e., event time) when he first becomes aware of the input message. The elementary operation can be seen to be part of Staff Action Categories 1, 2, and 3 (Figures 3-2, 3-4, and 3-5). In these event threads there are two possible outcomes from the execution of the operation: either formal staff action is initiated or else the action started by the receipt of the input message is terminated.

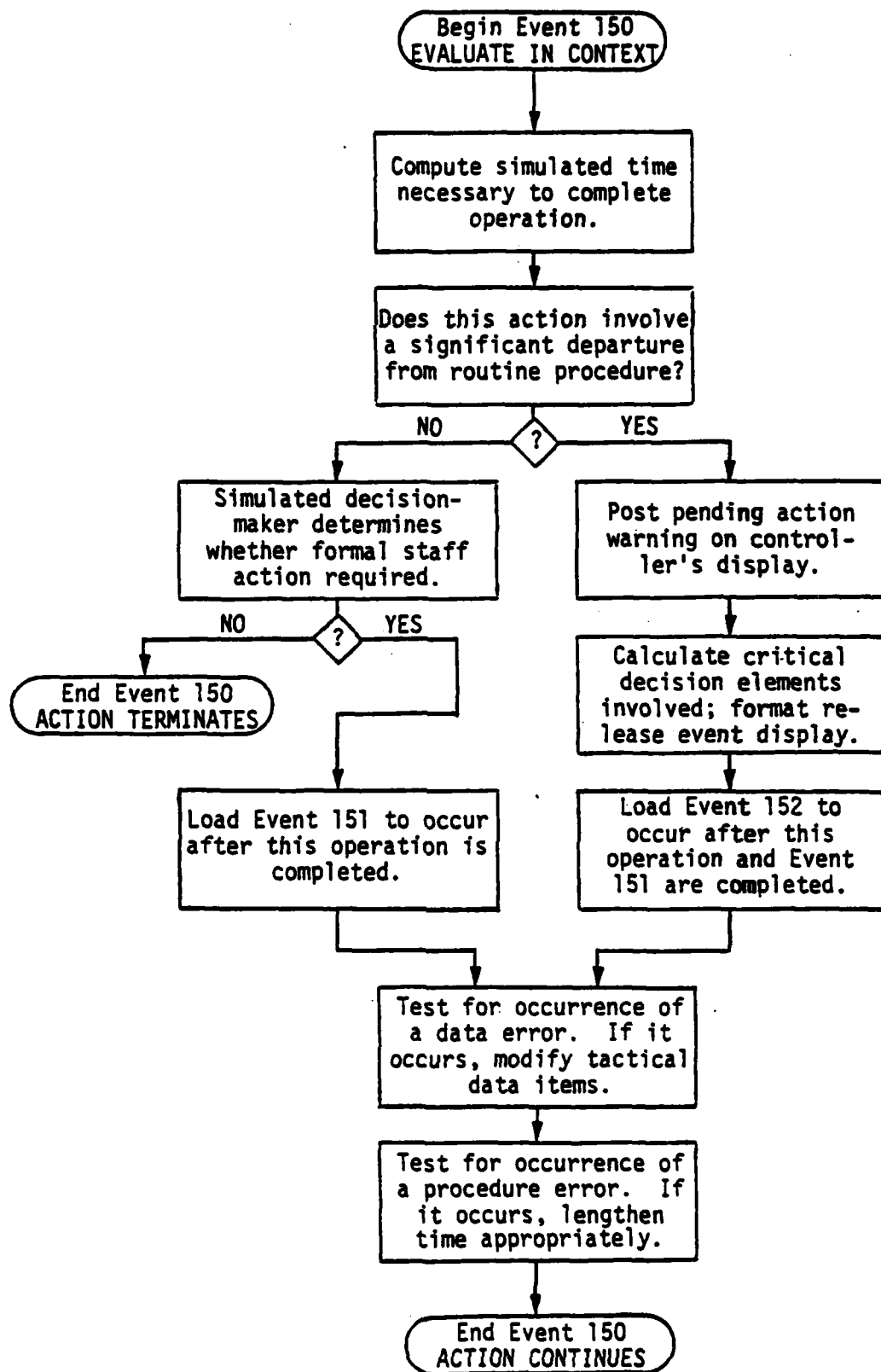


FIGURE 4-4. LOGICAL FLOW DIAGRAM OF EVALUATE IN CONTEXT

EVALUATE IN CONTEXT is a Class 1B event because there are, in all three categories, input tactical messages spelling out significant departures from routine staff activity. Examples are as follows:

- In Category 1: G2 receives an NBC Report.
- In Category 2: G3 receives a retransmitted copy of a Combat Intelligence Report.
- In Category 3: G1/G4 receives a non-concurring chops response from G3.

In each of these staff actions the cognitive processes required of the simulated decision-maker must be provided through controller intervention.

In the diagram, the logical flow on the right-hand branch is the added structure provided in a Class 1B event. The left-hand branch, and the remainder of the boxes are the required structure for all Class 1A events.

One important logical property should be noted in the algorithm for EVALUATE IN CONTEXT. If the computer decides that the tactical importance of the action calls for controllers intervention, the determination of whether formal staff action is required becomes automatic. The simulated decision-maker will always "decide" on immediate formal staff action whenever the action is more than routine staff processing.

4.2.2.1 Using Computerized Section Data Bases

The discussion above makes clear that all Class 1 events will be implemented by computer routines containing the required, Class 1A logical structures. Only a small number of the routines will possess additional Class 1B logical structures providing the automatic switch for controller intervention to substitute for the decision-maker's cognitive processes. The question now arises; how will the Class 1A logical structures operate if the simulation software provides for section data bases? As stated in the last subsection, section data bases are the bodies of information in the separate staff sections from which the decision-makers generate their

perceptions of problems and ultimately base their tactical decisions. Each staff section organizes its section data base according to its own area of functional responsibility. In a manual staff system, a section data base consists of the filing cabinets, tote board displays, situation maps, etc., all organized (and used) according to particular area of responsibility of the staff section. Now suppose the simulation software provided computer files that were organized and filled with tactical data in a manner emulating a real staff section under a manual mode. How, in this framework, would the simulated staff modules work?

The simulated staff processing using the third data base will be based on Class 1A logical structures which will explicitly modify, update, and retrieve tactical data in the section data bases according to the definitions of the elementary operations. This means that those operations associated with putting data into the section data bases will explicitly add more tactical data items or else update existing items; and those operations associated with data extraction will explicitly read the data from its appropriate computer file. The operations related to the former are hereafter called update operations. They are as follows:

- Event No. 125 ENTER
- Event No. 126 FILE
- Event No. 133 POST or PLOT

These are the only operations in which data are put into the section files/displays*. The second and third items in the list involve a wide variety of different data repositories across the five staff sections. The operations involved with data extraction are hereafter called retrieval operations. They are as follows:

- Event No. 134 RETRIEVE
- Event No. 141 COORDINATION COMPLETE?
- Event No. 150 EVALUATE IN CONTEXT
- Event No. 151 SYNTHESIZE DATA

These are the only operations in which data are read out of the appropriate repositories*. The remainder of the operations may involve manipulation of tactical data from input messages, or data items already extracted from the section data base, or simply procedural rules to be followed in staff processing; they do not involve the explicit update or retrieval of data from the third data base.

* The reader is reminded that this section treats simulated staff modules only. In populated modules the cognitive elementary operations may involve additional access to files.

4.2.2.2 Without the Section Data Bases

If the software design does not provide computer files for the third data base, the Class 1A logical structures for the update and retrieval operations will have to be set up in a different manner. The update operations will not involve the explicit placement of data items in an appropriate data repository; instead the algorithm will simply mark time to simulate the time necessary to complete the operation. The tactical data items contained in input tactical messages will already be resident in the perceived data base at the times the messages are received by the staff. The tactical data items constituting the staff output frag orders will be lost in the sense that after the frag orders have been transmitted to the addressee(s) in the BOG, there will be no repository of data representing the file copies of issued orders.

The retrieval operations will have to access tactical data from the perceived data base. Without a third data base, the only body of information that can represent the section files/displays is the body of unaggregated tactical data in the second data base. Although the algorithms can be structured so that they aggregate (or reaggregate) the tactical information according to the retrieval format requirements, the information in the perceived data base may very likely have changed at the time of retrieval. As stated in paragraph 4.1.1.2, the perceived data base will change dynamically throughout the simulated conflict in a manner more-or-less independent of any actions taken by the personnel (or machines) in the division staff. Simulated staff processing under this stilted framework can be illustrated by the following vignette:

At 1000 hours, the G3 receives a SITREP from the first brigade. After noting that there are no significant changes in the first brigade situation, he files the report so that it may be used when the Division SITREP is to be prepared. The update operation FILE is simulated by marking off a completion time of one minute without any explicit transfer and storage of tactical data. At 1130 he embarks on the preparation of the Division SITREP. In synthesizing the data for the report, he withdraws from file the brigade SITREP received at 1000 hours. The retrieval operation SYNTHESIZE DATA is simulated by accessing the perceived data base and reformatting the first brigade SITREP from the tactical data. However, the precise contents of

this reconstructed report may not be the same as that received at 1000 hours. During the intervening 90 minutes of simulated combat, the data of the perceived data base could reflect a considerable difference in the situation for the first brigade. While one might conclude that the reconstructed report represents an improved basis for preparing the Division SITREP, the updated situation report actually represents a distortion of reality in the simulated staff processing.

4.2.3 Class 1B Events

The Class 1B logical structures will provide the mechanism which allows the investigator/controller to intervene and substitute for the decision-making operations in a simulated staff module. The mechanism will consist of three parts, as follows:

- Discrimination logic to determine whether the staff action involves sufficient departure from routine to warrant controller intervention.
- A means to display a pending action warning for the controller. This warning must be posted some five or ten minutes before the release event is scheduled to occur.
- A routine providing interactive data entry procedures by which the controller effects the release of the decision made by the simulated decision-maker.

The first two parts of the mechanism as well as certain preparatory aspects of the third are illustrated as macro logic boxes in Figure 4-4.

Class 1B logical structures will encompass a slightly different thread of Class 1 events in each of the seven staff action categories. Category 5 Actions (Figure 3-7) will never involve controller intervention at all. In each of the remaining categories these will be three events delineating the sequence of decision-making

operations that the controller will direct. The first event is the "trigger" event which contains the discrimination logic and which posts the pending action warning for the controller if intervention is required. The second event is the release event itself whose release must be effected by the controller on or before the time of the event. The third event is the last decision-making operation in the sequence before the simulated processing reverts back to wholly Class 1A logic structures. Table 4-1 identifies the three events for each of the relevant staff action categories.

The general requirements for the controller's release routine will involve special edit/update software and special formatted display screens. A trade-off will exist between the human engineering requirements for simple keyboard procedures and the limited display screen size and core space in the computer. The information displayed to the controller when he must release a decision will have the following special requirements:

- It must show the staff action category and type of tactical message that has triggered the decision-making.
- It must show the critical decision elements which the decision-maker is addressing.
- The critical decision elements must reflect all the data errors that might exist in the decision-maker's perception.
- It must show the alternative procedural choices open to the decision-maker. For example, in the formal staff processing of a tactical message from the BOG, there are three alternative procedural choices in the decision-maker's operation EVALUATE DATA.
- It must provide for the insertion of a cognition error.
- It must provide for the keyboard entry of the selected action.

TABLE 4-1.

CLASS 1B LOGICAL STRUCTURES IN THE STAFF ACTION CATEGORIES.

Staff Action Category	"Trigger" Event	Release Event	End of Sequence
1	Event No. 150 EVALUATE IN CONTEXT	Event No. 152 EVALUATE DATA	Event No. 165 SELECT ACTION
2	Event No. 150 EVALUATE IN CONTEXT	Event No. 152 EVALUATE DATA	Event No. 165 SELECT ACTION
3	Event No. 150 EVALUATE IN CONTEXT	Event No. 152 EVALUATE DATA	Event No. 165 SELECT ACTION
4	INITIATE BY SELF	Event No. 152 EVALUATE DATA	Event No. 165 SELECT ACTION
5		(none)	
6	Event No. 100 INITIATE BY CLOCK	Event No. 152 EVALUATE DATA	Event No. 154 EXTRAPOLATE SITUATION or Event No. 165 SELECT ACTION
7	Event No. 151 SYNTHESIZE DATA	Event No. 154 EXTRAPOLATE SITUATION	Event No. 154 EXTRAPOLATE SITUATION or Event No. 165 SELECT ACTION

The limited screen size and the short period of time the controller will have to execute the release of the decision will preclude the display and provision for the enumeration of action alternatives and the evaluation criteria to be used in the action selection. The controller will have to assimilate these aspects of the process from his knowledge of the on-going simulated conflict.

4.2.3.1 Cognition Errors

Unlike data errors and procedure errors, both of which will be simulated by means of a Monte Carlo process, cognition errors will be simulated by explicit keyboard insertion during the release of a decision. The frequency of occurrence of such errors as well as the substantive meaning in terms of the wrong decisions drawn by the decision-makers will be handled entirely as part of the controller's intervention.

As a consequence of this logical structure, simulated staff processing will accommodate the occurrence of a cognition error only if the action involves critical tactical questions alling for a release event. Simulated cognition errors will never occur in more-or-less routine staff actions involving Class 1A logical structures by themselves.

4.2.3.2 Internally Initiated Actions

Category 4 Actions, as described in paragraph 3.2.1.4, are actions that are spontaneously initiated by a senior staff officer because he holds a perception of the situation or problem in his mind and is spurred to act on it at once. In simulated staff modules Category 4 Actions will be triggered by the elementary operation INITIATE BY SELF. INITIATE BY SELF will require special treatment beyond that described above for Class 1B logical structures. In order to simulate internally initiated actions, the controller will be required to insert the event but without any prior timing guidance from the simulator. The computer software cannot be made to anticipate the moment "when the light comes on" in the mind of the simulated decision-maker. Consequently, the triggering by the controller will require data entry of both the timing of event (when does the decision-maker initiate the action?) and the subject matter (what is the problem he is addressing?). It is assumed that such

entries will always be made in the dynamic framework of the event progression observable by the controller and with the basic objectives of the exercise firmly in mind.

4.3 CONCLUSIONS ON SIMULATED STAFF PROCESSING

On the basis of the considerations brought out in Section 2, Section 3, and the preceding discussion of this section, it is concluded that the first added design requirement of this study, namely, to structure the simulated staff modules in the model so that they can accommodate variant human staff performance is achievable with certain qualifications. Software can be developed that will simulate the staff processing in the event thread framework specified by the staff action charts in Section 3. These routines can be tied to certain input parameters that will provide (1) investigator control of the simulated human staff performance and (2) investigator control of the simulated staff response times. The first set of parameters will allow behavioral scientists to establish the human performance environment for the live players in populated modules; the second set will allow the model to be exercised either under a manual staff system or else in a staff system using ADP assistance.

The salient operational characteristics of simulated staff modules are presented below, first for a manual staff system and second for a staff system provided with ADP assistance. The qualifications attendant on these conclusions follow thereafter.

4.3.1 Simulated Staff Processing in a Manual System

The simulated staff modules can be made to operate with the following properties for a manual staff system:

- Realistic time delays for each elementary operation. The median time delays may be preset by input parameters.
- Random occurrences of data errors and procedure errors, governed by other input parameters.

- Normal coordination and review responses if the populated modules make errors in their staff actions.
- Investigator/controller intervention (with release events) whenever the simulated decision-maker must address important tactical decisions.

4.3.2 Simulated Staff Processing in an ADP-Assisted System

The simulated modules can be made to exhibit the following properties for an ADP-assisted staff, based on the same software structures:

- Realistic time delays for each elementary operation but with rapid responses for machine operations and slower responses for those operations still performed by human beings.
- Random occurrences of data errors and procedure errors but only for those operations performed by personnel.
- Input, output, coordination, and review processes will be largely automated, but the simulated modules will exhibit normal responses if the live modules make errors in their staff actions.
- Controller intervention as described above.

4.3.3 Qualifications

The following qualifications are associated with this approach to simulated staff processing:

- Insufficient data have been found to exist for the relative frequencies of occurrence of the three types of human errors.

- Insufficient data have been found for human performance times on elementary operations involving ADP terminal devices.
- The discrimination logic necessary to determine whether controller intervention is substituted for the simulated decision-maker has not been fully designed.
- The critical decision elements associated with a controller-inserted decision have not been fully identified.

The lack of applicable error analyses may well be a blessing in disguise in that it forces the simulation design to accommodate a wide range of error frequencies. This means the behavioral researcher will be provided with considerable flexibility for studying human error effects. The model may become a vehicle for accumulating a body of needed data on human performance in staff information processing. The discrimination logic and the associated decision elements will require additional work. They will be addressed in more detail at a future date.

SECTION 5

CHANGING THE INTERFACE BOUNDARIES

5.0 INTRODUCTION

This section presents a trade-off analysis of alternative configurations for a simulation of command and control processes. The alternative configurations are based on different specifications of the interface boundary in a populated staff module between the human players and the simulator. The analysis is oriented to the second design requirement of this current effort. The requirement, as stated in Section 1, is as follows:

Is it feasible, in the interest of economy of operations and player motivation, to vary the interface boundaries of the staff modules? This will allow the controller/investigator, in some experiments, to eliminate certain repetitive, low-skill procedural tasks (e.g. answering radios or telephones, transmitting messages, routine filing, etc.) from the live staff procedures.

The trade-off considerations cover four specific trade-off areas: (1) the realism of the staff operations performed by players, (2) the ability to measure player performance in the framework of the stated objectives of an experiment, (3) the cost of running experiments (in terms of the number of players and controllers involved), and (4) the cost of implementing the configuration (i.e., the computer hardware/software).

The section begins by specifying six different configurations of the simulation where the interface boundary covers different sets or sequences of elementary operations in all the staff action categories developed in Section 3. For the purposes of the organization of the analysis, the configurations are labeled with different letters of the alphabet and are specified by identifying the elementary operations that occur right at the interface between player and simulator. Two tables are presented: the first shows what the interface operations might consist of (e.g., field telephones, radio net stations, TTY, keyboard data entry, electronic display, hard copy printer, etc.); the second shows the formal definitions of the six selected configurations.

The section then develops the four trade-off areas. The essential cost-effectiveness of a simulation for behavioral research applications is clearly related to how well the system can set the stage for an experiment and then measure the performance of the staff players in terms of the experimental objectives. The cost effectiveness

is also dependent on the total number of people (i.e., players plus controllers) required under the configuration as well as the hardware/software requirements. The discussion on trade-off areas culminates with a table of paragraph references for the detailed discussions.

The section then presents the detailed arguments leading to the trade-off judgments. The judgments are ultimately expressed in terms of simple 1-word or 2-word trade-off ratings such as GOOD, FAIR, or POOR.

The section is concluded by an analysis summary table showing the trade-off ratings for each configuration across the four areas. The table also repeats the paragraph references for the detailed discussions. The concluding material also mentions one aspect of the variable interface boundary question not reflected in the trade-off analysis. This is the hardware/software implications of providing the capability to switch from one configuration to another in a system used for alternative behavioral research experiments.

The analysis summary table in this section forms the basis for the principles of task design developed in the companion volume, Some Guidelines for Effective Task Design in Command and Control Simulations.

5.1 ALTERNATIVE CONFIGURATIONS

The preliminary discussion on variable interface boundaries (paragraph 3.2.2) described two extreme boundary locations for the populated modules. The first of these was specified as the left margin/right margin of the staff action event thread charts; it encompassed all defined staff operations (Figures 3-11 and 3-12). The second was the boundary location that reduced the staff module to that of a single player who acted alone as the senior staff officer and decision-maker.

All intermediate boundary locations must be somewhere between these extremes. The delineation of an individual intermediate location, however, should be specified by a method different from that used for the two extremes. Instead of drawing the interface boundary line (as illustrated for one extreme location in Figures 3-11 and 3-12), intermediate configurations should be specified by identifying all the elementary staff operations where a player will interface with the computer and/or controller(s).

For the purpose of this analysis, we have selected nine operations out of the 27 defined in Table 3-2 to serve as possible "interface" operations. The alternative ways that these operations can be implemented at the interface between player and simulator are given in Table 5-1.

TABLE 5-1
INTERFACE ELEMENTARY OPERATIONS IN ALTERNATIVE CONFIGURATIONS

E. O. DESCRIPTOR (from Table 3-2)	E. O. DEFINITION (from Table 3-2)	ALTERNATIVE MODES FOR INTERFACE BETWEEN PLAYER & SIMULATOR
RECEIVE (or ACCEPT)	RECEIVE: Transform oral communications received by radio or telephone into a hand written message, making one or more copies at the time. ACCEPT (subsumed under RECEIVE): Accept a hand written/printed message delivered by a courier.	(1) Player copies telephone message, copies radio message, or accepts message from courier. (manual system) (2) Player tears off message from TTY printer. (manual system) (3) Computer terminal indicator flashes message receipt to player. (ADP system)
TRANSMIT (or DELIVER)	TRANSMIT: Transform a hand written message into oral communications on a radio or telephone. DELIVER (subsumed under TRANSMIT): Hand over a written message to a courier or hand carry the message to its addressee.	(1) Player transmits message on telephone or radio or hands over message to courier for delivery. (manual system) (2) Player hands message to controller through a window. (manual system) (3) Player composes message by keyboard entry and then triggers the automatic transmission. (ADP system)
FILE	Place a received/generated message, or elements thereof, in the appropriate staff file.	(1) Player enters message or document by keyboard and triggers the automatic file update. (manual system or ADP system)

TABLE 5-1 (continued)

E. O. DESCRIPTOR (from Table 3-2)	E. O. DEFINITION (from Table 3-2)	ALTERNATIVE MODES FOR INTERFACE BETWEEN PLAYER & SIMULATOR
POST (or PLOT)	POST: Transfer oral or written data onto a graphic display or status board. PLOT (subsumed under POST): Transfer onto a scaled situation map.	(1) Player enters posting/plotting data by keyboard and triggers the automatic file update and playback display. (manual system or ADP system)
RETRIEVE	Withdraw a received/generated message from its appropriate staff file.	(1) Player "queries" by keyboard and evokes display of message, document, or map. (manual system or ADP system)
COORDINATION COMPLETE?	Determine whether concurring responses have been received from all sections to which chops requests were submitted.	(1) Player "queries" by keyboard and evokes display of journal entries. (manual system or ADP system)
EVALUATE IN CONTEXT	Determine whether the received message generates the requirement for formal staff action at this time. The determination may be based on the message content alone or on a trigger criteria existing for certain type messages.	(1) Player "queries" by keyboard and evokes display of original input message. (manual system or ADP system)
SYNTHESIZE DATA	Generate from the available data a picture or perception of the situation or problem.	(1) Player (decision-maker) uses RETRIEVE mode many times, as required. (manual system or ADP system)

It can be seen in the table that the RECEIVE and TRANSMIT operations can serve as interface points under three alternative modes, depending on the manual vs ADP mode and on the method employed with the former for handling staff inputs and outputs. The remainder of the interface operations (which, in fact, consist of the update and retrieval operations from paragraph 4.2.2.1) permit only one basic means for the player(s) to communicate with the simulation. These structures are assumed to be the same regardless of whether a manual or ADP-assisted system is being emulated.

Table 5-1 provides the basis for specifying six representative configurations where the interface boundary covers different sets or sequences of elementary operations in the staff actions.

Table 5-2 presents the formal definitions of the six selected configurations. The configurations are described in more detail in the following paragraphs.

5.1.1 Configuration A

With the interface boundaries set under Configuration A, the populated staff modules would be structured like, and would function in the same manner as, a full-scale corps-level or division-level command post exercise (CPX). The individual staff sections would be provided with their own staff materials, including the field telephones and radio net equipments prescribed for the section. The staff personnel would carry out their assigned operations according to standard operating procedures (SOP), including the maintenance and update of the section files/displays. The RECEIVE (1) and TRANSMIT (1) interface operations would be performed by having a "voice at the other end" provided by separate individual controllers. All battlefield information would be generated by the simulator and then displayed or otherwise communicated to the controllers.

5.1.2 Configuration B

Under Configuration B, the populated staff modules would contain sufficient personnel to cover normal staff workload requirements. The RECEIVE (2) and TRANSMIT (2) interface operations would circumvent the requirements for radio telephone operators (RTOs) by providing TTY printouts for all incoming messages and transference by hand to controllers for outgoing traffic. The most significant departure from the full treatment called for in Configuration A would be that the staff inputs would be governed entirely by the computer simulation and the staff outputs could be processed and entered by only one or two controllers.

Configuration B corresponds to the proposed implementation scheme presented in the Phase 1 design.

TABLE 5-2
ALTERNATIVE CONFIGURATIONS FOR POPULATED STAFF MODULES

Interface Boundaries for:	Interface Operations (from Table 5-1)	Player-Performed Operations	System Being Emulated
CONFIGURATION A	RECEIVE (1) and TRANSMIT (1)	All remaining operations including own file maintenance.	Manual Staff System
CONFIGURATION B	RECEIVE (2) and TRANSMIT (2)	All remaining operations, including own file maintenance.	Manual Staff System
CONFIGURATION C	RECEIVE (2), TRANSMIT (2), ENTER, FILE, RETRIEVE, COORD. COMPLETE?, EVAL IN CONTEXT, SYNTHESIZE DATA.	All remaining operations, including own displays & maps.	Manual Staff System
CONFIGURATION D	RECEIVE (2), TRANSMIT (2), ENTER, FILE, POST, RETRIEVE, COORD. COMPLETE?, EVAL IN CONTEXT, SYNTHESIZE DATA.	DECS, DIRS, COMPOSE, DECOMPOSE, and all remaining level Vs & VIs.	Manual Staff System
CONFIGURATION E	FILE, POST, RETRIEVE, COORD. COMPLETE?, EVAL IN CONTEXT, SYNTHESIZE DATA.	Decision-making operations (level Vs & VIs) only.	Manual Staff System or ADP-Assisted Staff
CONFIGURATION F	RECEIVE (3) and TRANSMIT (3), FILE, POST, RETRIEVE, COORD. COMPLETE?, EVAL IN CONTEXT, SYNTHESIZE DATA.	All interface operations and decision-making operations.	ADP-Assisted Staff

5.1.3 Configuration C

Configuration C represents the first intermediate boundary location that replaces (but does not eliminate) certain low-level repetitive operations in a manual system. Every populated staff module has a section data base consisting of (1) "invisible" files and (2) visible displays, situation maps, and tote boards. The invisible files are the filing cabinets in which documents, special files, and tactical information are stored. In this configuration the operations associated with the invisible files such as ENTER, FILE, RETRIEVE, etc., are replaced by interface operations so that, in effect, the invisible files become data repositories inside the computer. This means that the individual defined elementary operations are replaced by data entry or data retrieval tasks using a suitable terminal device. The visible displays, tote boards, and situation maps will remain as they were in Configuration B.

5.1.4 Configuration D

Configuration D takes the second step in replacing certain low-level, repetitive operations in a manual system. This configuration provides that the entire section data base associated with the staff section is now contained in the computer, both the invisible files and the visible displays such as status boards and situation maps. In order to retain some semblance of a manual system, however, the creation and maintenance of the section data base will still be the responsibility of the human players. Instead of using filing cabinets, display boards, and map overlays, the players will execute their assigned operations by means of keyboard data entry or keyboard query using one or more terminal devices and suitable electronic displays (as shown in Table 5-1).

5.1.5 Configuration E

Configuration E represents the extreme interface location developed in paragraph 3.2.2. It is oriented to a live staff module consisting of only one player. The lone player serves as the senior staff officer and decision-maker for the staff section. Configuration E is intended for use in emulating either a manual system or an ADP-assisted staff section. Hereafter Configuration E refers to a manual system and Configuration E1 refers to the ADP-assisted mode.

In a manual system (E) the configuration assumes that all the low-level file maintenance and update operations as well as the low level output processing operations are simulated as being performed by human beings. At the point where formal staff action is required in the staff activity the lone live player will begin by executing the EVALUATE IN CONTEXT operation or the SYNTHESIZE DATA operation preparatory to embarking on the formal decision-making. These

interface operations are described briefly in Table 5-1. No provision is made for "scratch pad" formulations or calculations using the computer so that the decision-maker will be required to prepare his own reminder chits, memoranda, or list of alternatives that might be required in completing the decision-making process. After the SELECT ACTION operation has been completed, the decision-maker must then trigger the appropriate output processing by invoking one or more of the operations ENTER, FILE or POST. The remaining parts of the output processing will be simulated.

In an ADP-assisted mode (E¹), the same configuration assumes that front end file maintenance and update operations are performed entirely automatically by the field ADP facilities. At the point in the staff processing where formal staff action begins, the human decision-maker embarks on the decision-making process by executing either EVALUATE IN CONTEXT or SYNTHESIZE DATA operations as described above. While executing the full decision-making process, however, the player may use supplementary "scratch pad" data space in his computer to enter and record hypotheses about his perception of the situation, lists of alternative courses of action, or evaluation criteria to be used in the action selection. This capability is assumed as part of the field ADP facilities. Following the SELECT ACTION operation, the human player again must trigger the output processing in the same manner as described above.

5.1.6 Configuration F

Configuration F is intended to provide the fully populated staff module when the system emulates an ADP-assisted staff system. The precise definition of the configuration cannot be stated at this time because very little is known about ADP-assisted staff processing other than the general procedural flow given in Section 3. The functions provided by the field ADP system and the specifics about the terminal and display equipments to be used by the staff have not yet been determined.

In the absence of these specifications, Configuration F assumes the following rules or characteristics about an ADP-assisted staff module:

- The staff module is provided with two or more terminal devices and a number of electronic displays including a fully automated situation map display.
- All files and tactical data repositories constituting the section data base are stored in the ADP facilities. Access to any part of the more general tactical data base (covering the whole division-level or corps-level system)

is provided through keyboard queries on the terminal devices. Read-only access is generally authorized through the ADP system software.

- Data base modification and update functions are also effected by keyboard data entry, but the specific files which a staff section may change are limited by the software to those parts of the tactical data base specified as under the purview of the staff element. Thus the file for Organization for Combat can be modified only by the G-3 but may be accessed and read by any section. Similarly, the Enemy Order of Battle may be changed only by the G-2 but generally reviewed by any authorized staff element.
- All incoming tactical information messages are signaled as described for RECEIVE (3) in Table 5-1. All outgoing messages are transmitted under TRANSMIT (3).
- The staff module is provided with the scratch pad facilities described under Configuration E1.
- The staff module requires external physical file equipments (such as filing cabinets, situation maps, display boards, etc.) only if the configuration is to be played under circumstances of simulated ADP failure.

5.2 TRADE-OFF AREAS

The trade-off considerations to be applied to the six selected configurations cover four basic areas associated with the general cost/effectiveness of a simulation for behavioral research problems. The areas are as follows:

- The realism of the staff operations performed by players.
- The ability to make measurements on the player performance in the framework of the behavioral research objectives.
- The cost of experiments in terms of total number of personnel required (players plus controllers/investigators).
- The hardware/software costs to implement the configuration.

These areas are discussed in the following paragraphs.

5.2.1 Realism of Playing Staff Operations

The central feature of the Phase 1 design of the battle simulation provides a realistic dynamic portrayal of a combat situation and the resulting flow of staff inputs into the command

and control center. The basic idea behind the populated staff modules is to establish a similarly realistic stage setting so that the players execute their staff operations for the command and control of the combat units in exactly the same manner as they would in a real-life situation. The physical surroundings of the player team should always approximate the command post facilities the staff section would have in the field.

The most important aspects of the player environment, however, are the staff equipments and staff procedures the individual players employ in acting out their different roles in staff processing. Any player, regardless of whether he is concerned with high-level decision-making processes or merely lower-level information processing, should be provided with the necessary stage props so that he can carry out his staff processing tasks exactly as he would perform them in the field. He should not require elaborate additional training or special instructions in order to act out his role as a staff member.

The key element, therefore, in judging the realism of the staff processing by players lies in the similarity of the ways the players execute their individual tasks in the simulated battle and in a real situation.

5.2.2 Behavioral Research Measurements

The ability to measure player performance and to control certain factors affecting that performance is the second trade-off area. The area is subdivided into six separate attributes because variable trade-off indications are anticipated in the six sub-areas. The attributes are as follows:

- Ability to measure process times taken for low-level operations.
- Ability to measure process times in decision-making steps.
- Ability to measure incidence of data errors or procedure errors made in low-level operations.
- Ability to measure incidence of data errors or procedure errors in decision-making steps.
- Ability to measure the frequency with which the decision-maker accesses the section data base (particularly under operation SYNTHESIZE DATA).
- Ability to control or bias the tactical information quality in the section data base in order to focus on a particular behavioral research objective.

The relevance of these attributes is discussed briefly below.

5.2.2.1 Process Times in Low-Level Operations

The cumulative time taken in any staff action to complete the information processing preparatory to the formal action and to culminate the output processing after the decision has been made is a fundamental indicator of the effectiveness of the staff. The ability to measure the process times of elementary operations is the first attribute indicative of the value of the configuration. The measurement of process times applies to low-level operations only in this category.

5.2.2.2 Process times for Decision-Making

A second attribute of the alternative configurations is the ability to measure the times taken by the decision-maker to execute the discrete steps of the formal process of arriving at his decision.

5.2.2.3 Incidence of Errors in Low-Level operations

The third attribute is the ability to detect the occurrences of data errors or procedure errors made by players. Here again, a distinction is made between errors in the low-level operations and errors committed during the cognitive operations. The ability to identify human errors is generally dependent on the presence of hard copy in the various steps of the staff processing. If, as will be seen in the evaluation of some of the configurations, no hard copy record is produced during the course of the staff processing, the ability to identify errors is severely limited.

5.2.2.4 Incidence of Errors by the Decision-Maker

The fourth attribute is the ability to identify data errors or procedure errors committed by the decision-maker during the cognitive processes. It should be noted that, as stated in paragraph 3.3, the model cannot provide adequate treatment of the third category: cognition errors. In any configuration which has the ability to identify errors by the decision-maker, the distinction between data errors and cognition errors will largely be lost.

5.2.2.5 Accession Frequency

The fifth attribute is the ability to measure the number of times the decision-maker accesses various parts of the section data base in order to formulate his perception of a situation. This measurement will serve to identify the categories of tactical information the decision-maker really uses in approaching his decision. It must be remembered, however, that in some configurations, particularly

manual systems, the measurements may be misleading because the decision-maker will have retained in his own mind certain tactical data elements simply from his own participation on the lower level information processing operations.

5.2.2.6 Input Variable Control

The final attribute is the ability to influence or bias the quality of the tactical information used by the live staff module in executing its staff processing. This type of control is desirable because it opens the door to a wide range of behavioral experiments related to human information processing and human decision-making. The extended design concept for the simulation now provides direct input variable control for the following:

- Selected omissions or deletions in staff input messages.
- Human error rates reflected in the simulated staff modules.
- Process time norms in the simulated staff modules.

Except for the limitations imposed by live module configurations, the controls appear to provide a basis for many alternative experiments. Two such limitations are evident, however. First of all, if the configuration calls for a large number of controllers, then the experiment will hinge on the strict and uniform adherence by all controllers to the stated objectives. Second, if the configuration provides little or no control over the tactical data flow after it gets in the hands of the players (as in a full scale manual system), then the objectives of the experiment can become largely diluted or lost.

5.2.3 Cost of Experiments in Terms of Personnel Required

The third trade-off area is simply the cost of experiments in terms of the total number of personnel required. In any configuration, the total consists of the number of players in the populated staff module plus the number of controllers required to direct and implement the experiment.

The number of players in a staff module is assumed to be the normal shift complement unless this number is reduced by the specific deletions called for in the configuration. Thus the player team size will vary from a fully manned staff section (as in Configuration A) to a one-man module (as in Configuration E or E1).

The number of controllers is assumed to be large in Configuration A because one controller is required for each voice or TTY communication channel into the staff module. The number of controllers for all the remaining configurations is assumed to be no more than two qualified personnel.

TABLE 5-3
INDEX OF PARAGRAPH REFERENCES FOR THE TRADE-OFF ANALYSIS

CONFIGURATION AND DESCRIPTION	REALISM OF STAFF PROCESSING	PERFORMANCE MEASUREMENTS	PERSONNEL REQUIRED	HARDWARE/SOFTWARE COST
A Fully manned staff module; all operations played; manual system.	5.3.1.1	5.3.1.2	5.3.1.3	5.3.1.4
B No RTOs; all operations played except communica- tions; manual system.	5.3.2.1	5.3.2.2	5.3.2.3	5.3.2.4
C No RTOs; invisible files in computer; manual system.	5.3.3.1	5.3.3.2	5.3.3.3	5.3.3.4
D No RTOs; section data base in computer; manual system.	5.3.4.1	5.3.4.2	5.3.4.3	5.3.4.4
E Single player; decision- making operations only; manual or ADP-assisted.	5.3.5.1	5.3.5.2	5.3.5.3	5.3.5.4
F Fully manned staff module; all required operations played; ADP-assisted staff system.	5.3.6.1	5.3.6.2	5.3.6.3	5.3.6.4

5.2.4 Hardware/Software Costs

The final trade-off area is the capital investment cost required to provide the necessary computer hardware and software to implement the configuration. All configurations call for a central computer which will provide data processing assistance in setting up and running experiments. The peripheral equipments required with the central processor will vary according to the nature and kind of the interface operations cited in Table 5-1. The software in the computer will be based on a battle outcome generator (BOG) which will be common to all configurations, but with alternative controller-player-input-output-switching routines to match the specifications of the individual configurations.

The hardware costs are estimated simply on the basis of number and types of peripheral equipments.

The software development costs are based on the implied complexity of the switching routines.

5.2.5 Trade-Off Matrix

The four trade-off areas described above complete the definition of the matrix of configurations vs trade-off considerations. The detailed discussion of the trade-off analysis is presented in the following subsection. A paragraph reference index to the trade-off matrix elements is shown in Table 5-3.

5.3 DETAILED DISCUSSION

The basic trade-off judgements for the six selected configurations across the four trade-off areas are presented in the following paragraphs. The evaluations of the realism of the staff processing and the performance measurement attributes are rated by the single keywords GOOD, FAIR, or POOR. The evaluations of the personnel required and the hardware/software costs are rated by the words HIGH, MEDIUM, or LOW.

5.3.1 Configuration A

Configuration A is a fully manned staff module emulating a manual staff system. All elementary operations are performed by players.

5.3.1.1 Realism

Configuration A will provide excellent realism in the staff processing by players. Rating: GOOD.

5.3.1.2 Measurements and Control

Measurement of lower level process times is feasible
Rating: GOOD.

Measurement of decision-making process times will be difficult because shunting by the decision-maker will prevent initiation of process timing and the transition from one procedural step to the next cannot generally be identified.
Rating: POOR.

Measurement of error occurrences in information processing or output processing will be difficult because large amounts of the staff processing will be performed by voice communication interchanges without hard copy. Data errors and procedure errors cannot always be identified.
Rating: POOR.

Measurement of similar error occurrences in the cognitive processes will also be difficult for the same reason.
Rating: POOR.

Accession frequency data will be impossible to measure because the decision-maker will undoubtedly employ a high shunting rate and a high reliance on his own memory.
Rating: POOR.

Input variable control will be difficult to implement because large amounts of the processing will be done by voice communication interchanges without hard copy. Information flow control will be ineffective when staff personnel can overhear the conversations. Also the large number of controllers manning the radio or telephone circuits will probably dilute the basic thrust of the research objectives because these controllers cannot stay well coordinated in their slanting or biasing of the staff input data.
Rating: POOR.

5.3.1.3 Personnel Required

Configuration A calls for a fully manned team of players and a large number of controllers. There must be a controller at the other end of each radio or telephone circuit. The total requirement for personnel in experiments is very large. Rating: HIGH.

5.3.1.4 Hardware/Software Costs

The amount of man/machine interfacing in the computer will be small. The hardware/software investment cost will be relatively small.
Rating: LOW.

5.3.2 Configuration B

Configuration B is a staff module emulating a manual staff system. It is manned by a normal shift team of staff personnel but without the radio/telephone operators (RTOs). All elementary operations are performed by the team except the RECEIVE and TRANSMIT operations. These operations are interface operations as described under RECEIVE (2) and TRANSMIT (2) in Table 5-1.

5.3.2.1 Realism

Configuration B will provide high realism in the staff processing by players. Two subtle departures from normal staff processing will exist. First the players will be constrained to hard copy data--either handwritten messages or computer printed messages. Second the RECEIVE and TRANSMIT operations will be constrained as described in Table 5-1. Rating: GOOD (-).

5.3.2.2 Measurement and Control

Measurement of lower level process times is feasible except for the RECEIVE and TRANSMIT operations whose process times are simulated. Rating: GOOD.

Measurement of cognitive process times remains difficult for the same reasons cited in paragraph 5.3.1.2. Rating: POOR.

Measurement of error occurrences in information processing and output processing is feasible because all staff processing is based on hard copy messages. Rating: GOOD.

Measurement of error occurrences in the decision-making processes remains difficult. Rating: POOR.

Accession frequency data will be measurable in part because of the hard copy, but it will still be largely lost because the decision-maker will continue to employ a high shunting rate and a high reliance on his own memory. Rating: POOR (+).

Input variable control will be significantly improved over that of Configuration A because information flow control can be maintained in part through hard copy messages. Rating: FAIR.

5.3.2.3 Personnel Required

The size of the player team will be reduced by the absence of RTOs. The number of control personnel will be reduced to no more than two. Rating: MEDIUM

5.3.2.4 Hardware/Software Costs

The investment cost of the computer hardware/software will increase because the controller(s) must have full interactive control of the preprocessing and running of experiments. Rating: MEDIUM.

5.3.3 Configuration C

Configuration C is a staff module emulating a manual staff system. It is manned by a normal shift team but without the need for radio/telephone operators. The elementary operations associated with filing or retrieving from file tactical information normally stored in filing cabinets or other covered containers (the invisible files) are replaced by interface operations (see Table 5-1). All the remaining elementary operations are performed by players.

5.3.3.1 Realism

Configuration C will depart significantly from the reality of staff processing in the field. All players performing the update and retrieval operations on the invisible files must be trained in keyboard data entry and keyboard query techniques prior to participating in experiments. Rating: FAIR.

5.3.3.2 Measurement and Control

Measurement of low-level process times can be made only for those elementary operations not involved in communications or invisible file manipulation. The process times of RECEIVE, TRANSMIT, ENTER, FILE, and RETRIEVE will be simulated, some of them with times that will be dependent on the individual players keyboard capabilities. Rating: FAIR.

Measurement of cognitive process times will still be difficult for the same reasons cited in 5.3.1.2. Rating: POOR.

Measurement of error occurrences in information processing or output processing will be less reliable than in Configuration B. All staff processing operations will still be based on hard copy data, thereby providing a means for the spotting of errors, but certain data errors will occur because of keyboard transfer mistakes related to the player's level of ability with the interactive terminals. Rating: FAIR.

Measurement of error occurrences in decision-making will be improved in the sense that errors made when extracting invisible file data (as in EVALUATE IN CONTEXT or SYNTHESIZE DATA) can be recorded. Rating: FAIR

Accession frequency data can be measured insofar as accessions to the invisible files is concerned. Rating: FAIR.

Input variable control will be more effective than in Configuration B because only the visible files remain uncontrolled.
Rating: GOOD (-).

5.3.3.3 Personnel Required

Configuration C does not alter the personnel requirement for experiments from that of Configuration B. Rating: MEDIUM.

5.3.3.4 Hardware/Software Costs

The significant departure in the hardware/software requirements lies in the requirement for terminal devices for players and in the automation of the non-visible files of the section data base. These requirements raise the basic investment costs.

Rating: MEDIUM (+).

5.3.4 Configuration D

Configuration D is a staff module emulating a manual staff system. It is manned by a normal shift team but without radio/telephone operators. The elementary operations associated with updating the section data base or retrieving information from it are all interface operations in which the players enter data or submit queries on a terminal keyboard. The display of retrieved information may call for several alternative electronic displays, thereby providing for the simultaneous display of different files (or situation maps) from the section pool of tactical information. The remaining elementary operations, those that involve manipulation of tactical data from input messages or data items already extracted from the section data base, or simply procedural rules to be followed in the staff processing, are still performed by players exactly as they would be performed in the field.

5.3.4.1 Realism

Configuration D will significantly distort the player environment from that of a manual staff system in the field. Although the players will execute the staff action procedures exactly as they are specified in Section 3, all elementary operations associated with section data base update or retrieval will be carried out by means of a computer terminal. The players will require preparatory training in keyboard data entry and keyboard query techniques probably quite remote from their previous staff experience. Rating: POOR.

Measurement of cognitive process times will still be difficult for the same reasons cited in paragraph 5.3.1.2. Rating: POOR.

Measurement of occurrences of errors in the low-level operations will be practically useless because the distinction between staff processing errors and errors at the terminal keyboards cannot be made. Rating: POOR.

Measurement of errors in the cognitive processes will, by contrast, improve significantly if it can be assumed that the decision-maker will make few keyboard errors in his accessions to the section data base. All shunting is eliminated. Rating: GOOD.

Accession frequency data will now be measurable. Rating: GOOD

Input variable control will now be fully effective. Rating: GOOD.

5.3.4.3 Personnel Required

The personnel required for an experiment will remain unchanged from that in Configurations B and C. There exists the possibility that controller personnel who are uniformly highly skilled at interactive operations at a computer terminal might be substituted for the low skill personnel on the player team. In this case the total personnel requirement still remains unchanged. Rating: MEDIUM.

5.3.4.4 Hardware/Software Costs

Configuration D increases further the computer hardware-software investment costs. The configuration not only calls for additional electronic display hardware but also requires complex software development to provide the storage of situation map data and the flexible display thereof. Rating: HIGH.

5.3.5 Configurations E and E¹

Configuration E is intended to provide a one-man staff module covering the decision-making operations only in a manual staff system. Configuration E¹ is basically the same structuring except that it emulates the decision-maker in an ADP-assisted staff environment. Both configurations badly assume that all information processing and output processing within the staff procedures are carried out "behind the curtain," that is, outside the immediate physical location and eye sight of the decision-maker. In Configuration E, the decision-maker performs his cognitive processes in the

same manner as he would in a manual system in the field. However, he must trigger the decision-making sequence by invoking the EVALUATE IN CONTEXT and/or SYNTHESIZE DATA interface operations using the terminal and display devices. After he has arrived at his selected course of action, he must trigger the output processing and transmission again by keyboard data entry. In Configuration E1, the decision-maker will perform the same formal staff action sequence but with two basic differences. First of all the sequence of cognitive operations will be guided by a set of rules assumed as part of the decision-making aids within the field ADP system. The player must perform his command and control function as it is specified in the operating procedures for the field computer system. Second, in the framework of the ADP procedures, the decision-maker will generate his perception of the situation, hypotheses regarding the missing elements, the alternative courses of action, the evaluation criteria, and the final evaluation of choices all by means of keyboard data entry and keyboard query on the "field" terminal. These data formulations will be stored temporarily in the scratch pad area of the simulator.

In both configurations all other low-level operations will be simulated.

5.3.5.1 Realism

Both configurations depart significantly from a realistic decision-makers environment. As stated in paragraph 2.2 of this report, human decision-makers generally employ a shunting mechanism across certain sequences of information processing steps in order to give themselves a running start on the formal decision process. This shunting mechanism requires that the decision-maker observe or participate in the front end processing of a staff action. In these configurations all information processing is simulated and wholly removed from the eyes of the decision-maker.

In Configuration E the manual system environment is further distorted because the decision-maker must nonetheless sit at a computer terminal to exercise his cognitive processes.

Rating for Configuration E: POOR.

Rating for Configuration E1: POOR (+).

5.3.5.2 Measurements and Control

In these configurations the measurements and control in experiments are clearly very effective with respect to the cognitive processes and totally non-existent for low-level processes.

No process time measurements can be made on low-level processes.

Rating for Configuration E: POOR.

Rating for Configuration E1: POOR.

Measurements of cognitive process times will be difficult in Configuration E because the procedural steps in the decision-making steps cannot be identified. In Configuration E¹, by contract, the procedural steps are sequenced automatically by the field ADP system

Rating for Configuration E: POOR.
Rating for Configuration E¹: GOOD.

Measurements of error occurrences are not possible for low-level processes.

Rating for Configuration E: POOR.
Rating for Configuration E¹: POOR.

Measurements of error occurrences on the cognitive processes will be very effective.

Rating for Configuration E: GOOD.
Rating for Configuration E¹: GOOD.

Accession frequency data can be effectively measured.

Rating for Configuration E: GOOD.
Rating for Configuration E¹: GOOD.

Finally the control of the information flow by experimenters will be very effective in both configurations.

Rating for Configuration E: GOOD.
Rating for Configuration E¹: GOOD.

5.3.5.3 Personnel Required

Both configurations require very few players and controllers.

Rating for Configuration E: LOW.
Rating for Configuration E¹: LOW.

5.3.5.4 Hardware/Software Costs

The hardware/software costs of these configurations are estimated to be about the same as those for Configuration D. The hardware necessary for one-man modules is slightly smaller than that for a multiple player team, but the software development necessary to provide ADP system emulation is greater.

Rating for Configuration E: HIGH.
Rating for Configuration E¹: HIGH.

5.3.6 Configuration F

The sixth selected configuration is a fully manned staff module emulating an ADP-assisted staff system. The basic assumptions regarding the field ADP system characteristics are stated in paragraph 5.1.6. It should be noted that these assumptions are necessarily vague in detailing the ADP-assisted methods and procedures for the information-processing aspects of staff processes. For the purposes of this trade-off comparison, it is further assumed that the ADP-assisted staff module has the necessary organizational structure and basic procedures to provide the decision-maker with low-level process assistance.

5.3.6.1 Realism

Insofar as the organizational structure, staff procedures, and ADP equipments are known at this time, the player environment provides a realistic setting. Rating: GOOD.

5.3.6.2 Measurements and Control

Measurement of low-level process times will be highly effective. Rating: GOOD.

Measurement of cognitive process times will be the same as in Configuration E¹. Rating: GOOD.

Measurement of human error occurrences in low-level operations will be effective. Rating: GOOD.

Measurement of error occurrences in cognitive operations will be the same as in Configuration E¹. Rating: GOOD.

Accession frequency data measurements will be the same as in Configuration E¹. Rating: GOOD.

Finally input variable control will be effective. Rating: GOOD.

5.3.6.3 Personnel Required

The number of players and controllers required for experiments will be small. Rating: LOW.

5.3.6.4 Hardware/software costs

The hardware/software investment costs will be about the same as those for Configurations D, E, or E¹. Rating: HIGH.

5.4 CONCLUSIONS ON VARIABLE INTERFACE BOUNDARIES

Table 5-4 presents a summary of the trade-off analysis of the six selected configurations across four trade-off areas. The table repeats the paragraph references for the detailed discussions pertinent to the individual trade-off matrix elements.

5.4.1 Cost/Effectiveness of Alternative Configurations

The summary table by itself provides a basis for drawing broad conclusions about the cost/effectiveness of alternative configurations varying the interface boundary location. These conclusions are given in the following paragraphs.

5.4.1.1 Configurations Emulating Manual Staff Systems

Configurations A through E all emulate manual staff systems. The arrangement of these configurations in the table is such that they represent increasing amounts of interactive play between players and the computer simulation. On this basis the following conclusions are drawn:

- The realism of the staff processing will get progressively worse as the level of interactive play is increased.
- The ability to measure player performance and to control the information flow in experiments will generally improve as the level of interactive play is increased.
- The cost of experiments, in terms of the total number of personnel required, will go down as the level of interactive play is increased.
- The investment cost of computer hardware/software will increase as the level of interactive play goes up.

5.4.1.2 Configurations Emulating ADP-Assisted Staff Systems

Configuration E¹ and F represent alternative ways of emulating an ADP-assisted staff system. The difference between the two lies entirely in the focus of the behavioral research objectives in studying the staff processing. Configuration E¹ is intended as a means for concentrating on the cognitive processes only and for excluding the lower level information processing aspects of the staff activity. Configuration F, by contrast, spans the gamut of staff processing activities. On the basis of these alternative configurations, the limited structure (Configuration E¹) simply distorts the realism of the staff processing and diminishes the ability to measure the player performance while exhibiting at the same time the same personnel requirements and investment costs as the more general structure.

5.4.2 Switching Among Configurations

One aspect of alternative configurations not reflected in the trade-off analysis is now presented as the concluding discussion of this section. The material above has shown that there are a large number of ways the interface between staff players and the battle simulation may be configured. A more comprehensive analysis of the problem may well find that there is a wide spectrum of different configurations each of which represents a cost/effective approach to a separate, precisely stated, behavioral research study of staff processing. The question then remains: what are the cost/benefit

TABLE 5-4
SUMMARY TABLE OF THE TRADE-OFF ANALYSIS

CONFIGURATION	EMULATED SYSTEM	REALISM OF SETTING	MEASUREMENT AND CONTROL							PERSONNEL REQMTS	HARDWARE/ SOFTWARE
			LOW LEVEL TIMES	COGNITIVE TIMES	LOW LEVEL ERRORS	COGNITIVE ERRORS	ACCESSION FREQUENCY	INPUT CONTROL			
A	Manual	GOOD (5.3.1.1)	GOOD	POOR	POOR (5.3.1.2)	POOR	POOR	POOR	POOR	HIGH (5.3.1.3)	LOW (5.3.1.4)
B	Manual	GOOD(-) (5-3-2.1)	GOOD	POOR	GOOD (5.3.2.2)	POOR	POOR	POOR(+)	FAIR	MEDIUM (5.3.2.3)	MEDIUM (5.3.2.4)
C	Manual	FAIR (5.3.3.1)	FAIR	POOR	FAIR (5.3.3.2)	FAIR	FAIR	FAIR	GOOD(-)	MEDIUM (5.3.3.3)	MEDIUM(+) (5.3.3.4)
D	Manual	POOR (5.3.4.1)	POOR	POOR	POOR (5.3.4.2)	GOOD	GOOD	GOOD	GOOD	MEDIUM (5.3.4.3)	HIGH (5.3.4.4)
E	Manual	POOR (5.3.5.1)	POOR	POOR	POOR (5.3.5.2)	GOOD	GOOD	GOOD	GOOD	LOW (5.3.5.3)	HIGH (5.3.5.4)
E ¹	ADP-Assisted	POOR(+) (5.3.5.1)	POOR	GOOD	POOR (5.3.5.2)	GOOD	GOOD	GOOD	GOOD	LOW (5.3.5.3)	HIGH (5.3.5.4)
F	ADP-Assisted	GOOD (5.3.6.1)	GOOD	GOOD	GOOD (5.3.6.2)	GOOD	GOOD	GOOD	GOOD	LOW (5.3.6.3)	HIGH (5.3.6.4)

factors associated with a library (stable?) of alternative configurations so that the battle simulation facilities can be switched from one behavioral research investigation (with its specially tailored configuration) to another (with a different configuration)?

A preliminary answer to this question can be made by looking at several of the selected configurations described in this section. Suppose ARI had two basic research capabilities: (1) a battle simulation system for the study of staff processes under a manual staff mode (Configuration B) and (2) a battle simulation system for the investigation of staff processing under ADP assistance (Configuration F). Suppose, furthermore, that these capabilities were installed in the same computer* even though they exhibit different system architectures. Under these suppositions, what are the implications regarding a program of behavioral experiments in which it is desirable to switch back and forth from one configuration to the other?

The following points appear clear enough in this picture:

- The investment costs of the computer hardware/software will simply be the highest cost reflected among all configurations. In this hypothetical example, Configuration F requires the largest hardware/software investment.
- The cost of individual experiments will depend primarily on the total number of personnel required to carry out the experiments.
- With only one computer*, only one experiment can be carried out at a time.
- Switching from one configuration to another will not simply be a matter of throwing a few switches on the computer. The predominant factor will be the time it takes to modify the system architecture and to rearrange the staff equipments and materials in the player locations(s).

5.4.3 Companion Report

The material presented in this section provides the basis for the development of the principles of task design in the companion volume, Some Guidelines for Effective Task Design in Command and Control Simulations.

* A mini-computer is assumed.

APPENDIX A

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