Technical Report 915

Review of Command and Control Models and Theory

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A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

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This review examines command and control model and theory literature from 1975 to 1988. : identifies and discusses literature that discusses how command post staffs perform command ıd control functions and deliberately omits a fairly large body of literature that discusses angentially related material. Reports that dealt with communications or seemed to address ommand and control as a vehicle to demonstrate the potential relevance of some existing ıgineering or operations research methodology are omitted. A total of 66 reports and docu- ents are discussed. The literature has been classified into five basic types of models: l) models that evolve from literature, such as Field Manuals (implementational in intent), 2) organizational models that evolve from adaptations of organizational or management ıeorists' work, (3) behavioral system models that look at command and control in terms of ıman behavior, (4) systems-oriented models that emerge from the systems research perspective ıd (5) some attempts to develop network based models by applying existing analytical echniques.

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The literature supports the following conclusions:

1. Models and theory that support a purpose beyond discussion of the model or theory itself are more productive than products that derive from attempts to develop models or create theory independent of a specific application.

2. Research that is based on an organizational or management theory perspective is more productive than research that evolves from other research perspectives.

3. Research that considers decision making as the role of a command post is more effective when it does not artificially, and incorrectly, limit the decisions it considers to those implied in the military decision-making model. (The military decision-making model is used to explain how orders from next higher headquarters are evolved into orders by the echelon that receives them.)

4. No extant model is sufficiently well developed and supported by data that it can be used in a predictive or analytic fashion.

Beyond these conclusions, which clearly evolve out of considering the literature itself, there are other goals, or model and theory requirements, that should be adopted to provide guidance for the development of better models. These conclusions are partly drawn from the literature and partly the result of considering, in a broader fashion, the problems associated with the potential acceptance and utilization by the Army of command and control research. These ancillary conclusions are as follows:

5. Models should deal with a specific organizational structure.

6. Models should be based on observable tasks, processes, or behavior.

7. Models should be constructed so that the data that support them and model outputs can be easily related to the tasks, processes, or behavior on which they are based.

8. Models should support a theoretical development to define how the command and control function relates to battle outcome and, thereby, permit command and control research to be of value in determining how battle staff activity contributes to unit fighting effectiveness.

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Technical Report 915

Review of Command and Control Models and Theory

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Human Performance Effectiveness and Simulation

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The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) is conducting research to develop improved methods for measuring the performance of command staffs at corps, division, and brigade levels. The command and control performance measurement program also seeks to develop models that can manipulate command and control performance data. To be certain that full advantage is taken of relevant past research, a portion of this program has been devoted to a review of that part of the command and control model and theory literature that contains material that might be significant to the development of behaviorally based analytic and predictive command and control models. As the authors reviewed the literature, they found that it is scattered, sometimes hard to obtain, and often only tangentially, if at all, related to Army command and control. This review confines its coverage to those reports that appear to be of value to persons who perceive command and control as a person-oriented process. Hence, it omits material that deals exclusively with equipment, or communications, or other nonbehavioral aspects of command and control.

This report presents the reviewed literature in some detail and makes eight recommendations for future researchers who may be tempted to create models or develop theories intended to deal with Army command and control processes. The report will make it possible for interested parties to survey the command and control model and theory field in a relatively short time. The report will be of value as background material for all persons involved with the command and control modeling area and will help persons in the field evaluate its general state without extensive personal effort.

Edgar M. Johnson

EDGAR M. JOHNSON
Technical Director

REVIEW OF COMMAND AND CONTROL MODELS AND THEORY

EXECUTIVE SUMMARY

Requirement:

The literature that deals with command and control models and theory is quite scattered and of highly variable quality. It is also quite diverse because the term command and control is broad enough to encompass many meanings and to be applied in situations where other more specific terms, e.g., communications, would be more appropriate. As a result of these factors, it was appropriate to extract from the broader literature those reports that were directly relevant to Army command and control and to evaluate the potential contribution of past research to the development of models and theory to support the U.S. Army Research Institute for the Behavioral and Social Sciences' (ARI) command and control performance measurement program.

Procedure:

The procedures involved in the literature review were straightforward. Professional staff at the ARI Field Unit at Fort Leavenworth provided suggestions and insights and cited literature about work in the area. A search of the library at the ARI Field Unit provided additional literature--ultimately close to 100 reports, theses, and papers on the topics of command and control theory, and command and control models. An initial overview of these materials provided the reviewers a first clustering of the important domains within which command and control theorizing and model building were being conducted.

Based upon this information, a 10-year computerized literature search was conducted by the U.S. Library Staff at the Army Command and General Staff College. This search provided many additional references. The search was augmented by a brief reading of much of the literature and the identification of significant bibliographic references not identified in the computerized search. This process of reading and reporting on the literature in conjunction with searching for new bibliographic references and computer searches in new domains continued during the course of the project.

Findings:

The state-of-the-art in command and control modeling and theorizing is not well developed, although it may be that some writers in the area have overstated the case when they claimed that

> . . . the complexity of the (command and control) problem is such that many of its theories appear almost autistic, as though the attempt to make sense of it leads researchers down a path to convoluted and idiosyncratic theorizing.[1]

Certainly there are a number of reports that deal with command and control so tangentially that it is hard to see any relationship beyond the title. Some reports do little more than demonstrate that algebra works. Other reports deal so completely with communications problems, computer technology, or control theory--in the physics and engineering sense--that it appears that command and control--in the Army sense--is either in the title by accident or added to broaden the apparent scope of the work being reported.

There are, however, a few publications that do make a contribution to command and control theory and a number that present material of value to model development. It might be more charitable, and more factual, to describe most theorizing as simplistic rather than autistic, and to note that the major problem in the field is not that it is "convoluted and idiosyncratic" but that too much of it lacks a clear focus. This review, both in the material it omitted and in the material it included, has demonstrated the broad domain and often disjointed nature of the work performed under the rubric "Command and Control Theory and Models." Sutton (1986), in a review of the more general literature--such as military review articles--points out that there exists

> . . . a tendency to address the subject (of command and control) in an unbalanced and piecemeal fashion. Some articles tend to emphasize the importance of technology, both hardware and software. Other articles deplore the apparent fixation with technology and technical means, and urge a shift in emphasis to the role of leadership in C^2 systems. Another class of articles details the procedures, policies and techniques used by a certain unit in their command post system. Most of the articles are well worth reading, but one is soon convinced, to rephrase one old saw, that C^2 is defined by the senior man present.

Our review of the more research-oriented literature certainly supports this view, except that command and control seems more often to be defined in whatever fashion most conveniently justifies the work rather than by the senior man present. Some of the problems associated with the relatively uncontrolled application of researcher fit the definition of command and control that are apparent in this review even though its diversity was constrained by its rather narrow focus. Thus, some research tends to focus on how individuals make decisions rather than addressing how command and control decisions are arrived at in a specific command post environment; other research tends toward discussions of how computer programs can be used to create a command and control model; and other material seems to deal more with introducing proven engineering analytic methods than with the command and control process. Despite its limitations, the primarily modeling literature

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[1]Fischhoff and Johnson (1985)

incorporated in the review (66 items) does support the development of a model classification scheme and derivation of a set of eight conclusions concerning the state-of-the-art and future of Army relevant command and control model development.

The report develops a five element classification scheme that successfully categorizes existing models. According to the scheme, command and control models and the theory that supports them or derives from them can be implementational, organizational, behavioral system, systems oriented, or network. Implementational models, such as those in various Army field manuals and standard operating procedures, are intended to specify how a command post will look and function. Organizational models derive from applying an organization or management theory perspective to modeling the command and control process. Behavioral system models tend to have a somewhat narrower focus and evolve when a researcher opts to study how some particular command and control function (such as decision making) is performed. Systems-oriented and network models also result when the researcher applies particular techniques to develop his paradigm.

The literature reviewed in this report supports the following conclusions:

1. Models and theory that support a purpose beyond a mere discussion of the model or theory itself are more productive than products that derive from attempts to develop models or create theory independent of a specific application.

2. Generally, research that is based on an organizational or management theory perspective is more productive than research that evolves from other research perspectives.

3. Research that considers decision making as the role of a command post is more effective when it does not artificially, and incorrectly, limit the decisions it considers to those implied in the military decision-making model used to define how orders from next higher headquarters should be developed into orders at the echelon that receives them.

4. No extant model is sufficiently well developed and supported by data that it can be used in a predictive or analytic fashion.

Beyond these conclusions, which clearly evolve out of considering the literature itself, there are other goals, or model and theory requirements, that should be adopted to provide guidance for the development of better Army applicable models. These conclusions are partly drawn from the literature and partly the result of considering, in a broader fashion, the problems associated with the potential acceptance and utilization of command and control research. These ancillary conclusions are:

5. Models should deal with a specific organizational structure.

6. Models should be based on observable tasks, processes, or behavior.

7. Models should be constructed so that the data that support them and model outputs can be easily related back to the tasks, processes, or behavior on which they are based.

8. Model should be supported by at least the potential for a theoretical development that defines how the command and control function relates to battle outcome and, thereby, permit research concerning command and control to be of value in showing how battle staff activity contributes to unit fighting effectiveness.

Utilization of Findings:

Research and development in command and control is expensive, complex, and difficult. The command and control area also suffers because researchers and other professionals are often thrust into responsible positions with little opportunity to become aware of the existent body of research and the nature, however primitive, of the models and theory that have resulted. This report will make it possible for interested parties to survey the field of command and control models and theories and become aware of the extent and limitations of the research foundations of the area in a relatively short time. It will be of value as background material for all persons involved with the command and control modeling area and will help persons in the field evaluate the general state of the field without extensive personal effort to identify and obtain the relevant material.

REVIEW OF COMMAND AND CONTROL MODELS AND THEORY

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REVIEW OF COMMAND AND CONTROL MODELS AND THEORY

INTRODUCTION

Command and control has traditionally been considered by analysts and military experts to be one of the most critical battlefield components and "the essential apparatus for using military means effectively," (Cushman, 1983, p. 2-5.2). It has also been noted that Airland Battle Doctrine, with its increased demands for timely information and for rapid decision making in a quickly changing environment will, in the next conflict, place even "greater demands on the command and control system than in previous wars" (U.S. Army, Field Circular 101-55, p. 1-11). Because of the overwhelming importance of command and control, it is essential that trainers, evaluators and those who are developing future doctrine understand the nature of this critical military component. One way to aid in the understanding of a complex system is to develop, and then test, a simulation or model that describes that system's characteristics.

It is our intent in this paper to review the existing literature on command and control theory and models to determine the extent to which this development process has occurred. Such a review is useful in assessing to what extent the development of command and control models and related theory supports the Army need for unifying concepts that can form a basis for such diverse applications as performance evaluation, staff training developments, analytic evaluations, and the identification and development of research topics.

Approach

The procedures involved in the literature review were straightforward. Professional staff at the U.S. Army Research Institute Field Unit at Fort Leavenworth provided suggestions and insights and cited literature about current and known work in the area. A search of the library at the ARI Field Unit provided additional literature, which ultimately included close to 100 reports, theses and papers on the topics of command and control theory, and command and control models. An initial overview of these materials provided the reviewers a first clustering of the important domains within which command and control theorizing and model building were being conducted.

Based upon this information, a 10-year (1976-86) computerized literature search was conducted at the library of the Army Command and General Staff College. This search provided many additional references. The search was augmented by a brief reading of much of the literature and the identification of significant bibliographic references not identified in the computerized search. This process of reading and reporting on the literature, searching for new bibliographic references, and conducting computer searches in new domains continued during the course of the project.

During the review of the literature it quickly became apparent that command and control meant different things to different people. To some, command and control implied the overall management of a battlefield at some level such as theater, corps, or division. To others command and control was redefined as "command and control system" and their domain included all or many echelons. To still other researchers command and control became a communications or data processing problem. It is, therefore, our intent to provide a structure that will omit from the review some of the literature that deals with material not relevant to a narrower definition of "command and control."

It also will become apparent to the reader that theoreticians who are working toward the development of a command and control model, for the most part, are working in very different domains and often without attempting to understand or integrate work that has preceded their own. As Fischhoff and Johnson (1985) state:

> The stakes are so high that funders are willing to go with very long shots in hopes of producing some useful results. Yet, the complexity of the problem is such that many of its theories appear almost autistic, as though the attempt to make sense of it leads researchers down a path to convoluted and idiosyncratic theorizing. (p. 19)

It is our intent to compare and contrast various models to give a sense, not only of the current state of development, but also of how the models may be integrated, how they overlap, and in some cases, how they are discordant. Finally, it is our objective to critique current theorizing and development in this area and to suggest future directions.

Some Definitions

As mentioned above, it quickly became apparent during the literature review that command and control is a variably defined and often misunderstood concept. Because of the lack of one specific, accepted, and clearcut definition, the term has been used by theoreticians to describe such diverse things as: complex organizational behavior; the application of computers; simulations and decision aids; decision making processes; command post structure; communications; and information processing. A necessary first step in this review is a description of at least some of the more important meanings and applications of command and control in the literature.

The most important definition is provided by the U.S. Army. In Joint Chiefs of Staff Publication 1, command and control is defined as

> The exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. (p. 77)

This definition implies that command and control is primarily a management function, accomplished through the arrangement and coordination of personnel, equipment, communications, and other resources.

Unfortunately the management definition is rarely used in the reviewed literature. Finley, Muckler, Gainer, and Koe (1974) in their presentation of a command and control evaluation methodology, are among the few authors who take this perspective. They define command and control as "the management component of any system" (p. 15). They also suggest that the connection between command and control and management theory and practice is worthy of future exploration. "The similarities between the two areas and the relative contributions each can make to the other have not been sufficiently explored" (p. 15). These researchers also note that there is a great deal of similarity between command and control and the management of civilian systems, and that "Outside of the element of personal risk, there are no significant functional differences between military and civilian management. Differences are of degree and not of kind" (Finley, Muckler, Gainer, and Obermayer, p. 15).

In contrast to this definition of "command and control," a command and control system is defined in Joint Chiefs of Staff Publication 1 (DoD, 1987) as "the facilities, equipment, communication, procedures, and personnel essential to a commander for planning, directing, and controlling operations of assigned forces pursuant to the missions assigned" (p. 77). Often command and control systems are seen by theoreticians as the essence of command and control and the focus of their model building efforts, rather than as methods for supporting the command and control function. Akst (1982) concludes, in referring to the Joint Chiefs of Staff Publication 1 definition of command and control, "in interpreting this definition, we must realize that a command and control system is simply a tool the decision maker uses, not an end in itself" (p. 1).

While both command and control, and command, imply the exercise of authority in management, control tends to be used to describe the methods for ensuring that the intent of the commander is actually carried out correctly. Control is defined in JCS Pub 1 as the "physical or psychological pressures exerted with the intent to assure that an agent or group will respond as directed: (p. 88). Thus, while "command and control" stresses the design of management systems and the development and implementation of plans, control implies the regulation of operating systems or actions through feedback.

Varying definitions of command and control, the almost interchangeable use of command, and even of command and control system, lead to quite different views of what is being modeled and what body of knowledge forms the basis for evolving command and control theory and models. Thus, we have a definition of command and control as a management component, which enables some researchers to consider command and control as a function best understood in the context of organizational or management developments. Other researchers are aware of the extensive body of knowledge about the regulation of systems, much of it emanating from principles of engineering known as control theory, and hence, these control theories form a basis for much theorizing about command and control. Even within these more general areas there are definition problems. For example, one researcher (Akst, 1982) appears to have inadvertently suggested still another applied definition of command and control--the process of organizational decision making--while doing his modeling. Still other researchers seem to have simplified management issues dramatically so that decision making alone becomes the major focus in their model.

Model Types

The variations of definitions, potential model applications, and researcher backgrounds have led to a situation where a rather sparse literature has created the potential for a relatively complex classification of models by type. For example, the U.S. Army is concerned not only with theoretical models of command and control, but also with the structure, implementation, and actual working models of the battlefield command post organization. Many reports and articles produced by members and committees of the Armed Services are concerned with definition of actual command posts. Many of these documents tend to focus on such things as job descriptions, staffing, and actual functions of the Army in a battlefield situation. Documents of this type present a model or way to think about command and control which can be considered as an Implementation type of model.

A second group of models, which may be termed Organizational models, are developed from the perspective of researchers who derive their theoretical impetus from work done by persons dealing with business organizations. Organizational models may be either Process or Evaluation oriented. Organizational-Process models include those that describe methods for understanding the functioning of the whole command and control organization as a management system. Many examples of Organizational-Process models exist but have typically been applied to business organizations. Business oriented models include Systems Theory, Theory of Bureaucracy, and Likert's System 4, among others. Some of the models discussed in this report are attempts to apply such organizational models to the command and control organization. This includes attempts which use existing models and those which describe the use of new organizational models. A limited amount of work has occurred in this area and includes work in the area of military decision making which can be included in this category since it appears to represent a simplified management model. Organizational-Process models tend, therefore, to be of two kinds; those that deal with Decision Making and those that deal with Taxonomy or Functions.

The other category of Organizational models may be considered as Organizational-Evaluative since these models result from the research and model building which often occurs during system evaluations. Often attempts to evaluate a system occur prior to developing a model of that system. As a result, the evaluation process, particularly with regard to the content and methods of evaluation, often requires the researchers to develop a conceptual model for understanding the system or organization under investigation. Evaluation studies which have been applied to the command and control function have been relatively limited but include the Headquarters Effectiveness Assessment Tool (HEAT), the Army Training and Evaluation Program (ARTEP) efforts, and the Army Command and Control Evaluation System (ACCES). (For a more detailed review of command and control performance evaluation research, see Crumley, 1988).

Another group of models, although related to organizational models, may best be termed Behavioral System models. Models of this type focus on individual or group behavior as the critical aspect of command and control. In these models the behavioral system is viewed in isolation rather than from an organizational perspective and the concerns tend to be with some specific function such as decision making itself rather than command and control decision making. Researchers who operate from this perspective conceptualize the implementation or evaluation of command and control as unitary psychological or behavioral processes.

Systems Oriented models form yet another category. This type of command and control model describes and evaluates the operation of specific facilities, technology, and systems used to support the command and control function. These models fall within two sub-areas: Information Transformation Systems and Architecture.

The Systems Oriented-Information Transformation System models tend to define command and control as an area which includes those physical entities or systems that transfer, integrate, or transform information. This, of course, includes communication systems and information processing systems. Communications systems are a vital part of command and control and there is a large literature which focuses on communication in command and control. Unfortunately, many of these discussions focus on communications as if it were the whole of command and control. Other work in this area tends to deal primarily with computers which play a major role as decision or staff aids and in carrying out information processing in command and control. In fact, some theoreticians view command and control as largely a computer based capability. Computers are also often used in the development of simulations to measure other command and control processes. Both of these usages of computer technology represent models of the command and control process.

The other System Oriented sub-area may be defined as Architecture related models. Research that analyzes command post structure and builds models to aid in defining and solving the structure definition problem is uncommon. However, the command post structure has been analyzed as part of functional analyses performed to support development of the automated command and control and subordinate systems currently evolving to replace the manual systems of the past. Other models deal with the architecture of a system or structure and define the relationship that different parts of the system have to each other. Thus, one can separate architecture as a separate sub-area because some theoreticians view command and control models as primarily problems of architecture or the assignment and location of equipment and the persons who must operate them.

The final major model category can be characterized as Network models. This category primarily includes command and control models based on the use of network or PERT charting and other project management models. The literature in this area is limited and applications which have been found are primarily from the Soviet literature. There is, however, limited recent work which attempts to define a command and control model based on Stochastic, Timed, Attributed Petri Nets (STAPNs), a technique developed to characterize and analyze concurrent operations in computer systems.

Table 1 shows the model classification system, including sub-groups developed from the reviewers' efforts to create a suitable set of independent categories. Also shown is an "atypical" category which refers to a single report that attempts an all encompassing command and control theory.

Table 1

Classes of Command and Control Models.

1. Implementational
2. Organizational
   a. Process
      (1) decision making
      (2) taxonomy or functions
   b. Evaluative
   c. Atypical organizational, process, taxonomy or function model.[1]
3. Behavioral system
4. Systems Oriented
   a. Information transformation
   b. Architecture
5. Network

Review Structure

A significant portion of the documents reviewed for this report are shown in Table 2 classified under the system derived after several attempts to develop a suitable set of categories. It is not apparent from mere inspection of Table 1, but there are problems that result from attempting to structure a review around this classification scheme , or the several other reviewer developed, model typing schemes. The basic categories - implementational, organizational, behavioral systems, systems oriented, and network - serve well enough; but the distribution of reports and different intent of technical or research efforts tend to require the creation of subcategories which in turn create ambiguities in the assignment of reports to categories and considerable unevenness in both the quality and the quantity of reports assigned to the various categories.

For this reason, this review is structured around a ten-item classificatory system based on the model categorizations and one research report which is discussed independently because it differs so radically from all the others in its category.

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[1] A major attempt at an all encompassing theory for command and control which is discussed in a separate section but is not considered a separate model class.

Table 2

Typical Model and Theory Reports by Category

IMPLEMENTATION

- FM 101-5
- FC 101-55
- Corps and Division SOPs

ORGANIZATIONAL

Process (Taxonomy or Function)

- Olmstead, et al., 1973
- Finley, et al., 1974
- Finley, et al., 1975
- Olmstead, et al., 1978
- Miller, et al., 1979
- DSI, 1985[1]

Process (Decision Making)

- Maillefert, 1974
- Lawson, 1980a
- Fallows, 1981
- Wohl, 1981
- Boyd, 1981
- Orr, 1983
- DSI (HEAT), 1983
- Rios, 1985
- Land, et al., 1985
- U.S. Army C^2 paper, 1987 a, b
- ARI (ACCES), 1988

Evaluative

- ARTEPs
- AMTEPs
- DSI (HEAT), 1983
- ARI (ACCES), 1988

BEHAVIORAL SYSTEM

Decision Making

- Ryan, 1969
- Krumm, et al., 1970
- Krumm, et al., 1973
- Robins, et al., 1974
- Askt, 1982
- Athans, 1982
- Metlay, et al., 1985

Computer Technology

- Findley, et al., 1974, 1975
- Obermayer, 1975
- Pritchard, 1977
- Albert, 1980
- Witus, et al., 1984

SYSTEM ORIENTED

Information Processing

- Bouthonnier and Levis, 1984
- Cothier, 1984
- Tomovic and Levis, 1984
- Cothier and Levis, 1985
- Wilcox, et al., 1987

Architecture

- Bean, et al., 1983
- Bigler, et al., 1984

NETWORK

- Skachko, et al., 1968
- Ivanov, et al., 1977
- Barber and Kaplan, 1979
- FM 101-5
- Krupenevich, 1984
- Moore, et al., 1986

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[1]Discussed in the review as a separate case because of its unique nature.

LITERATURE REVIEW

Implementation Models

The single most important set of command and control models is the explicitly and implicitly stated set of models that appear in official Army documentation which describes how command posts are organized, how they operate, and what changes are being considered as new command and control enhancements are developed to replace the manual systems of today. Models in this category are of two types. Some define the structure of a command post and others define the command decision process. Thus, there are documents, such as Field Circular 101-55, Corps and Division Command and Control, which describe the equipment, layout, staffing, communications, and other physical factors involved in defining a command post. There are also documents, such Field Manual 101-5, Staff Organization and Operations, which describe the military decision-making process and how the command staff supports and executes the commander's decision process. Documents such as these and individual Army unit command post and command group Standing Operating Procedures are the basic models of existing and seriously considered command and control options.

Field Circular 101-55 (U.S. Army, 1985) shows the equipment, personnel, and layout of a variety of corps and division command posts. The heavy division material covers 31 pages. The Field Circular 101-55 material is representative of this genre of models in that it defines the physical arrangement of a CP, specifies the equipment available at each cell, indicates the number, level, and type of personnel assigned, and defines the equipment and contacts available for communicating among cells and with external units. Field Circular 101-55 also provides a section that lists "staff battle tasks" in a format that assigns tasks to specific staff sections. Models of this type define the official <u>structure</u> of the command post that they describe. Such models are available for corps, division, brigade, battalion, and indeed, probably every level of command post. There are tailored versions, Standing Operating Procedures, for individual units, e.g., 1ID, 1AD, III Corps, etc. These models and the corps and division conceptual models from Field Circular 101-55 form an important set of models which are in a sense the bottom line implementational models.

A related set of models results from the existence of official documents which describe what is generally called the military decision making process. Army Field Manual 101-5 (U.S. Army, 1984), Staff Organization and Operations, shows a decision making sequence, which relates staff actions to the commander's actions (see Figure 1). The Field Manual also provides supporting models. For example, it expands on the process shown in Figure 1 by providing a block diagram (model) which further details staff section (G1, G2, G3, G4 and G5) activities, it provides a list of actions, or tasks, which must be accomplished, and it describes the relationships between staff sections which occur as these tasks are accomplished. Between them, these two types of documents, with their incorporated model information, successfully define both the command and control process and the actual physical environment (people, procedures and equipment) in which the command and control process is conducted.

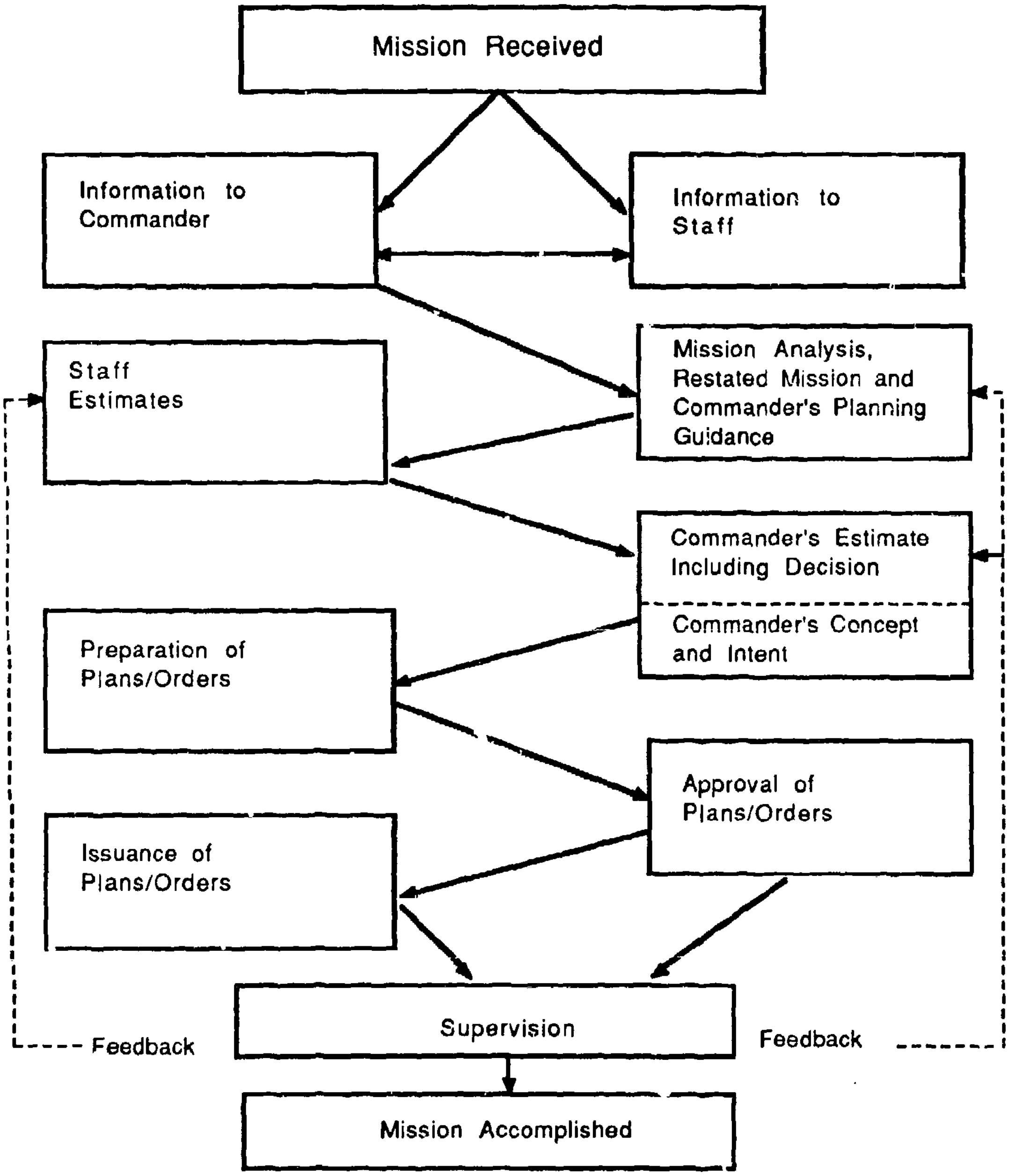

Figure 1. Military Decision-Making Process as shown in FM 101-5 (U.S. Army, 1984)

Other specifically military command and control models and related theory exist, but some of it is best discussed elsewhere since it does not appear in documents which, by their nature, make the material implementational in intent.

Organizational Models

The general class of models termed Organizational models appears to have evolved from an organizational theory view of the command and control process. It is convenient to treat this class of models as consisting of three subgroups and a single study, so anomolous, that it can best be treated alone. The three subgroups are: organizational process models that have a taxonomy or function definition thrust; organizational process models that have a decision making thrust; and organizational models which evolve from an evaluative intent. The final section deals with a model that appears to be of the Organizational-Process, (taxonomy or function) type but which attempts so much that it stands apart from others in this category or even in this general class.

Organizational-Process (Taxonomy or Function) Models

The most important work in this category is almost certainly a series of research efforts reported by Olmstead and his co-workers. Olmstead adapts the theoretical work of Schein (1965) and Bennis (1966) in the area of organizational systems theory in order to develop concepts about the processes which lead to command and control effectiveness. Olmstead's adaptation of past theoretical work in organizations is applicable to the management of a variety of organizations, including the command and control organization, and it is this latter application which is reported in Olmstead, Christensen, and Lackey (1973). This effort represents one of the few reports in the literature of attempts to explore or model command and control functions with the use of an organizational or behavioral theory.

In general, systems theory argues that an organization is in interaction with a dynamic environment, (an environment which itself consists of many other organizations or systems) and that an organization is best understood by studying the way it adapts to its environment. The system can then be specified in terms of the processes it employs to cope with the environment and, thereby, to fulfill its function. In a systems theory approach, organizational behavior is determined by dynamic problem solving processes which are used by the organization in adapting to specific situations that arise in the environment.

According to Schein the dynamic problem solving process used by the organization to adapt occurs through a six phase cycle called an "adaptive coping cycle." The sequences of activities or processes used to adapt to the environment are:

1. Sensing a change in the internal or external environment.

2. Importing the relevant information about the change into those parts of the organization that can act upon it.

3. Changing production or conversion processes inside the organization according to the information obtained.

4. Stabilizing internal changes while reducing or managing undesired by-products (undesired changes in related systems that have resulted from the desired changes).

5. Exporting new products or services that are more in line with the originally perceived changes in the environment.

6. Obtaining feedback on the success of the change through further sensing of the external environment and the degree of integration of the internal environment.

According to Schein, all organizations will use this adaptive coping cycle; but some will do it better than others. In later adaptations of Schein's work Bennis advanced the concept that "when organizations are viewed as 'open systems,' as adaptive structures coping with various environments, the most significant characteristic for understanding effectiveness is competence."

According to Bennis, organizational health or competence can be defined by the following criteria:

<u>Adaptability</u>: The ability to learn from experience and modify behavior as a result; provide a flexible response to the environment.

<u>Identity</u>: The extent to which an organization knows "who it is"; understands its function or mission; has its goals accepted by its personnel.

<u>Reality Testing</u>: The ability to assess or sense properties of the environment.

Thus for Bennis, the competent organization identifies its goals, assesses its environment and learns from that environment. It does this through the application of problem solving processes called the adaptive coping cycle.

These concepts - organizational competence, organizational effectiveness, and organizational adaptation - form the cornerstone of the Olmstead model as it is applied to command and control. This model is harmonious with systems theory views, and is in agreement with Bennis's view that the competence of an organization is based upon the quality of its dynamic problem solving process or adaptive coping cycle. Olmstead believes that formal organizational structural or social psychological variables impact effectiveness or competence only to the extent to which they impact the quality of the organizational processes involved in the adaptive coping cycle.

In the Olmstead, Christensen and Lackey (1973) model of command and control both organizational process and organizational competence criteria are defined. Organizational processes are defined based upon the components of the adaptive coping cycle. Organizational competence criteria are defined by using a modification to the criteria outlined by Bennis. Processes are then grouped in terms of which criteria of organizational competence they most directly impact.

The organizational processes identified in the Olmstead model for assessing command and control include:

1. Sensing, the process by which the organization acquires information about the external and internal environments.

2. Communicating Information, the process of transmitting information that is sensed to those parts of the organization that can act upon it.

3. Decision Making, the process of making decisions concerning actions to be taken as a result of sensed information.

4. Stabilizing, the process of taking actions to maintain internal stability and integration that might otherwise be disrupted as a consequence of actions taken to cope with changes in the organization's environments.

5. Communicating Implementation, the process of transmitting decisions and decision-related orders and instructions to those parts of the organization that must implement them.

6. Coping Actions, the process of executing actions against an environment (external and internal) as a consequence of an organizational decision.

7. Feedback, the process of determining the results of a prior action through further sensing of the external and internal environments.

As mentioned above, Bennis' competence criteria are modified in the development of the Olmstead model. The authors drop "Identity" because of its social-psychological nature and add "Integration" because of its operational nature. Integration is defined as the "maintenance of structure and function under stress."

Each of the seven identified organizational processes can be related to or grouped with one of the components of competence as shown below.

Competence Component	Organizational Process
Reality Testing	Sensing, Communicating Information, Feedback
Adaptability	Decision Making, Communicating Implementation, Coping Actions
Integration	Stabilizing

Systems theory holds that organizations that adapt better will be more effective. The Olmstead model similarly predicts there will be positive correlations between measures of individual and group performance on the adaptive organizational processes and of the competence measures with a criterion of organization effectiveness. Olmstead's design and methods are beyond the scope of our review which is focused on models rather than on experimentation or validation of the same. However, Olmstead's results indicated high levels of correlation between effectiveness and competence (.93). Effectiveness also correlated with reality testing (.96) and adaptability (.79). The correlation between effectiveness and integration was non-significant, and of the process components only stabilizing and feedback also had low and non-significant correlations with effectiveness.

In implementing the experimental procedure, Olmstead et al. found that ratings on the seven processes were specific enough to define a variety of subprocesses. Thus, Olmstead's model has three levels: competence components, (3), organizational processes (7) and organizational sub-processes (19). The relationship of the three components to the seven organizational processes have already been noted. Table 3 shows these relationships and the sub-process relationships.

Later a modification to the original Olmstead model was developed by Olmstead, Baranick, and Elder (1978) and applied to brigade command groups. Eleven brigades participating in Computer Assisted Map Maneuver System (CAMMS) exercises were selected for the study. As in Olmstead et al. (1973), this study was designed to identify process and competence components of organizational behavior that lead to successful performance and effectiveness. The model is structurally identical to the earlier Olmstead model but differs in terms of content. While the structure of the model is unchanged, only one of the original competence dimensions and two process measures from the original model were retained. The organizational process behaviors that are included and which define organizational competence in this revised model are presented in Table 4.

It is probably worth noting that in the earlier Olmstead et al. (1973) work the correlation between an overall organizational competence score, derived from the various competence components, and the organizational effectiveness measure (quality of decisions) was .93. A correlation of .93 indicates that good staff work accounts for 86% of the variance in determining if a quality decision will be forthcoming when the time arrives. Clearly there is merit to the widely expressed concept that the purpose of a staff is to keep the commander from making mistakes.

In the later Olmstead work (Olmstead et al., 1978) the correlation between two less rigorously determined organizational competence measures and a battle outcome based effectiveness measure was .63 and .67, still quite large but only high enough to suggest that organizational competence accounts for about 42% of the variance when battle outcome is used as the effectiveness measure. Some of this reduction in the measured relationship was certainly due to the use of less rigorous, subjectively obtained organizational competence measures. It is likely, however, that a good deal more of the reduced relationship was due to the fact that even at the battalion level dealing with a thinking, reacting enemy introduces a considerable uncertainty into any battle situation.

Table 3

Relationship of competence components, organizational processes, and subprocesses (from Olmstead et al., 1973)

REALITY TESTING

<u>Sensing</u>

- Passive Sensing
- Active Sensing
- Sensing Action
- Sensing of Brigade Decision
- Sensing of Platoon Recommendation

<u>Communicating Information</u>

- Communicating Information Sensed
- Communicating Information, Discussion, and Interpretation
- Communicating Recommendations

<u>Feedback</u>

- Feedback Action

ADAPTABILITY

<u>Decision Making</u>

- Decision Leading to Active Sensing
- Decision Leading to Sensing Action
- Decision Leading to Stabilizing Action
- Decision Leading to Coping Action
- Decision Leading to Feedback Action
- Decision to Rescind a Previous Decision

<u>Communicating Implementation</u>

- Communicating Implementation About Decisions
- Communicating Implementation, Discussion, and Interpretation

<u>Coping Action</u>

- Coping Action

INTEGRATION

<u>Stabilizing</u>

- Stabilizing Action

Table 4

Olmstead, Baranick, and Elder (1978) Model

Process	Dimension[1]
Information Acquisition and Processing	Information Acquisition Providing Information and Intelligence
Adaptability	Anticipating Contingencies Timeliness of Adjustments in Plans and Operations
Implementation	Planning Decision Making Coordination
Communication	Communication
Supervision and Control	Responsiveness to Subordinate Unit Requirements Amount of Control and Supervision Quality of Supervision Clarity of Objectives Clarity of Roles

While Olmstead's basic concepts are similar in this study to those in his previous work, it is important to realize the great flexibility in this kind of a model. As was stated, only one competence component appears in both the original and modified models, and of the 15 processes defined in this model, only two (decision making and communications) also appear in the original. It becomes evident in reviewing the research that the actual model content is highly dependent on the perspective of the researcher rather than upon empirical data or taxonomy of actual tasks, duties, and functions of the command and control group.

Other work reported in this category has not been as influential as the research just discussed. Finley, Muckler, Gainer, and Roe (1974) and Finley, Muckler, Gainer, and Obermayer (1975) define command and control as the management component of command and control systems and identify six major activities of this management component in order to achieve mission goals. These activities represent one of the few attempts in the literature to create a taxonomy to define the functions of a command and control component and as such represent a rudimentary command and control model:

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[1]What Olmstead, Baranick, and Elder (1978) have labeled as process appears to be most similar to competence in Olmstead et al. (1973), what they have labeled as dimension seems most similar to organizational process.

1. Define general and specific system goals and standards. The command and control element needs to define and clarify the goal (and standards) for all system elements.

2. Define procedures and techniques by which the system will achieve its goals. This activity allows for integration of the procedures of the subsystems and needs to be sensitive to the possibility of over restricting the subsystems with detail.

3. Define constraints under which the system will operate. This activity indicates what each system cannot do and enables the appropriate delegation of authority throughout the system.

4. Responsible for the level of system performance achieved. This implies that the command control element is accountable; accountability ought to lead to understanding why performance deviates from standards.

5. Responsible for defining precisely the optimal interaction between management activities within the command and control component and the rest of the system. That is, the command and control element needs to determine "how much" management needs to be provided to the systems.

6. Define precisely system data acquisition, data processing, and information needs for all levels of the system. Command and control specifies the data to be collected for each of the systems in order to avoid collecting too much data.

In spite of the fact that these studies take a management perspective on command and control, they develop a model of the command and control structure, presented here as Figure 2, which is based upon "the concepts of modern control theory and particularly the sections of modern optimal control theory," (p. 22) rather than one based upon the management literature.

In the Finley et al. model, command represents a process which transforms objectives into action in the system. It does this in a hierarchical structure by interacting with the environment using data processing and information acquisition. Since the thrust of the two research efforts reported by Finley and her associates was not command and control modeling as such, her model has not had much effect on subsequent efforts.

Later in the decade Miller, Rice, and Metcalf (1979) reported a methodology for describing command and control activities in the U.S. Navy. Again, this is not, in a technical sense, a model of command and control. Instead, it is focused on a specific need, that of matching command and control activities with decision aids. Despite this narrow intent, the methodology could be of value in the development of a command and control model.

The first step in the Miller et al. methodology is to define the dimensions along which command and control decisions are made. These dimensions or decision categories are provided in Table 5. According to this model, any decision making activity in a command and control setting can be defined along

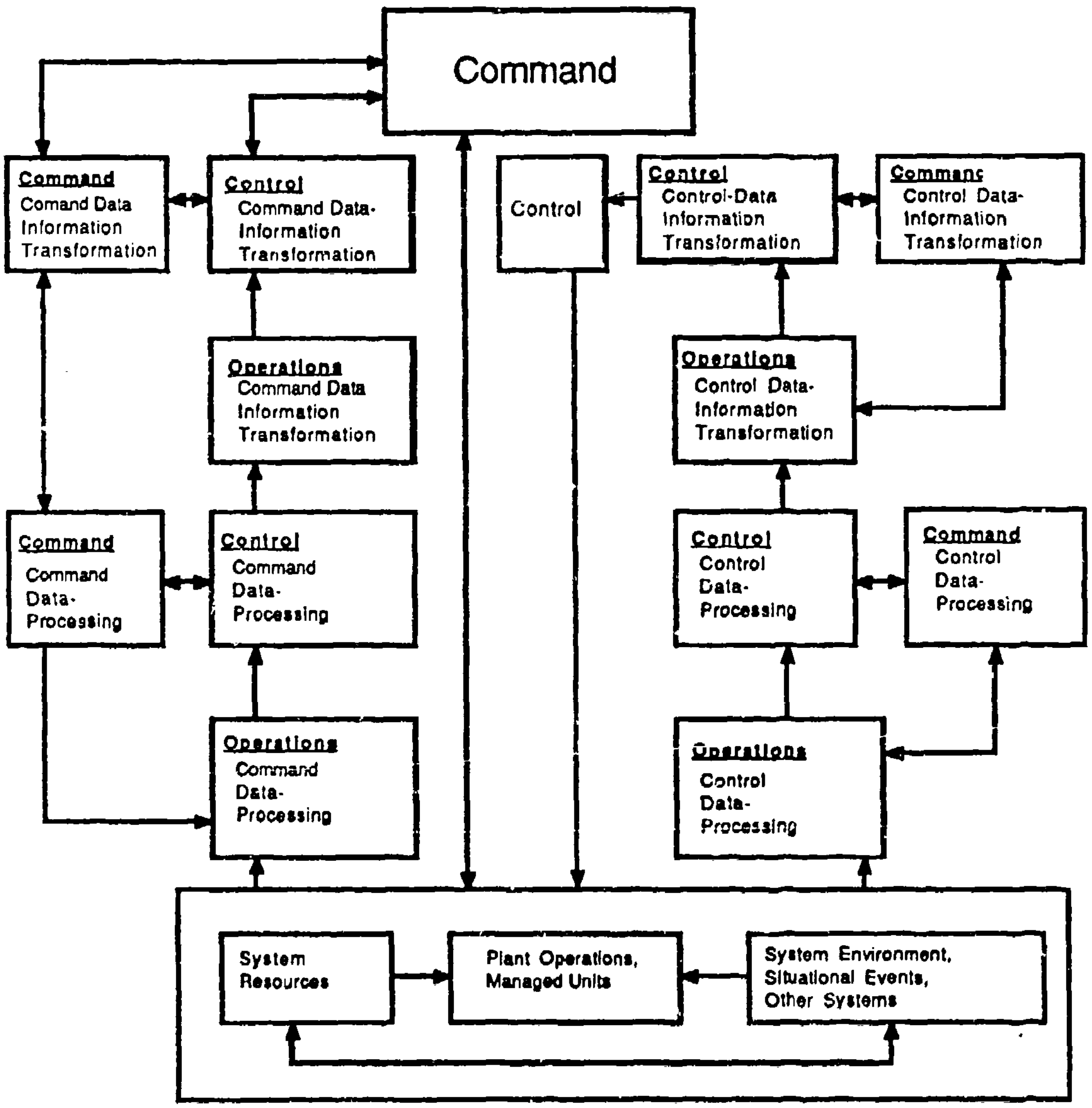

Figure 2. A Command and Control Functional Model from Finley, et al. (1974).

these dimensions. The second step in the methodology is to develop a taxonomy of decision characteristics. These characteristics include such things as the decision maker's resources, the importance of the decision, quantity of information available, and other things.

Table 5

Dimensions of the Taxonomy of Decision Categories (Miller et al., 1979)

A. Level of Command

1. Fleet
2. Task Force
3. Unit

B. Type of Warfare

1. Air Strike
2. Anti-Aircraft (AAW)
3. Anti-Submarine (ASW)
4. Amphibious
5. Surface
6. Intelligence
7. Logistics
8. Other Support Activities

C. Decision Function

1. Specify Subobjectives or Subtasks
2. Select Assets to Accomplish Each Subjective or Subtask
3. Position Forces and Specify Timing

D. Decision Context

1. Planning
2. Execution
3. Emergency

The point made by the authors is that all of the characteristics in the second taxonomy are important criteria for the selection of appropriate decision aids. Thus, decision making activities can be described using the first taxonomy and then analyzed using the second taxonomy. This leads to good decisions about the use of decision aids. It appears that the attempt to taxonomize decision relevant parameters is a worthwhile approach. It would rest on stronger grounds however if there were a systematic method for defining decision categories and characteristics. The authors do not describe how these dimensions were developed and do not develop their concepts enough for them to have been significant in influencing later work. It appears to be a reasonable conclusion that of the organizational based modeling efforts reported in this category, the most important work is that of Olmstead and his various coworkers.

Organizational, Process (Decision Making) Models

Organizational-Process models that appear to be oriented toward the decision cycle, as opposed to having a taxonomy or function thrust, are more common than other model types. This class of model seems to have begun to arrive shortly after Olmstead and his coworkers transferred the adaptive coping cycle concept from organizational theory to the command and control research arena. Representative models in this class do not appear, however, to be based on the adaptive coping cycle concept. Indeed, it would seem that it was the Zeitgeist that led to the movement toward decision making models that involved cyclical interactions with the environment. It appears that a Naval War College study by Maillefert (1974) was one of the earliest examples of this model type. Maillefert describes a command and control model which includes both a decision making process and an interaction with the environment. According to Maillefert, the decision making process requires the use of information and communication systems. The decision process itself includes a definition of the problem, diagnoses, search for information, development of options, and the selection of a course of action; these steps are not very different from many of the other military decision making models. Figure 3 shows the model Maillefert provides which he says summarizes the key elements of the control cycle.

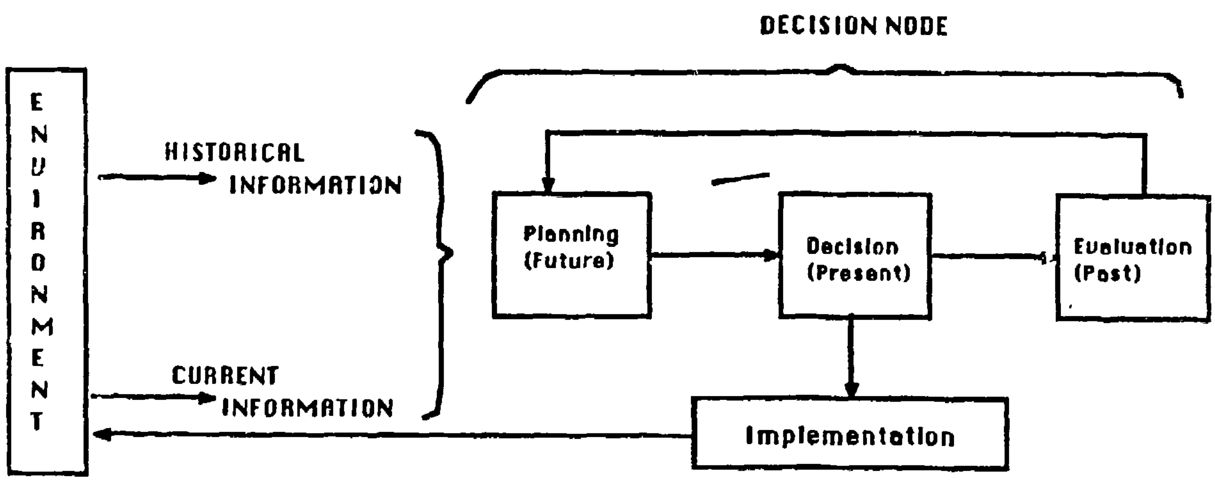

Figure 3. Decision Node, Control Cycle and Interaction with Environment (Maillefert, 1974).

Maillefert presents his model primarily as a control model and states that:

> Command and control is an input/output system designed to allow the maximum integration of all necessary information to produce a meaningful and realistic context for the commander, at each echelon's nodal point, to make decisions pertaining to the planning, directing, and coordinating necessary for his mission. The system uses communications for the transfer of information and this must be interactive throughout the organization: . . .(p. 14)

Later, the author quotes the Webster's Dictionary definition of control (control - to exert a restraining or directing influence on events) and states that the figure shows the key elements of the control cycle or sequence by which the decision-maker can fulfill his intentions through modification of other parts of the system via the medium of communications.

Other models of this type followed with some variations, and, in some cases, limited attempts at integrating prior efforts also followed. For example, in order to assess the role of time or timeliness in a command and control system, Lawson (1980a) first needed to develop a model of the command and control process. This model (Figure 4), which describes a decision making process, is conceptually similar to the military decision making model described elsewhere. The Lawson model can be applied to a command post or headquarters considered as an organizational decision making entity or it can be applied to a specific person or commander as an individual process. The model states that the command and control system needs to:

- Sense the environment
- Process information
- Compare present and desired states
- Decide on an action
- Act

This process is iterative in that after acting, the system continues to sense or monitor the environment for changes that create further decision requirements.

The hierarchical nature of the model should be stressed. Supervisors can direct an action of their subordinates or they can set a desired state (objective) required of a lower echelon. Once the desired state has been set, subordinates will use their command and control process to achieve that goal. It is within this framework that Lawson examines the role of time and its impact on command and control systems using a mathematical approach that is beyond the scope of this review.

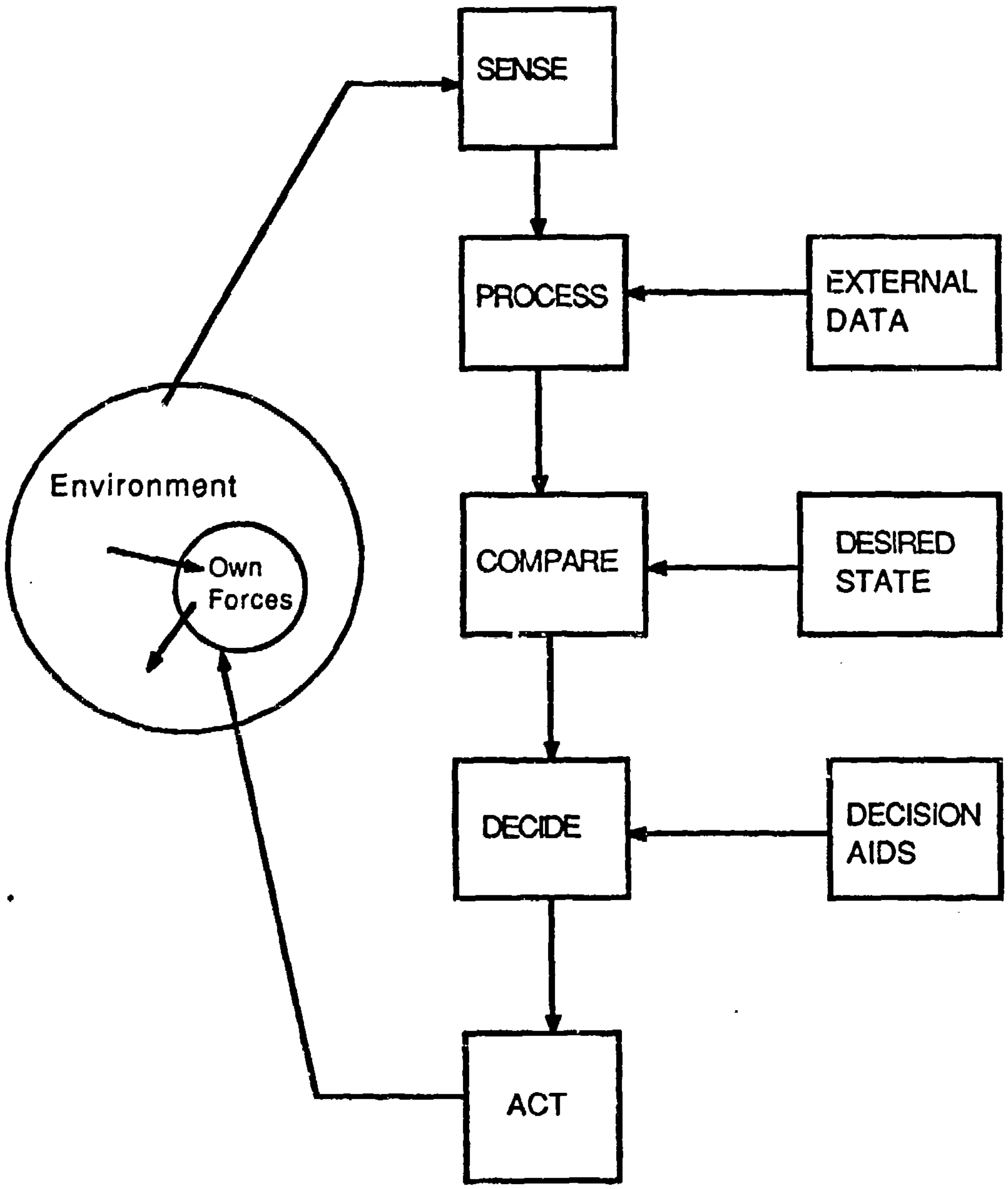

Figure 4. Command and control model from Lawson (1980a).

In another version of this model, Lawson (1980b) revises the manner in which he considers the intelligence aspect of the decision process. This later model, referred to as Lawson's C^3I Model, specifically includes an intelligence process component that interacts with the environment and the command and control process (see Figure 5). In Lawson's earlier model, the intelligence function was simply assumed to be part of several of the stages of the model including Sense, Process, and Decide.

Later, Orr integrated Lawson's C^3I model with a combat process model offered by Boyd (1981)[1]. Boyd's model is developed from his concepts about air to air combat and air warfare, and is more nearly a combat process model than a command and control model. According to Fallows (1981), what matters is "getting inside an adversary's O-O-D-A Loop." This "loop" consists of a cycle of (O) observing the enemy's actions, (O) orienting oneself to the unfolding situation, (D) deciding on a course of action and then (A) acting (Figure 6). The principle is that the side which can complete these cycles more quickly will ultimately prevail. Fallows, in discussing Boyds model says:

> The ultimate purpose of these maneuvers, in Boyd's view, is not to wear down the enemy's forces, but to destroy his view of the world . . . from Clausewitz, Boyd took the principle of reducing one's own "friction" (through simple equipment, decentralized commands, etc.) as one key to success. From Sun Tzu, he took the premise that the enemy could be destroyed if his friction was significantly increased.

Orr's integration of the Boyd and Lawson models is presented as Figure 7. Note that unlike the other decision making models, this model includes an interaction with higher and lower echelons as well as the direct inclusion of the Intelligence Analysis block. The Sense block in this model is identical to Boyd's Observe block while Process and Intelligence are comparable to Boyd's Orient block.

Another model from the same time period appears in a report by Wohl (1981) which describes the SHOR model of decision making. According to Wohl, there are four elements in command and control decision making - stimulus, hypothesis, option, and response. Each of these elements include specific functions and process specific kinds of information (Figure 8). While at first this model may appear to be structured differently than the others, the dynamics of the SHOR model are quite similar. When presented in a different format (Figure 9), the similarities of this model to what has been referred to as decision making models are apparent.

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[1] Orr references the Boyd model to Patterns of Conflict, a briefing Colonel Boyd presented at the Air War College, Maxwell Air Force Base, Alabama on 29 September 1981. Orr notes that at the time of his thesis, dated July 1983, Boyd had not published his concepts but that they had appeared in discussions by other authors including Fallows (1981).

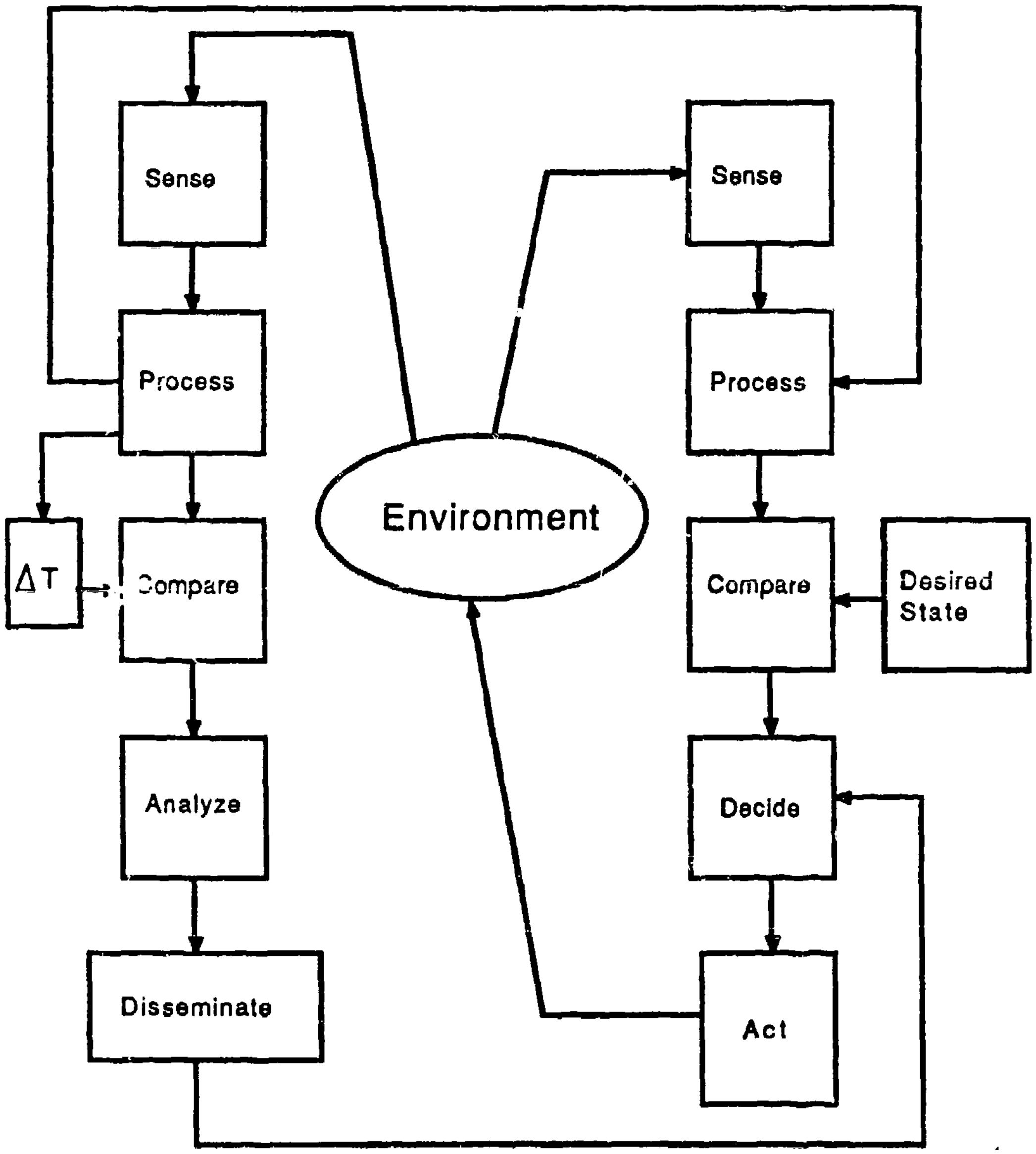

Figure 5. C3I Process Model from Lawson (1980b).

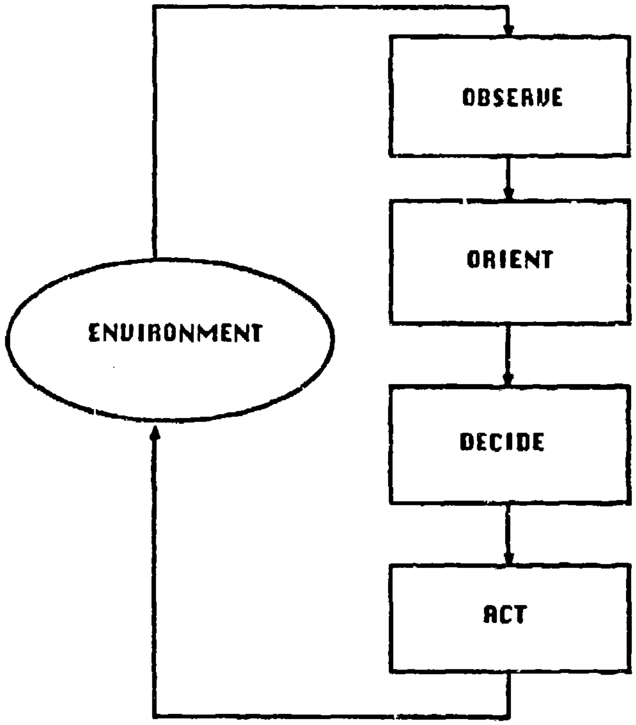

Figure 6. Boyd's O-O-D-A Loop Structure.

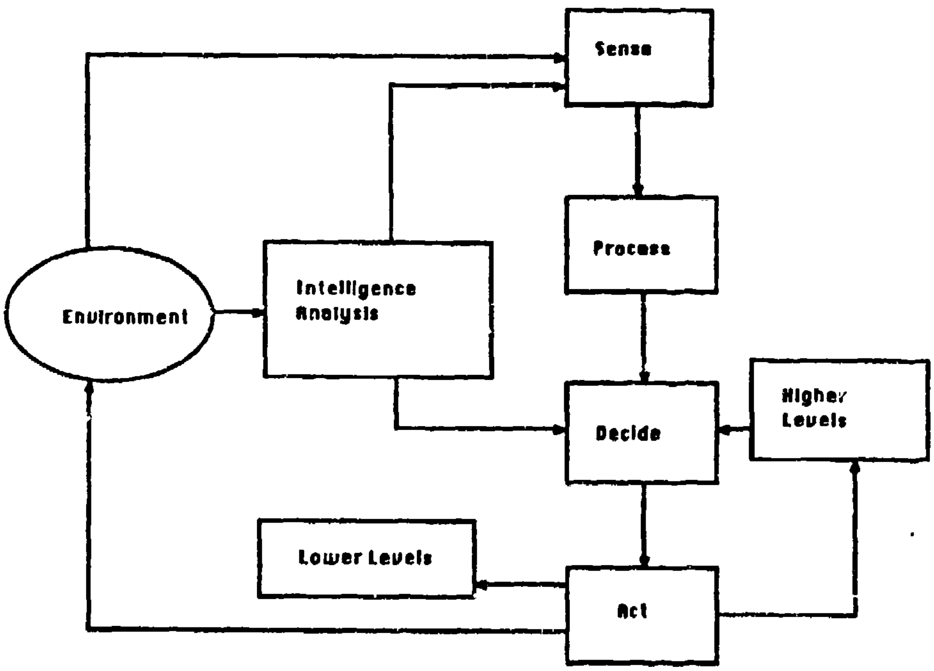

Figure 7. Conceptual Combat Operations Process Model (Orr, 1983).

Generic Elements	Functions/Required	Information Processed
Stimulus (Data) S	Gather/Detect	Capabilities, Doctrine: Position, Velocity Type; Mass, Momentum, Inertia; Relevance, and Trustworthiness of Data
	Filter/Correlate	
	Aggregate/Display	
	Store/Recall	
Hypothesis (Perception) Alternatives H	Create	COMMANDER'S CATECHISM: Where am I? Where is the enemy? What is he doing? How can I thwart him? How can I do him in? Am I in balance? How long will it take me to ...? How will it look in .... hours? What is the most important thing to do right now? How can I get it done?
	Evaluate	
	Select	
Option (Response Alternatives) O	Create	
	Evaluate	
	Select	
Response (Action) R	Plan	The air tasking order: Who What When Where How How Much The Near-Real-Time Modification/Update
	Organize	
	Execute	

Figure 8. Anatomy of Tactical Decision Process - the SHOR Model (Wohl, 1981). © 1981-IEEE

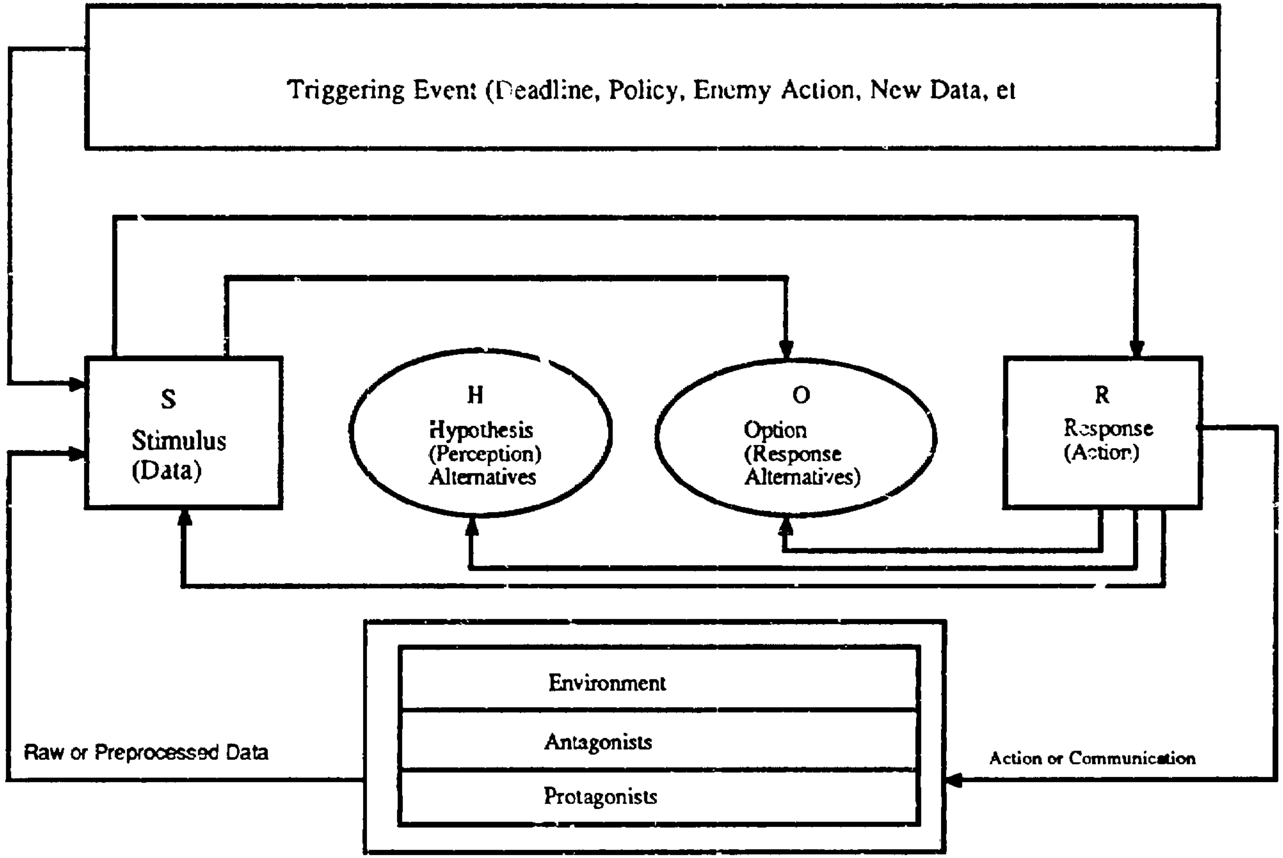

Figure 9. Dynamics of the Tactical Decision Process - the SHOR Model from Wohl, 1981.
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Rios (1985) describes command and control as the commander's process to focus the efforts of a force. His model includes: Assessment, Intent, Planning, and Execution as the steps in the process. According to Rios, Assessment is the process of defining the capabilities of one's own and the enemy's forces; Intent describes the commander's will or decision outcomes based upon the Assessment; Planning synchronizes maneuver and support at the right place and time; Execution is directly related to the "act" block of other models (See Figure 10). Rios' model is used to support his examination of the implications of the communications process problems which have traditionally interfered with the execution of the commander's intent in real battle situations. He observes, not unwisely, that problems in controlling forces arise in tactical headquarters as they are forced to rely on vulnerable communications systems to exert their control and maintain their awareness of the battle.

Another model which probably owes its heritage to the Lawson models is reported by Sweet, Metersky, and Sovereign (1985). The authors report on the results of an interdisciplinary, interagency workshop held to develop models and evaluation techniques for command and control. An expert panel (Land, Bean, Godfrey, Grange, Newman, Snyder, 1985) at this workshop developed a conceptual model of the command and control process which is presented as Figure 11. The model includes six basic stages:

Sense: The collection of information about the environment.

Assess: The transformation of basic data into information about intentions and capabilities of enemy and friendly forces.

Generate: The development of alternatives, based upon specified criteria in order to achieve a desired state.

Plan: The development of implementation details to execute selected alternatives.

Direct: The distribution of decisions to the forces.

The Land et al. model expands slightly on the Lawson model. Whereas Lawson speaks of a "decide" phase, the Land model breaks this phase down into "generate alternatives" and "select" a course of action. Whereas Lawson's model includes a phase called "act," the Land model breaks this phase into "plan" and "direct."

In spite of this somewhat increased fidelity in the Land model, Lawson's model is superior for several reasons. It adequately deals with the interactions of several organizational levels. In the Lawson model a higher echelon can direct the actions of lower echelons by providing information about the desired state to lower echelons. This ability is not explicitly recognized in the Land model. In addition, in the Lawson model a lower echelon can provide information or feedback to a higher level. Again, this is not explicitly described in the Land model.

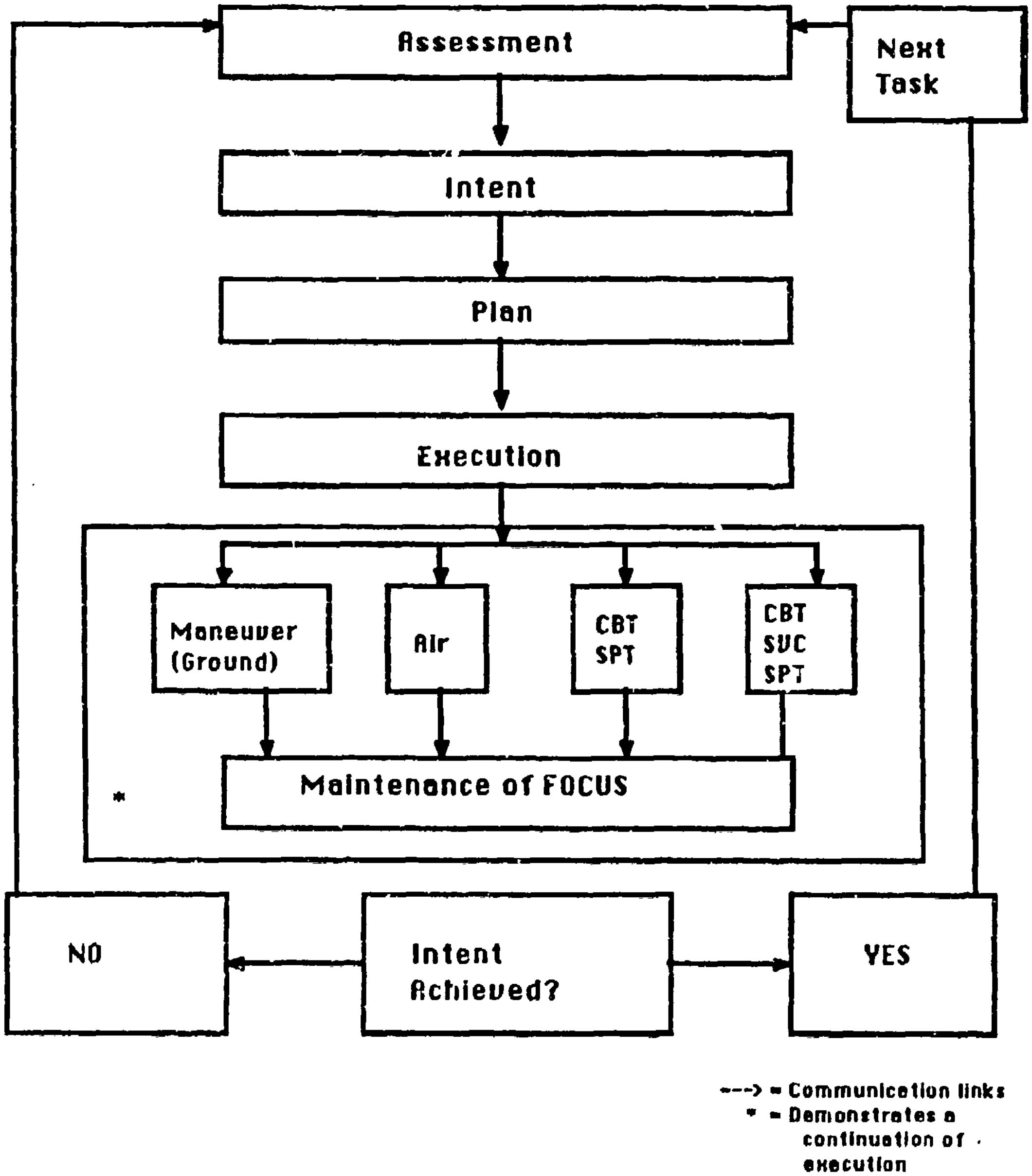

Figure 10. Command and Control Model from Rios (1985).

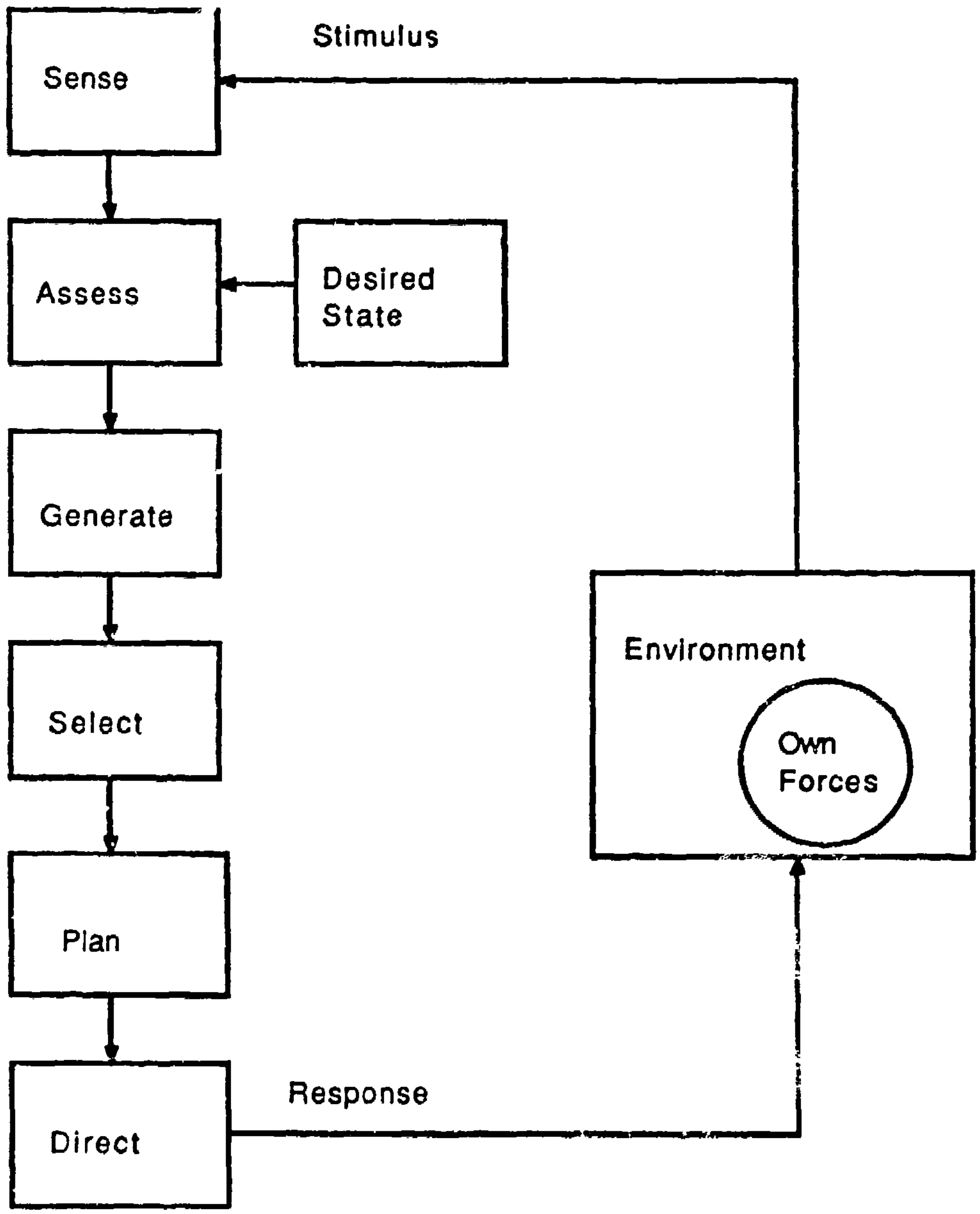

Figure 11. The Land et al. Conceptual Command and Control Process Model from Sweet, Metersky and Sovereign (1985).

Models of the type just discussed are rather well accepted, in one form or another, throughout the command and control community. For example, a U.S. Army Command and Control Operational Concept paper (1987a) provides a model of command and control that is relevant to the Airland Battlefield. In this model the major activities of the commander are decision making about the employment and sustainment of force. These activities are executed through the military decision making process which is called here C^3I (command, control, communications, and intelligence). According to this report, in some of the literature this same process is referred to as C^2 (command and control). But since C^2 assumes communication and intelligence, C^2 and C^3I are equivalent terms. A model of this command and control process referred to as the military decision making process is presented as Figure 12.

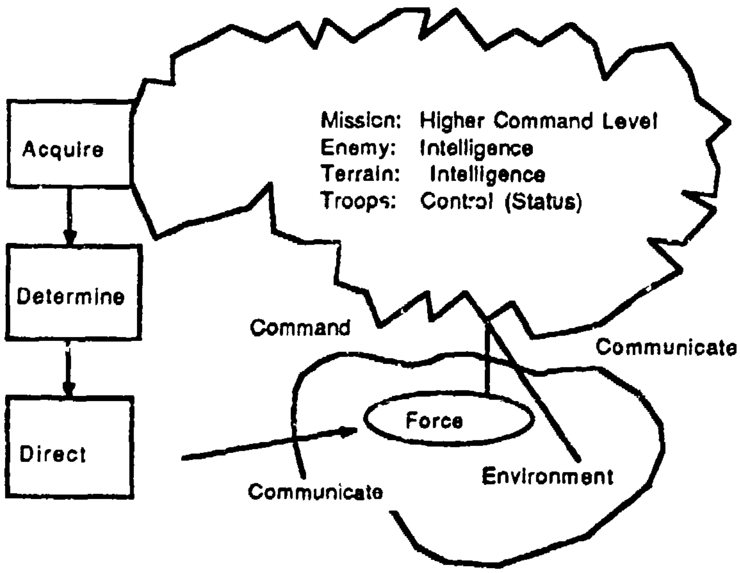

Figure 12. Command and Control Process from the U.S. Army Command and Control Operational Concept Paper (1987a).

According to this model, the intelligence function gathers information about the enemy and environment and provides it to the commander and staff. The control function determines if friendly troops are "in consonance with the intent of the commander" by providing information on their status. Note that this model is primarily focused on decision making and that the major product that flows through the system is information. Intelligence information, control information, and mission information from higher levels are all input or acquired by the command function. This function estimates the situation (Determines) and Directs the application of power. Communication is the means by which information flows through the system. The basic ideas in this model have been seen repeatedly in many of the process models discussed earlier. These models all tend to include a basic decision making process, an interaction of the system with the environment and a concern with information flowing through the system. The Army Command and Control Operational Concept paper also offers a paradigm for the command and control process, the human body. In this analogy, the senses acquire information and the information is sent to the brain through a communications system for decision making. The sequence ends with a transmission which results in an action by the neuromuscular system. In a later version of the paper (1987b), a step (Assess) is added but the model remains relatively unchanged (See Figure 13).

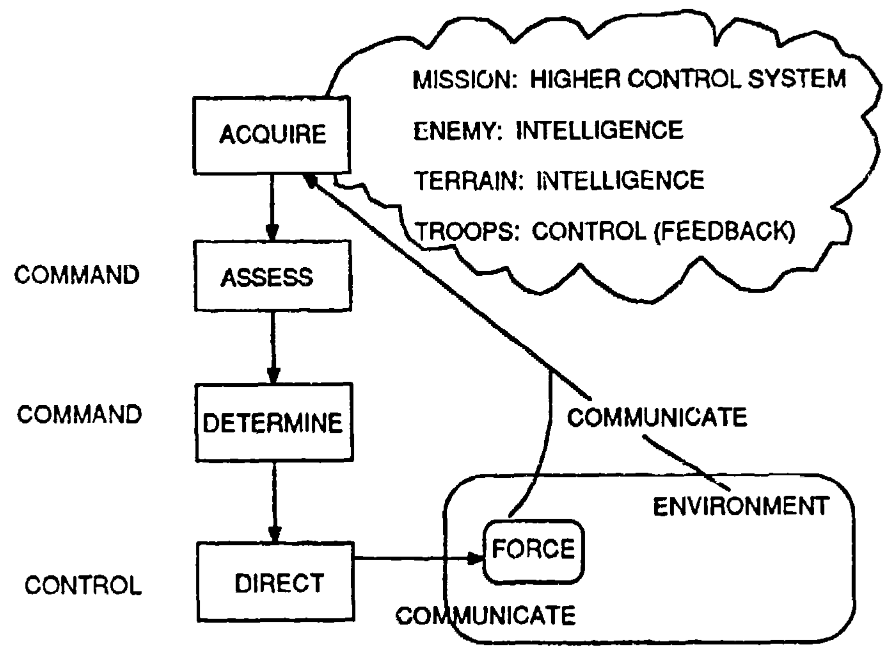

Figure 13. Command and Control Process from U.S. Army Operational Concept Paper (1987b).

It is interesting to note that there are some similarities between Olmstead's model based upon Management System Theory, the Finley model which taxonomized command and control tasks and the various decision making models. Both the Finley and Olmstead models actually provide a taxonomy of functions or activities required by the command and control component. The Finley model is focused on command and control component goals while Olmstead focuses on functional activities ostensibly to achieve similar goals. The functional activities in the Olmstead model are not very different from the "blocks" of activities described in the decision maker's models. That is, there is not much difference between the decision making model's concept of "acquire" and Olmstead's concept of "reality testing"; between decision making's "determine" and "adaptability"; and between "act" and "integration."

A final model of this type which needs to be discussed here is best known as the HEAT model. (HEAT is the acronym for the Headquarters Effectiveness Assessment Tool.) In the HEAT model (See Defense Systems, Inc. [DSI], 1984), the command and control process in a headquarters is considered an adaptive control system with six steps as shown in Figure 14. The steps of the headquarters cycle are described in DSI documents as:

Monitor. The headquarters staff must obtain information concerning those aspects of the environment that it wishes to control. The quality of monitoring can be measured by directly comparing the perceptions in the headquarters to reality. A secondary measure is the age of the information available to the headquarters.

Understand. The headquarters staff processes the available information to produce an assessment or understanding of the situation, i.e., a set of hypotheses about what is going on now and what can occur in the immediate future. The quality of the assessment or understanding of a situation can be assessed by measuring how correctly the set of hypotheses developed and considered by the headquarters staff matches what really occurs.

Alternative Actions. The headquarters staff develops alternatives specifying what can be done to alter the situation understood to exist. The quality of alternatives can be measured by determining how well they address the hypothesized situations in the understanding.

Prediction. For each alternative action considered, the headquarters staff makes a prediction about consequences. This includes at least two elements whether the material and force assets exist or can be assembled to carry out the alternative and what the enemy's response to it will be. Predictions can be evaluated by determining their completeness and the correctness of those predictions which are tested by the plan adopted.

Decisions are made on the basis of the predictions. There are no direct measures of decision quality in the HEAT system. However, decisions always take the form of a plan to be implemented, specifying missions, operating boundaries, assets, and a timetable for subordinate forces. The measure of effectiveness in the HEAT methodology is how long the plan works.

Direction. Plans are communicated to the appropriate organizations in the form of some directive. The correctness of directives can be assessed by examining the extent to which the decision and plan are correctly stated.

The HEAT model represents a good transition to the final two categories of organizational models; HEAT's concepts were created as part of an attempt to develop an evaluation process and although the basic model is a decision cycle based model the addition of certain concepts create a more sophisticated model with clear evaluation features. A derivative of HEAT, called ACCES (The Army Command and Control Evaluation System) is also of this type. A joint development of ARI and DSI, it is described in the next section when HEAT is revisited.

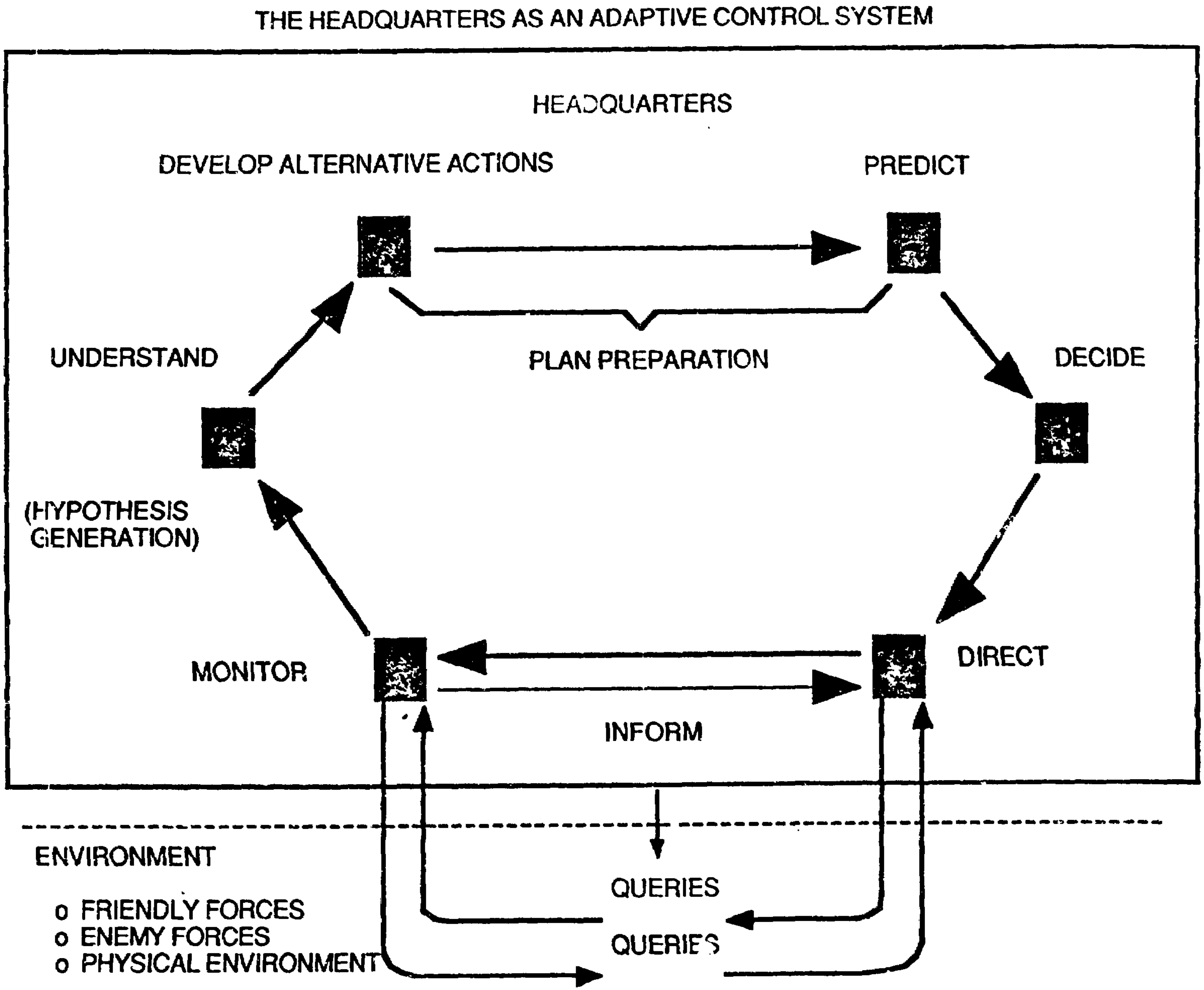

Figure 14. HEAT Model from DSI (1984).

Organizational, Evaluative Models

Attempts to develop systems to evaluate command and control activities can provide an implicit model of the command and control function. Two evaluation systems are discussed below: Headquarters Effectiveness Assessment Tool (HEAT) and the U.S. Army Training and Evaluation Program (ARTEP). The HEAT system is based upon the model described earlier. The ARTEP system has additional model features, discussed below, which expand it and form the basis of an evaluation system.

The DSI (1985) Model of Command and Control forms the basis of a method to evaluate headquarters command and control operations. This evaluation system, the Headquarters Effectiveness Assessment Tool (HEAT) has been developed for the assessment of what DSI describes as the command and control cycle activities for echelons above corps. The basic HEAT methodology consists of three sets of measures and a related model, explicitly stated, of the command and control process. The basic model defines the adaptive control cycle that forms the basis of the evaluative procedure. The model developers added another dimension to their model in the form of effectiveness measures based on the demonstrated success of the adaptive control cycle. By supporting these basic concepts with a series of measures that reflect how well five of the six cycle phases (decide is not measured) are performed, how well command post coordination is accomplished, and how well the various locations (nodes) in the command and control share common--and correct--views of the situation, HEAT creates a diagnostic capability which permits command group performance to be compared to command group effectiveness.

There are two major indications of effectiveness in the HEAT system. According to the HEAT User's Manual (1984), the basic overall measure of the effectiveness of headquarters is the "average percent of expected time that plans. . . are actually in force". The headquarters, of course, identifies either explicitly or implicitly how long a battle plan is intended to last. The second measure is based on how a plan degrades in those cases where new plans are required. The HEAT model perceives three "replanning" situations each based on how deviant the actual situation differs from the situation the plan attempted to create. The difference, termed incongruence, may be minor, moderate or major. In a minor incongruence situation, no change of plan is needed except for adjustments which can be made by the persons in the command post who are monitoring, and fighting, the battle as it progresses.

Moderate and major incongruences represent the development of situations that the current plan is not able to handle. In cases where understandings, alternative developments, and predictions already made are such that the unfolding events are within a set of contingencies already considered, the incongruence is considered moderate since the work already done permits new decisions and plans without redoing the complete decision cycle. In those cases where the incongruence is so large that it was not considered as a possible contingency, a complete cycle is required. These three situations, and the basic model, are diagrammed in Figure 15.

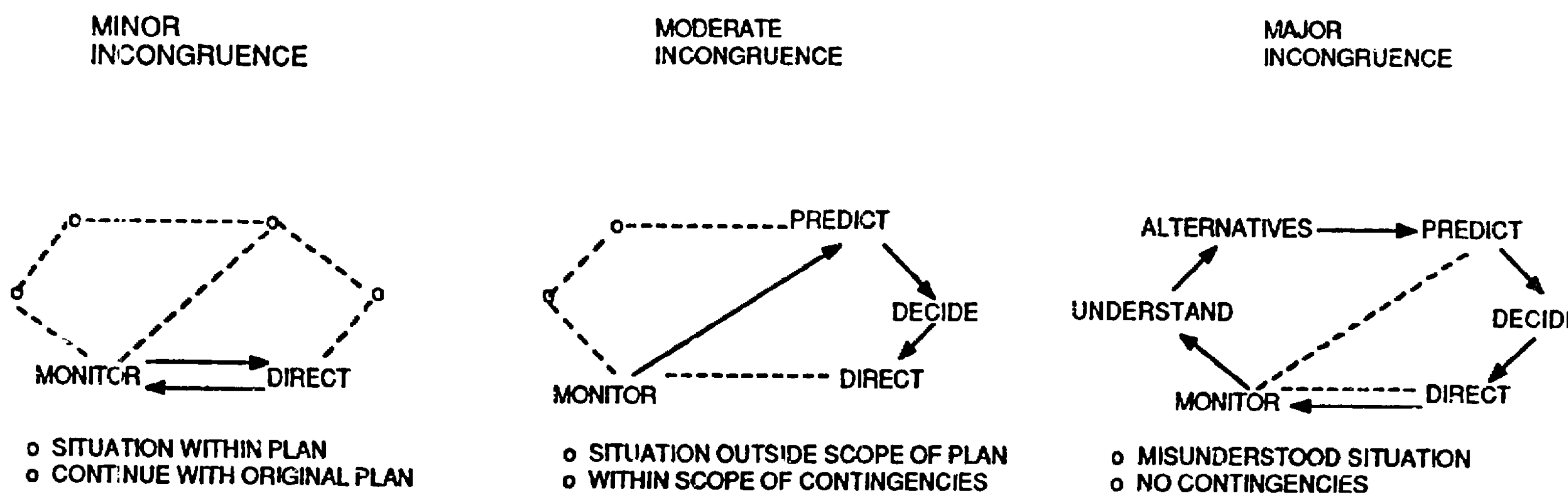

Figure 15. Decision Cycle Alternatives as Defined in HEAT (DSI, 1984).

ARI, working with the contractor who developed HEAT, has modified the HEAT concepts and revised the HEAT model to better support a command and control evaluation system for Army corps, divisions, and brigade headquarters. The system is referred to as the Army Command and Control Evaluation System (ACCES).

The ARI-ACCES model, as described by Crumley (1988a, 1988b) incorporates four major concepts. First it depicts a six phase decision cycle: monitor, assess, generate, decide, plan, and direct. The second concept addresses the need for tasks which must be performed to support the decision cycle related command and control processes. These tasks, called Alpha and Beta tasks in the model, refer to how well the battle staff passes information throughout the various command post sections and how well the command post maintains its relationship with the exterior world. The Alpha measures relate to coordination, CP network capability, and maintaining a common perception of the battle. The Beta measures deal with reporting to higher echelons, coordinating with major subordinate commands, and the time required to distribute and clarify orders to all critical users.

ACCES provides measures for five of the six decision cycle phases and the two sets of support tasks. ACCES does not measure the decide process. Instead the third ACCES concept is that how well the decision survives provides a subtle, indirect measure of battle plan effectiveness. ACCES, like HEAT, postulates that good plans last longer than bad plans. ACCES does not use plan duration as the measure. Instead the number of basic assignments changed from those in the original battle plan is tallied over the expected life of the plan. The division command posts' assignments are missions, assets, schedules, and boundaries. If many changes are needed ACCES infers that the planning process was less effective than if there were few or no changes.

By describing command and control using these concepts ACCES avoids the need or even the appearance of a need, for ACCES observers to evaluate the quality of a plan or the correctness of decisions. Instead command and control effectiveness is indirectly inferred from the action of senior decision makers who, as they look at how the battle is progressing, decide when the situation needs corrective action from their level and how major an action must be undertaken. This approach enables the modelers to consider the competence of the command post and its resulting effectiveness independent of the need to evaluate the competence and effectiveness of the totality of the unit being commanded, but to do this in a context, as depicted in Figure 16, which permits such comparisons when unit data on competence or effectiveness is available.

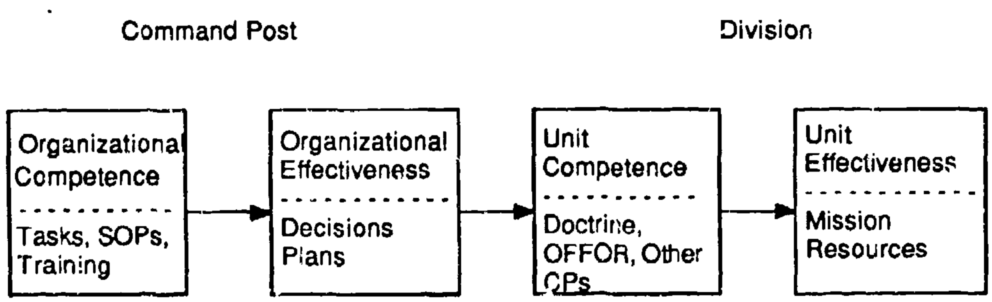

Figure 16. Command post vs. unit commanded model (Crumley, 1988b).

The fourth concept deals with the magnitude of the deviations, or incongruences, that occur as a plan is exposed to the machinations of a thinking enemy. There are five levels of deviations, each is based on how the immediate or perceived future situation differs from the situation the basic plan was trying to create. When things are going "according to plan" only tactical or minor changes are needed to maintain the original plan. An intermediate level incongruence occurs when the original plan can no longer be maintained by minor and tactical changes but a suitable alternative has been previously considered and is available. A major incongruence requires a full trip through the decision cycle and indicates that the battle staff has been surprised. The chaos state represents the situation where the events of the battle have become so obscured that there is not enough understanding to support a replanning effort and, hence, more monitoring is needed before an attempt can be made to assess the situation. Figure 17 depicts the ACCES model.

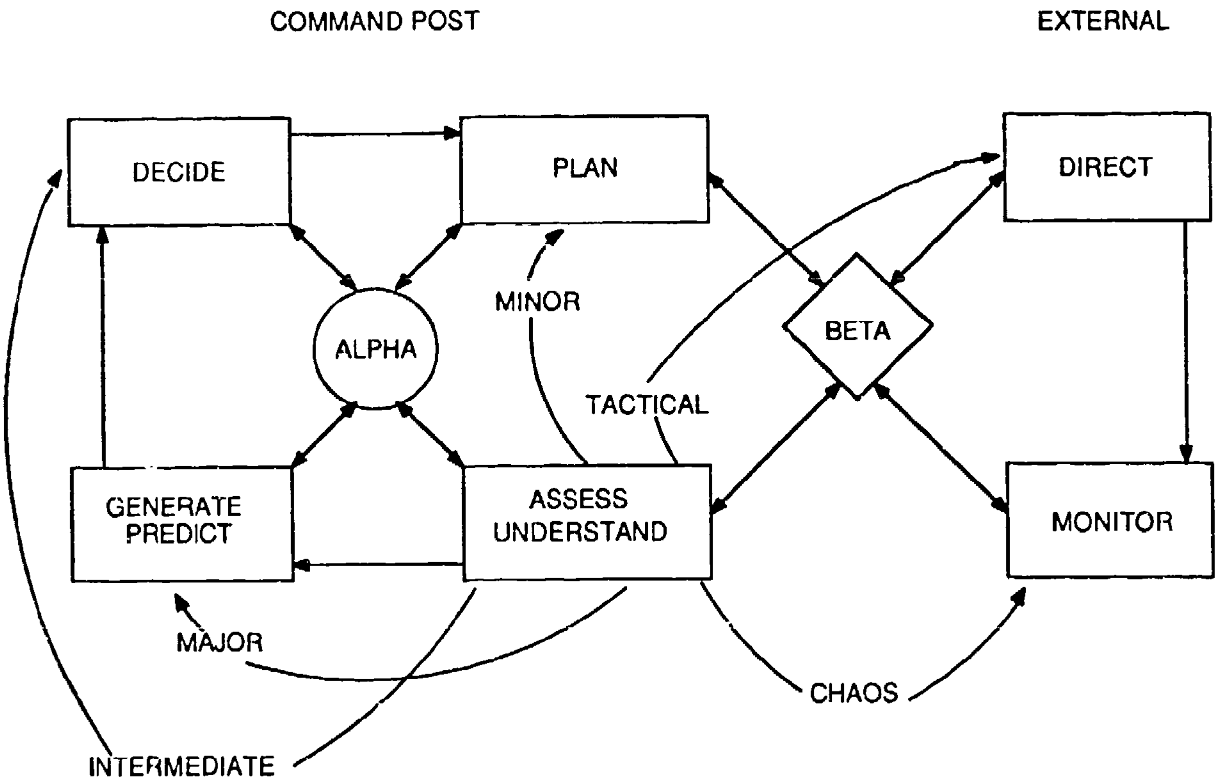

Figure 17. ACCES model showing decision cycle steps, ancillary tasks, plan degradation levels and the relationship of internal and external factors from Crumley (1988b).

A major training and evaluation tool, the Army Training and Evaluation Program (ARTEP) has been developed by the U.S. Army. Some of these training programs are developed for use as command post evaluations and therefore represent, at least implicitly, a command and control model. ARTEPs exist at present for battalion, brigade and division command posts. Barber and Kaplan (1979) have provided a figure, reproduced as Figure 18, which diagrams battalion ARTEP tasks. The ARTEP model of the battalion command and control process, only implicitly defined in the ARTEP, is a task oriented model of the command and control process.

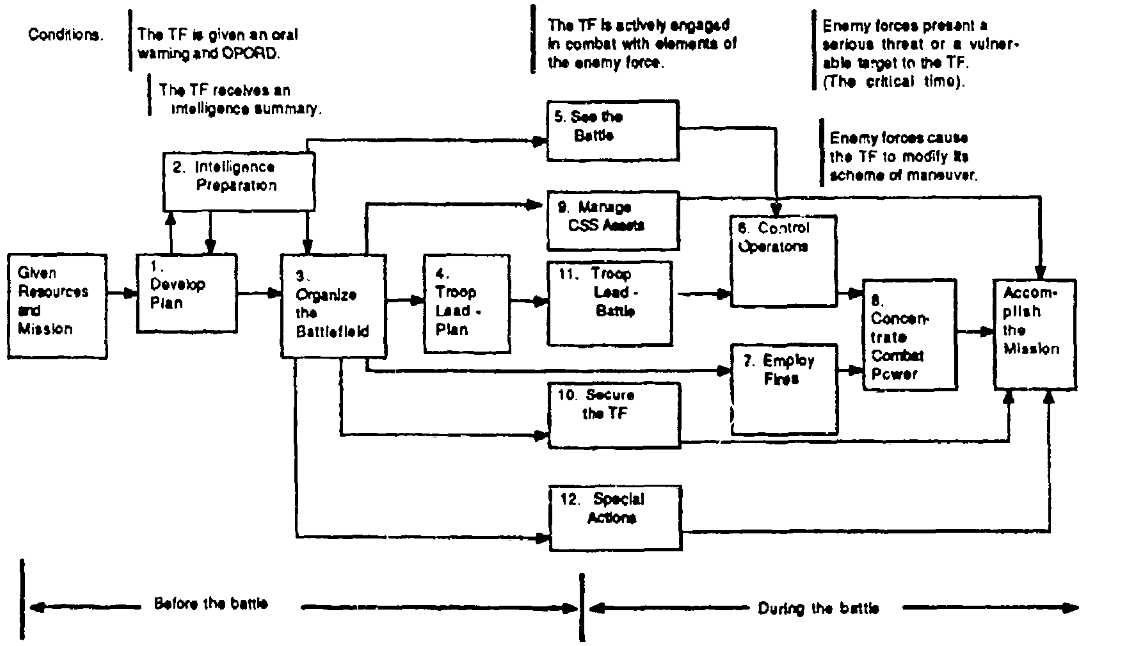

Figure 18. Flow Diagram of the Battalion Command Group ARTEP (Barber and Kaplan, 1979).

Similar representations can be derived from brigade and division ARTEPs, and more recent, AMTEP[4], documentation. For example, the Light Infantry, Command Group and Staff ARTEP defines three functional areas for division command: Planning the Battle, Fighting the Battle, and Sustaining the Division. Within these areas specific tasks and subtasks are developed for the command group along with recommended procedures to be followed by the various sections for performing each of these tasks. The responsibility for each of the tasks is well defined in the model and these tasks are grouped together by: Strategic Deployment, Tactical Command Post, Main Command Post, and Rear Command Post.

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[4]AMTEP refers to Army Training and Evaluation Plan, Mission Training Plan, an expanded title that recognizes that Division and Corps ARTEPs are mission oriented.

The ARTEP thus requires a command post architecture and a list of tasks and activities. All of these required supportive materials are, of course, provided by documents such as SOPs, FMs, etc., which constitute the basis of the implementation type models discussed earlier.

A Command and Control Theory Attempt

The final research effort that needs to be discussed under the general category of organizational models is one that also fits into the category previously labeled Organizational-Process (Taxonomy or Function) Models. It needs to stand alone, however, because it is an attempt to develop a complete command and control theory and as such it becomes, by its very intent, a different kind of model than the other models discussed in this review which have a much more narrow focus.

In their model, DSI (1985) defines seven elements as essential parts of Command and Control Theory. Each of these elements: (1) Military Environment, (2) Control Theory, (3) The Command and Control Cycle, (4) Information Transformation, (5) Nondominant Command and Control Countermeasures, (6) Time and Network Capacity, and (7) Dynamic Adjustment, will be described below in more detail.

This model is an attempt to go beyond previous thinking in command and control in that it includes as part of the model specific concerns about the nature of warfare as well as an attempt to include thinking about the nature of organizations. Unfortunately, the organizational perspective is primarily based on an engineering or control theory modeling with a lesser focus given to human behavior and activities. More importantly, the elements of a command and control theory are presented without a real attempt to integrate the concepts. Thus, the model remains at best a disjointed listing of important issues. Our view of how the elements of the theory appear to fit together are presented below.

Command and Control Cycle. The most important of the seven elements of the DSI Command and Control Model is the Command and Control Cycle. This cycle is somewhat like the military decision making model; it is described as a critical set of command and control activities or behaviors. Within the command and control cycle, as in the Olmstead Model, the command and control component must adapt to its environment while attempting to achieve its objectives. The cycle involves the six steps shown earlier in Figure 14. The other six elements of the command and control theory define the nature and constraints upon the command and control cycle. The command and control cycle is developed from concepts used in Control Theory. The goals of the cycle are defined as a result of the nature of the Military Environment. The cycle operates within and is constrained by the current nature of warfare which is best described in terms of Non-Dominant Counter Measures. According to the model, the job of the command and control cycle is primarily Information Transformation. Communication is thus a critical aspect of command and control theory, but is limited by Time and Network Capacity and by Dynamic Adjustments in these network systems. Figure 19 shows how the researchers depict the relationship of command and control to their Dynamic Adjustment, Military Pattern, Movement, and Methods concepts. The concepts are described in the following manner.

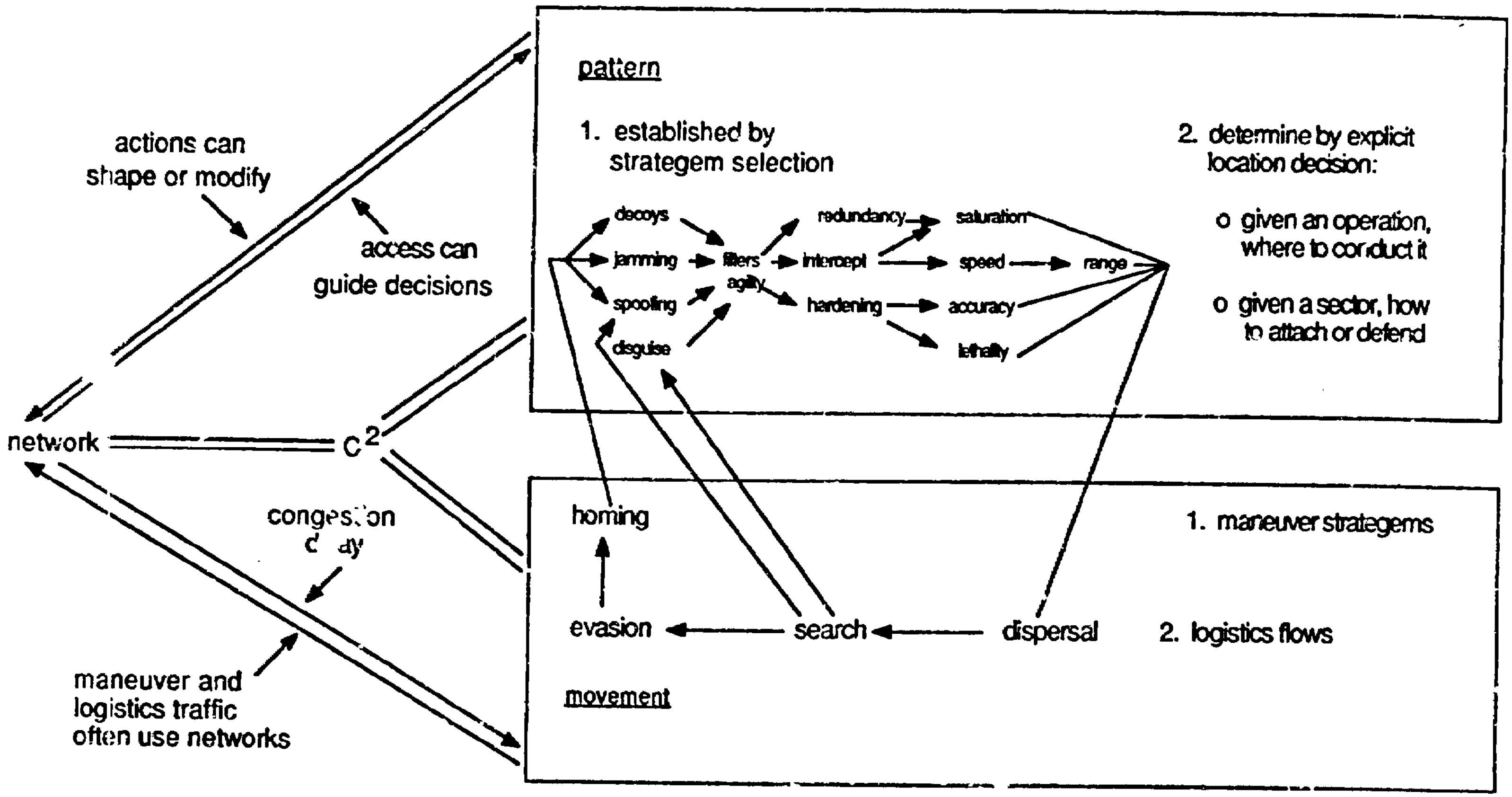


Figure 19. Dynamic Adjustment Schematic Relating Command and Control to Military Pattern, Movement, and Methods (from DSI, 1984).

Control Theory. Control theory examines, from an engineering perspective, the variety of techniques used to guide or manipulate a process to a goal or objective. According to the authors, control theory is directly applicable to command and control systems because these systems require a variety of regulatory mechanisms. The regulatory systems described below resolve the randomness and other disturbances in the command and control implementation process and are used in an effort to reduce the gap between a desired state and current achievements.

The authors suggest that there are four types of control systems:

Regulators: Systems designed for specific and preplanned problems.

Error-response: Systems regulated by success or failure (outcomes) of the process.

Adaptive: An error response system that learns from experience and that can adapt quickly.

Look ahead: An adaptive system that can avoid problems through the use of prediction.

All of the classes of control systems may be found within a large command and control system.

Military Environment. The nature of the military environment, described below, leads to specific goals for the command and control cycle. The military environment is conceived of as consisting of own and other forces. Each of the opposing sides has the following components:

Sanctuary: A civilian population and resources.

Force: A military force.

Support "pipeline": The support provided by the sanctuary to the force.

Counterforce attack: An attempt to reduce the opponent's military process.

Sanctuary attack: An attack directly on the sanctuary.

"Pipeline" attack: An attack on the support pipeline from sanctuary to opposing forces.

Counterforce defense: Defense against counterforce attack.

Sanctuary defense: Defense against sanctuary attack.

Each of the opposing sides can choose from among these military options. Command and control, then, according to this model is the decision making process involved in choosing from and then monitoring the implementation of the chosen options. "Such selection - which implies decisions and implementation plans - requires command and control." In developing their options the command and control team also needs to consider which of the following goals it is attempting to achieve:

Guidance: Produce plans for action by own forces.

Understand the opponent: Understand the opponent's command and control process so that you can interfere with opponent's future plans.

Shaping: Understanding the opponent well enough to determine the opponent's decisions.

Protect: Protect your own process from the opponent's manipulation.

Non-Dominant Command and Control Countermeasures. The effectiveness of the command and control cycle is reduced by the attempts of the opposing force to cause error in command and control cycle predictions. These attempts to cause error, to make it difficult to predict the outcomes of a strategy, are called countermeasures. Thus, an attempt by one force, for example, to use a search strategy will lead the opposing force to evade, disguise and spoof. Since every such measure has a countermeasure, the result is a state of non-dominance between two opposing forces. That is, there is no one ultimate strategy. "Combat results are inevitably determined by. . . the decisions of both sides."

Thus command and control systems must:

- Possess multiple repertoires
- Be able to move quickly from one action to another.
- Be able to induce error in the opposition.
- Be able to shape the opponent's actions.

Information Transformation: The control cycle, according to this model, is conceived of as handling a flow of information. Information is selected, modified, and then rearranged by the cycle and yields directives. Thus, information transformation becomes a component of the model.

The authors focus primarily on the use of information transformation concepts for evaluation purposes. It is our belief that the measures developed, however, could be developed without necessarily basing them on information transformation concepts. Specifically, according to the authors, information can be used to define three things: the actual situation (ground truth), the estimate of the situation and the target situation or the goal. Comparisons among these three variables provide the following measures:

Process quality: Comparison of the actual and expected situation. It is a measure of the cycle's ability to use information to predict the truth.

Perceived success: Comparison of the expected situation with the target situation or goal. It is a measure of the error involved in the control cycle's estimate of success.

Achieved success: Comparison of the actual situation and target situation. It is a measure of the control cycle's ability to achieve its target.

Time and Network Capacity. A window of time exists, defined largely by the opponent's capabilities, within which the command and control cycle must occur. A defensive combat window begins with a prediction of or beginning of an offensive action by enemy forces while an offensive combat window begins with the staff collecting information about the status of a threat. The combat window closes with the selection of appropriate counter measures.

Military systems are necessarily composed of large forces operating over large geographic areas with requirements for many different skills. To become coherent (sic), forces are diversified, dispersed, and broken down into smaller units. They thus require a communication network to join them together. The command and control network creates a capacity for information flow or "traffic" which flows between points in the network called "nodes." Required traffic capacity at each node depends upon how the node is defined.

According to the authors, these factors define a node's required capacity:

- Role - command tasks required.
- Centrality - concentration of authority and control.
- Connectivity - rate at which communications are transmitted between nodes.
- Functions - composite of role and centrality.
- Structure - elements and their reporting relationships.
- Size and Resource Mix - resources available to operate network.
- Procedures - methods of guiding traffic.

Dynamic Adjustment. The authors suggest that the concept of dynamic adjustment provides an integrating framework to merge the other command and control concepts. It states that the components of the command and control network will adjust to each other over time. Adjustment can be described using the following terms:

- Patterns - geographic arrangements of entities.
- Movement - traffic among entities.
- Network structure - configuration of nodes.
- Connectivity - quality of service for any movement.

Figure 20 shows how the researchers portray their command and control variables in a Dynamic Adjustment situation.

As we have suggested, we believe this model requires better development and more integration so that it can be used for prediction and so that it presents testable hypotheses. It appears that it has been developed with the primary goal of using its concepts to support development of the command and control evaluation system, called HEAT, which was discussed earlier. Unfortunately, in the proposed evaluation system only two factors are stressed--the goals of the command and control cycle and the cycle itself--while little in the methodology examines the other supposedly critical components of command and control.

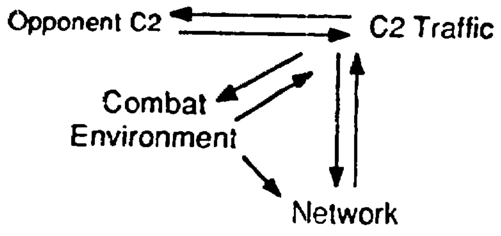
This apparent lack of consistency does not deter the report's anonymous authors however, and they do provide some indications of how their model relates to selected performance measures. They indicate, for example, that performance measures can be developed for each level or goal (see Military Environment, p. 41) of the command and control cycle and for each step in the cycle.

Behavioral System Based Models

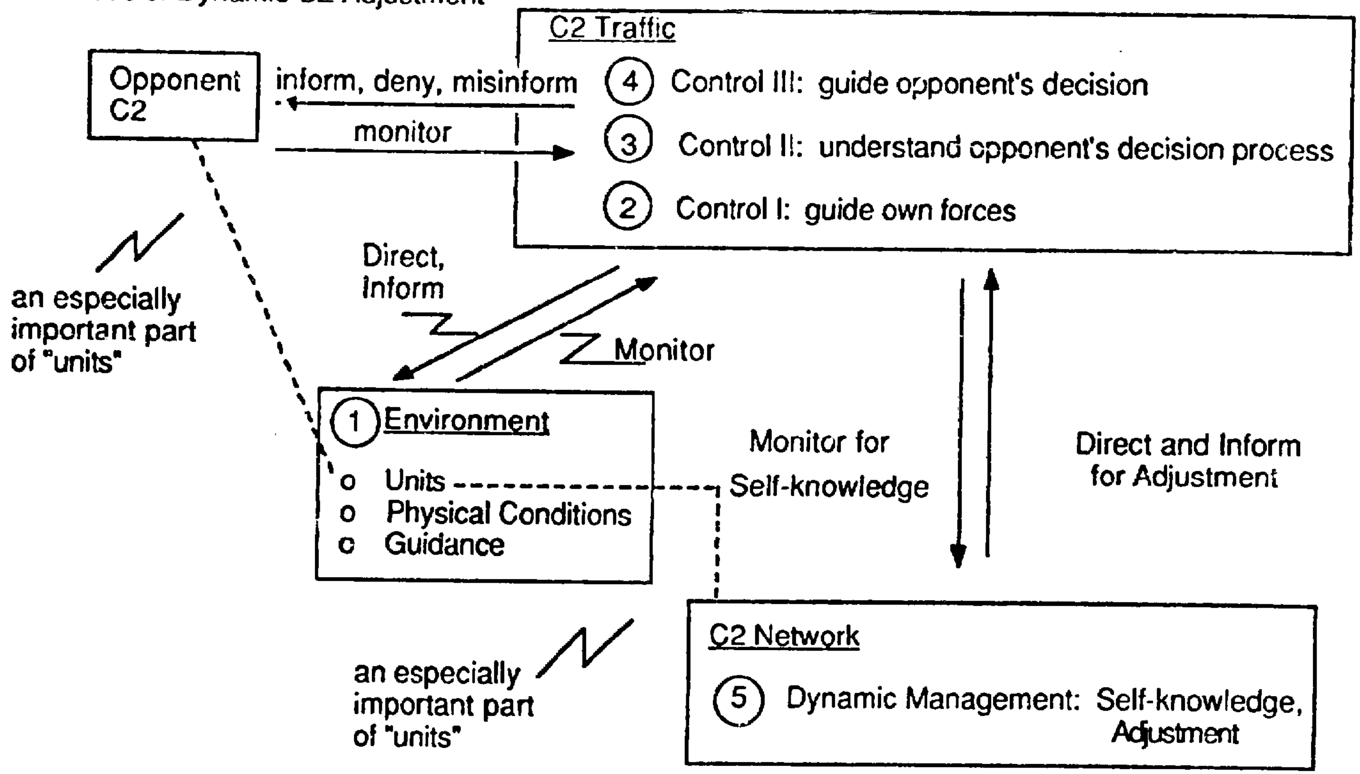
There are two types of behavioral system based models; those that evolve from decision making research and those that exist because of a computer related impetus.

Behavioral System, Decision Making Models

Military decision making models and organizational decision making models which have been applied to the command and control function have been presented under "Organization Process Models." There is also some discussion of the literature concerning the individual decision making process. Much of this work has not been applied to the command and control environment and is beyond the scope of this report. Studies reported on below are those in which decision making within a command group was modeled or studied.



a) Summary Schematic of Dynamic C2 Adjustment



b) Expanded adjustment schematic showing families of C2 Variables

Figure 20. Command and Control Variables in the Context of Dynamic C2 Adjustment (From DSI, 1985).

A series of studies conducted for the U.S. Army Research Institute for the Behavioral and Social Sciences (Krumm, Rowe, and Torpey, 1970; Ryan, 1969; Krumm, Robins, and Ryan, 1973; Robins, Buffardi, and Ryan, 1974) focused on developing a methodology for assessing and evaluating the quality of decisions made in command and control military situations. The Robins, Buffardi and Ryan (1974) report is representative of these efforts. In their study, subjects were given appropriate information concerning a Command and General Staff College (CGSC) developed scenario which required developing a division in defense Operation Order (OPORD). Subjects completed the sequential planning phases by filling out response sheets to record allocation of combat power to the echelons of defense, task organization, and missions for subordinate brigades. The CGSC school solution was used as the criterion measurement. The subjects' solutions were scored using scales that measured how much their solutions deviated from the CGSC's schoolhouse solution. The quality-of-solution scores were then correlated with behavioral and biographic data to see if such data predicted decision quality.

The research outcome is not particularly germane to this review, but results did show that a dedicated research facility helps make such research possible and that the schoolhouse solution, which is, of course, based on expert judgement, provides a suitable method for determining planning effectiveness. More important for purposes of this review is the fact that in order to conduct the experiment, the authors needed to develop a definition or model of the military tactical decision making process. This process was termed the "command cycle" and was packaged as a four-phase sequence. The command cycle developed by the researchers is presented as Figure 21.

A later research effort by Akst (1982) identified and evaluated seven different command and control decision making "alternatives" in order to determine differences between these systems. Akst's work was conducted in an effort to evaluate different command and control effectiveness levels between certain existing and evolving systems. The seven alternatives were:

Full TCO: A current tactical combat operation system being developed. It provides assistance to the operations and intelligence staff from headquarters to infantry battalion and squadron operations centers.

Nodally Austere TCO: Identical to Full TCO but eliminates operation centers at infantry battalions and squadrons.

Functionally Austere TCO: Identical to Full TCO but eliminates all decision aids and large screen display.

Very Austere TCO: Identical to Full TCO but eliminates both operation centers and decision aids.

Wavell: Automated command and control system used by British Army.

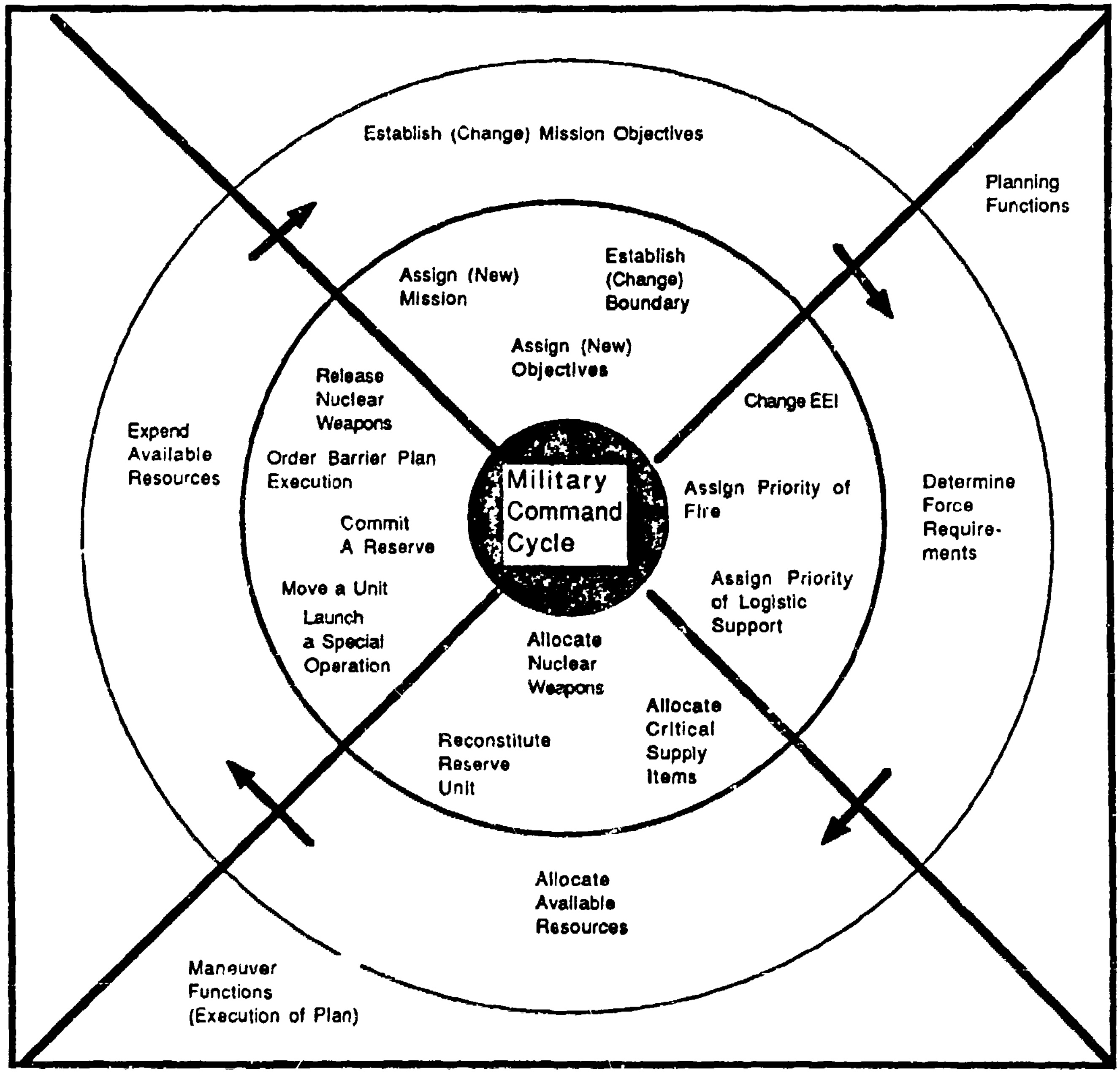


Figure 21. Examples of Typical Decision Situations in the Military Command Cycle, from Krumm et al. (1973).

Maneuver Control System: Planning and operations command and control system the U.S. Army is developing.

Manual System: Current Marine Corps system information. It is maintained on file cards, status boards and acetate covered maps.

The effectiveness of the alternatives was compared on three levels - the performance of individual systems, the effect of performance differences on decision making, and the effect of decision making on battle outcomes. The predominant sources of information for the assessment were "system simulations performed at the Marine Corps Tactical System Support Activity . . . tests of existing systems that performed functions similar to those planned for TCO (and) . . . several user evaluations" (p. 4). The individual performance measures assessed were timeliness, the time delay between events and actions taken by friendly forces, accuracy, and improvements due to decision aids.

The effect of performance on decision making was represented by the following equations which is in effect a model of decision making in the command and control environment:

$$N^*(t) = (1 - P_D)\ N^*(t-1) = P_D\ N(t - t_d)$$

Where: N^*t = Estimated strength at time t

$N(t)$ = Actual strength at time t

P_D = Probability of detection

t_d = Time delay

Basically, this model of decision making says that the current perception is a function of the previous perception and new information, which itself may be old because of a time delay. Old perceptions and new information are modified in accordance with a confidence factor.

His results showed that the impact of decisions on battle outcomes could be evaluated by a computerized model of the command and control process using estimates of the ratio of enemy losses/friendly forces (losses) after two days of battle. The model presented in Figure 22 was used for the simulation. It is, of course, a model of the tasks required to conduct command and control.

A different model resulted when Reaser, Stewart, and Tiede (1982) attempted to identify the skills and behaviors, used in battalion command and control groups, that contribute to effective performance. In order to do this, the authors developed and applied yet another model of command-control group behaviors. Testing was conducted on the Combined Arms Tactical Training Simulator (CATTS) at Fort Leavenworth, Kansas.

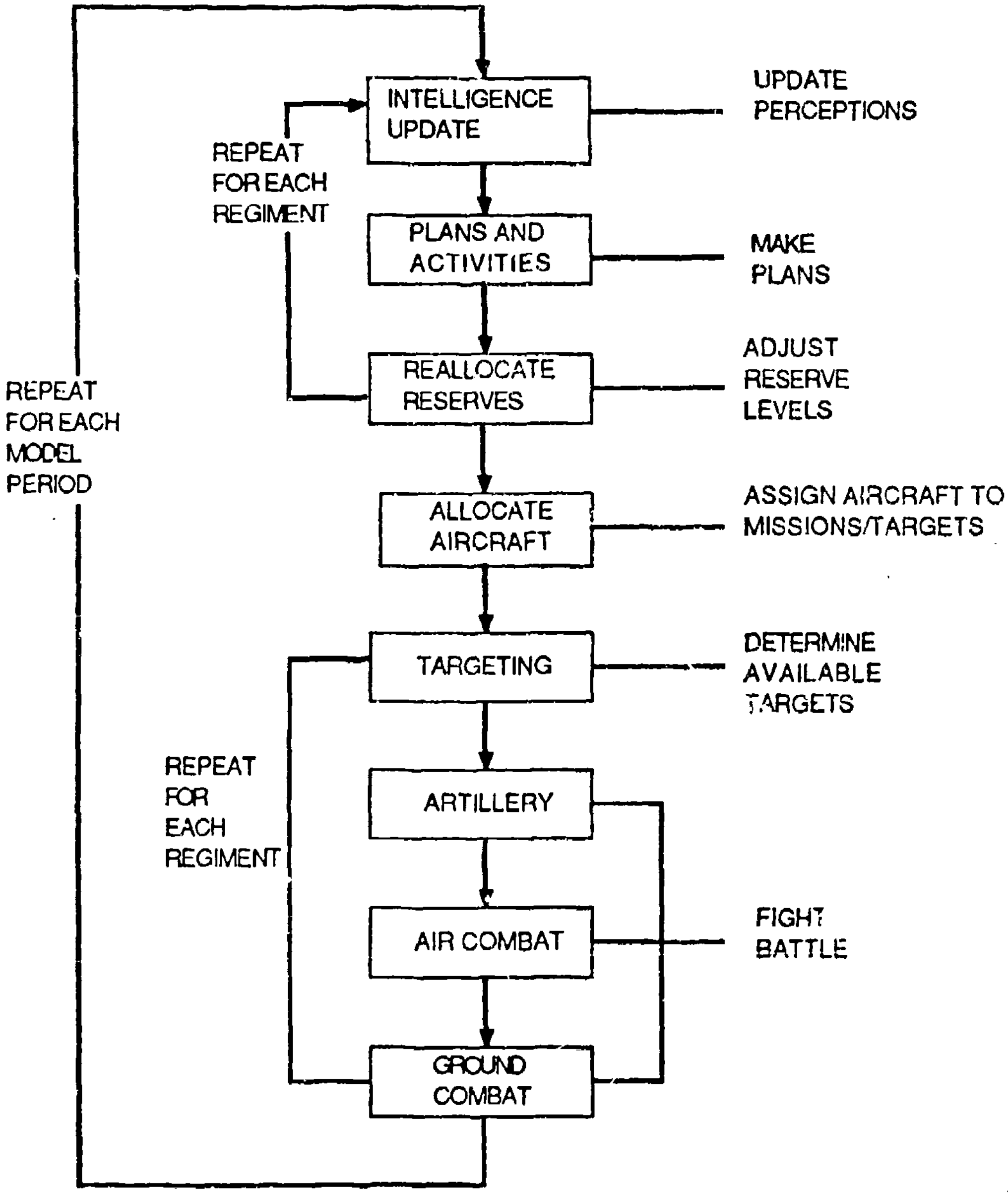


Figure 22. Overall Structure of the C2 Model developed by Askt (1982).

The Reaser et al. model views command and control as a decision making process. The command-control node engages in five categories of behaviors in its decision making. (Figure 23)

- Input processing
- Pre-decision processing
- Decision processing
- Post decision processing
- Output processing

The model may have some value as a method of defining a taxonomy of decision making behaviors so that a fuller description of those behaviors can be detailed, but the application of the model described in this experiment is not well conceived. The variables for which data are collected are not those initially defined and instead appear to be measures of system performance, i.e., time required to switch channels, number of nodes which sent transmissions. Thus, while the model may or may not be a good one, it is not used by the authors in this research.

Metlay, Liebling, Silverstein, Halatyn, Zimberg, and Richter (1985) designed a methodology for evaluating decision making in command groups. As a necessary requirement for the study, a model of the decision making process is developed which is consistent with many of the command and control military decision making models previously reviewed. The research team, in fact, began with the military decision making model and added to this model their observations from videotaped planning sessions engaged in by battalion command groups during Combined Arms Tactical Training Simulation (CATTS) exercises. This ultimately led to a model which both fit the behaviors they observed and was still consistent with the military model.

The military decision making model has been presented as Figure 1. The Metlay et al. revision is shown as Figure 24. There were two interesting points concerning this research. One is that the researchers were primarily concerned with developing a measurement process and do indeed provide such a methodology. Hence, this model could to be considered evaluative in type. The second item worth noting is that in this model the decision making sequence is not considered complete until the decision has been presented and made clear to those persons who will be controlled by the OPORD.

The final model in this category is somewhat anomalous since it deals with the concept of a person's internal decision making model and carefully delineates between command and control systems (a human function) and command, control and communication systems (a physical entity). Athans (1981, 1982) suggests that each commander develops an internal model of his warfare area based upon his training which allows him to make superior tactical decisions. This model, which is not explicitly described, is called the principal expert model (PEM) and represents the commander's decision making process. Each commander, according to the Athans Model, also needs to develop concepts about the PEMs of commanders with whom he interacts. These models are called Military Expert

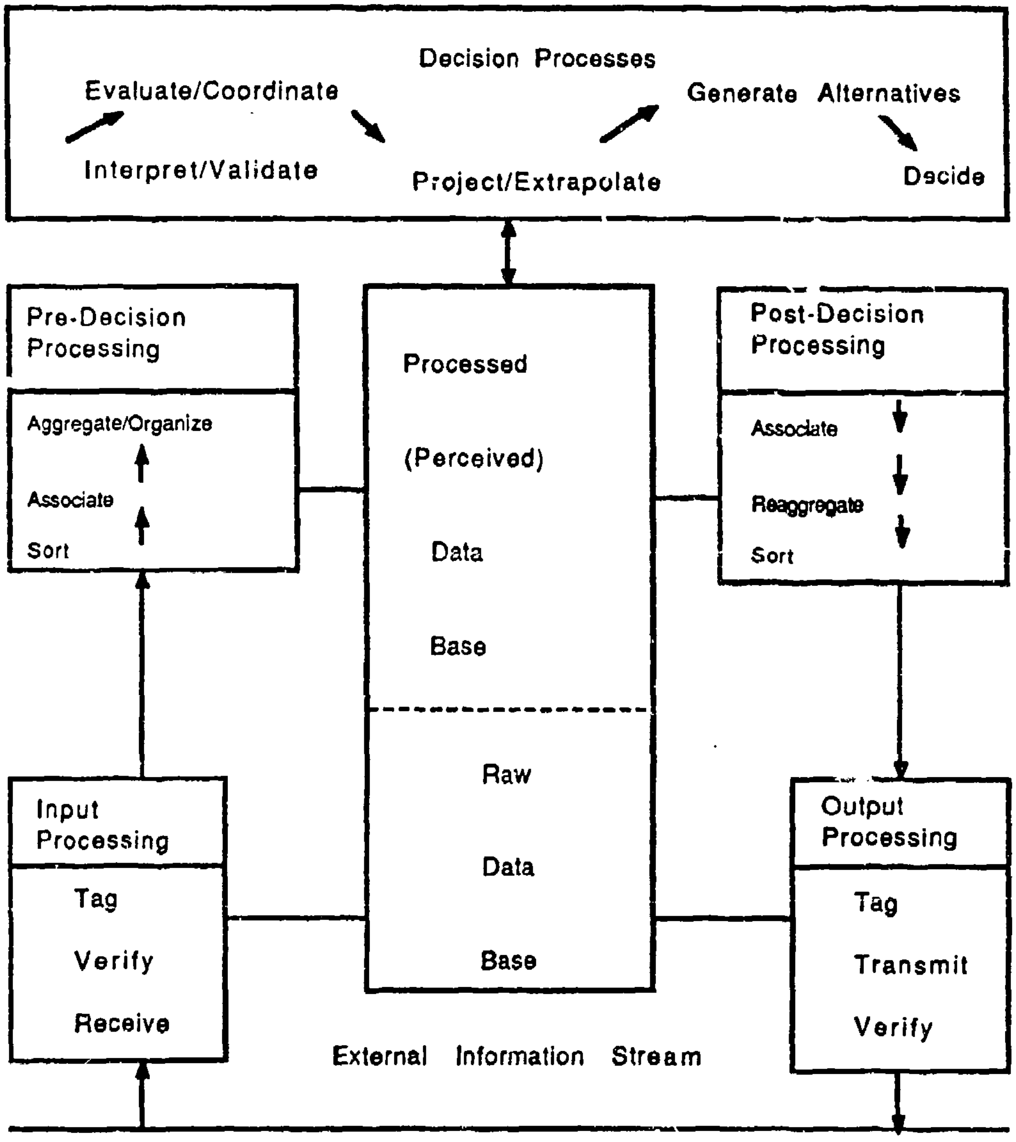


Figure 23. Model of Command Control Group Behavior from Reiser et al. (1982).

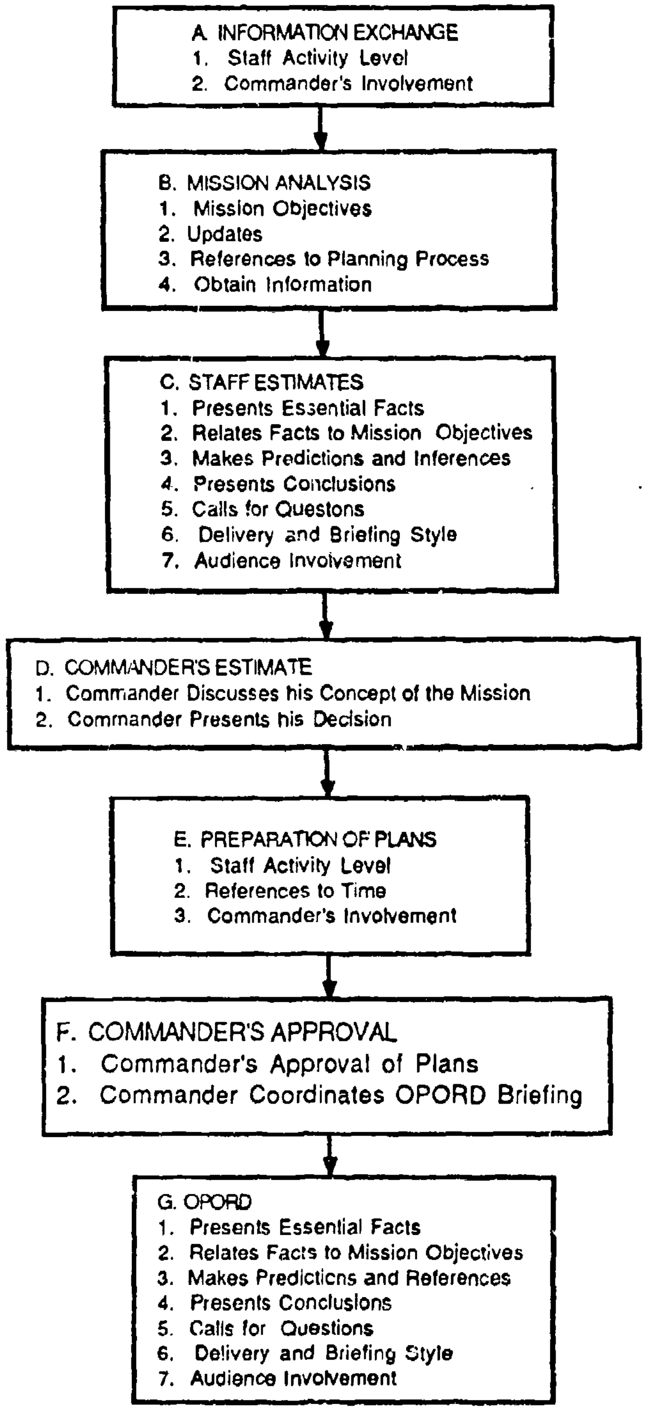


Figure 24. Analytical Model of the Planning Process from Metlay, et al. (1985).

Models (MEM) and represents each commander's beliefs or expectations about other commanders' decision making processes.

This model is primarily a decision making model where a commander's assessment of a situation is based upon information in the commander's "Model of the World" (Figure 25). The Model of the World includes the commander's knowledge and assessment about such things as his assets, the enemy's assets, capabilities of weapon systems and so on. Situation assessment is influenced by this "model of the world" and by the objective function; the responsibilities and objectives for the mission; the planning horizon; the time requirements for tactical decisions, allowable decisions, constraints or decisions imposed by the C^2 organization; and available resources and dynamic constraints such as the speed and maneuverability of resources. From the Situation Assessment commanders generate decisions, options, and then select a decision which impacts the environment, and in turn receive feedback from the environment.

Athans offers a model of the command and control organization which is based upon his decision making concepts (Figure 26). In this model commander A is a superior to commanders B and C. P_A, P_B, and P_C represent the PEM of commanders A, B, and C, respectively. Each commander also has an MEM for each other commander with whom he interacts. Thus, Commander A has two MEMs, one for Commander B (M_{BA}) and one for C (M_{CA}). Similarly, Commander B has two MEMs (M_{AB} and M_{CB}) and Commander C has two MEMs (M_{AC} and M_{BC}). The crucial issue in this organizational design is that decisions that require coordination among the three commanders "can only be carried out on the basis of the MEMs."

This work is particularly interesting because Athans directly considers the issue of how the humans in the C^2 system relate to the physical (C^3) system that supports them. He addresses the need for there to be a "C^2/C^3 theory" before developers can properly analyze C^2-C^3 interactions and synthesize a combination that, given relevant measures of effectiveness, is "sufficiently good or even optimal."

Behavioral System, Computer Technology Models

There have been four modeling attempts which appear to have had as an impetus some need or application evolving from the computer technology arena. In the first of these, Obermayer (1975) describes a computer model based upon the model of command and control developed by Finley et al. (1974, 1975). There is little in Obermayer's description to indicate that the computer model effectively replicates the Finley command and control model. The Obermayer work seems primarily intended to demonstrate the use of a computer language called General Purpose System Simulator (GPSS) for developing command and control models. The computer simulation more directly models the flow of air traffic, and while it might be used to measure effectiveness of the total system, it does not measure command and control behavior or decision making. As Obermayer states:

> The analyst/programmer determines the mapping from the description of the system provided him (probably overly simple and incomplete), and the success of the model will depend on how well the analyst/programmer has done his mapping process. This at present is a complex creative process.

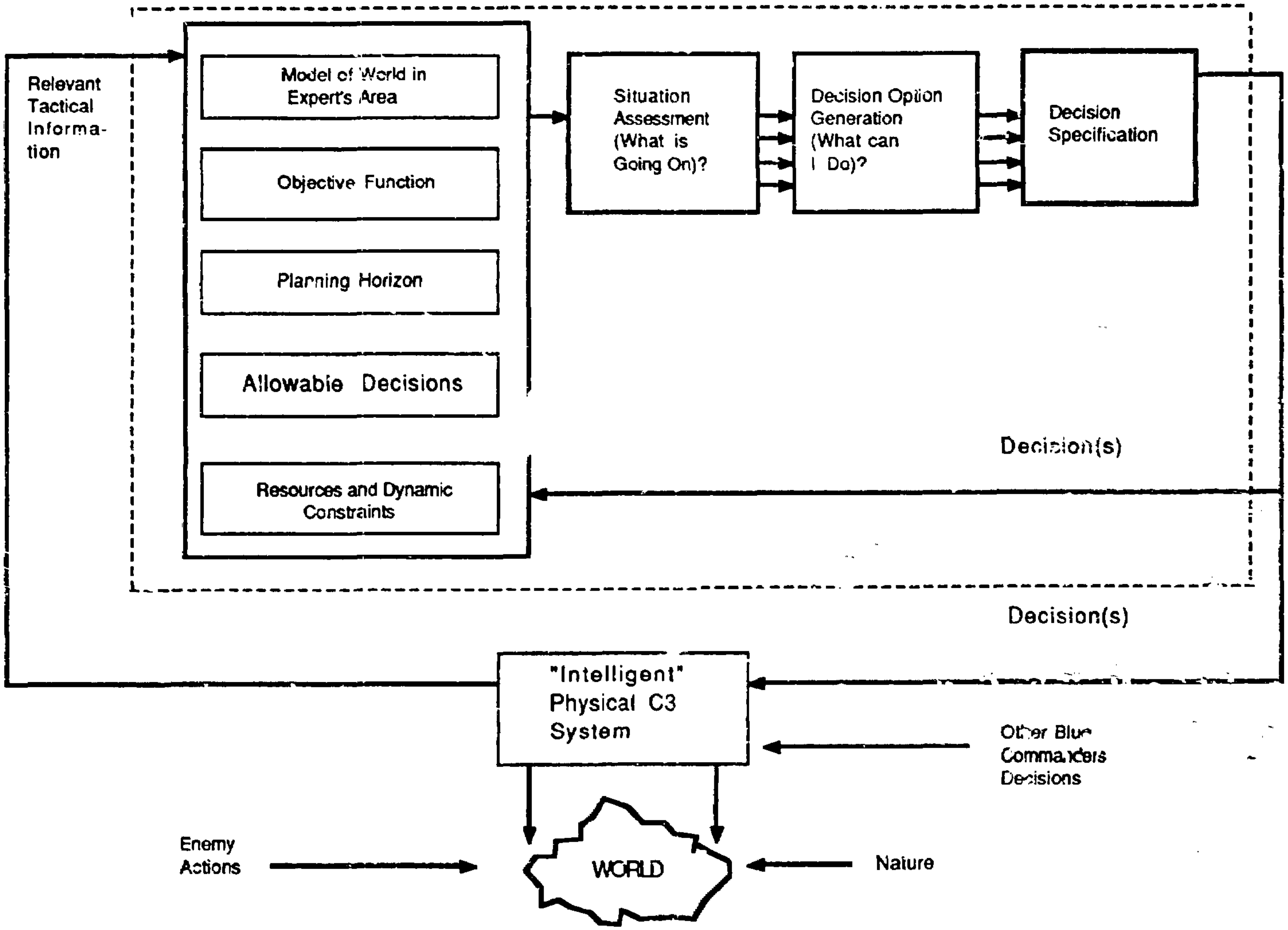


Figure 25. Principal Expert Model for a Blue Commander from Athans (1982). © 1982-IEEE

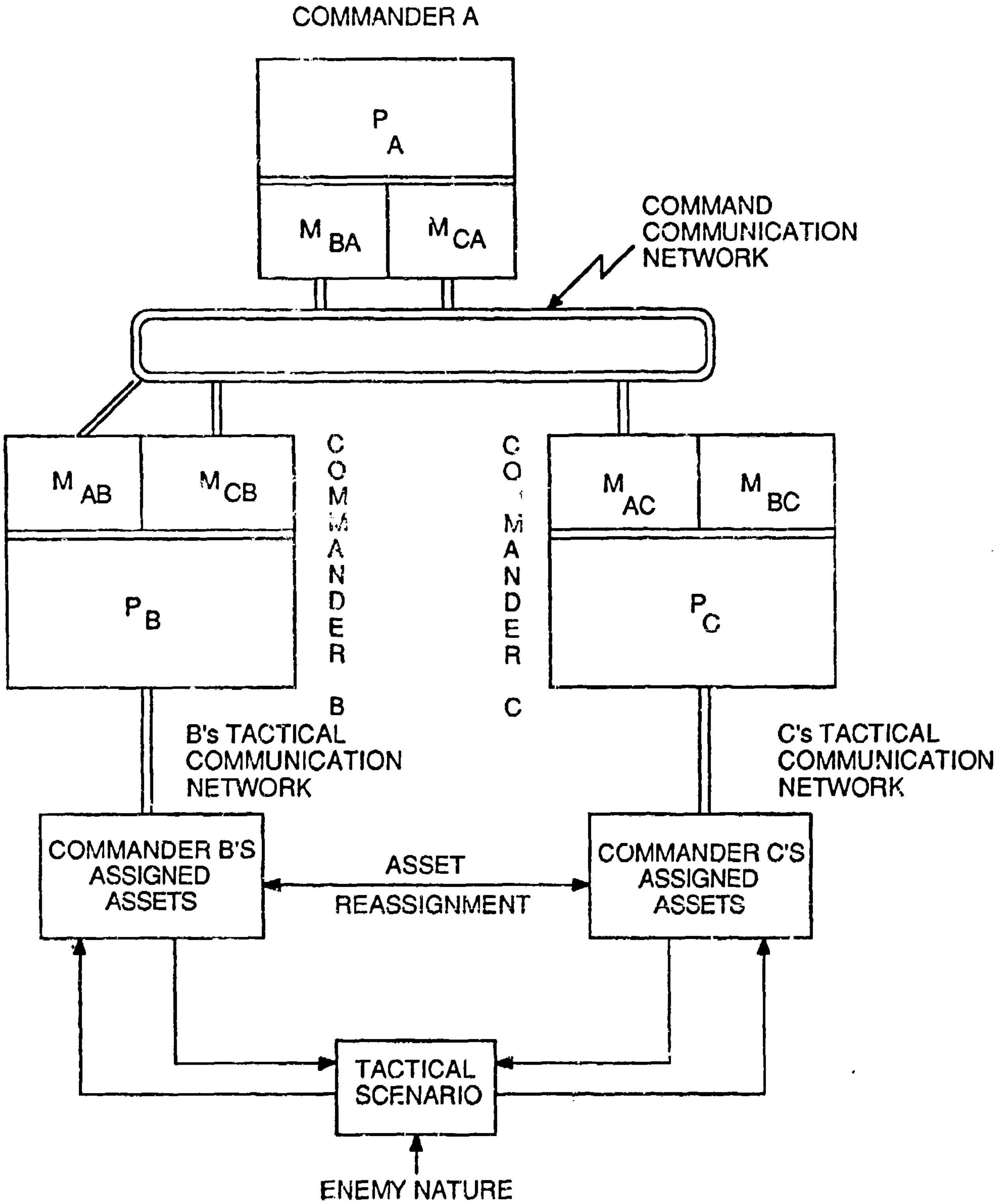


Figure 26. Athan's (1981) Hypothetical Command and Control Organization.

Prichard (1977) has described a model of battalion level command and control that is primarily designed to help in the development of combat simulations. The model is presented as a process flowchart (Figure 27). In this model, the Plan, Execute, Observe, Sense, Direct Fire and Fire Support cells each have their own process charts which merge with Figure 27. As an example, the Plan flowchart is presented here (Figure 28) because it most nearly relates to what other models of command and control are concerned with. The various flowcharts in the Prichard report are each of some value to understanding the operations of a command post.

Alberts (1980) provides a method for evaluating command and control information systems and attempts to develop a rudimentary model of the command and control process. The author does not specifically define what constitutes a command and control system and provides no formal diagram. Instead, he indicates that command and control systems are designed to manage forces. Since his analysis focuses on the improved quality of decision making with the use of computer technology and decision aids, we must assume it is a decision making definition of command and control that the author is using. Alberts points out that command and control systems exist to perform specific functions and/or missions. The performance of these systems can only be assessed by analyzing activity within the context of a scenario and the system's overall performance depends upon its functioning over a broad range of such scenarios. In order to accomplish missions and functions, these activities can be decomposed into tasks which are the major focus of Alberts' theory and analysis.

Measurement and evaluation of what the author refers to as "micro blocks" or building blocks of the command and control system take place at three levels. Level one is the assessment of system performance, that is, the characteristics of the hardware, for example, its speed and accuracy in accomplishing the task. Level two refers to measures of information attributes, that is, the quality and timeliness of the information flowing through the system. Level three is measures of value, which assess the utility or value added to the decision by information flowing through the system with these improved attributes.

In the last example of this type of model, Witus, Weintraub, and Miller (1984) conceptualize command and control as a decision making component that interacts with the other components of the force to achieve mission objectives. Thus, the authors use a very basic and straightforward decision making model for their command and control component. This model is presented as Figure 29. The authors understand that the specific tasks and activities engaged in by the command post staff will change during the course of a battle. Every staff decision will have an impact on the battle and will in turn require new tasks. The authors develop their model while considering how a combat simulation needs to follow this logic in what is called an automated s .ipt. In the automatic script command and control decisions determine events in the engagement and require new decisions in a kind of adaptive approach. Unfortunately, the "automated script is restricted to a predefined sequence of command and control decisions and can evaluate the battlefield dynamics only when that sequence is valid."

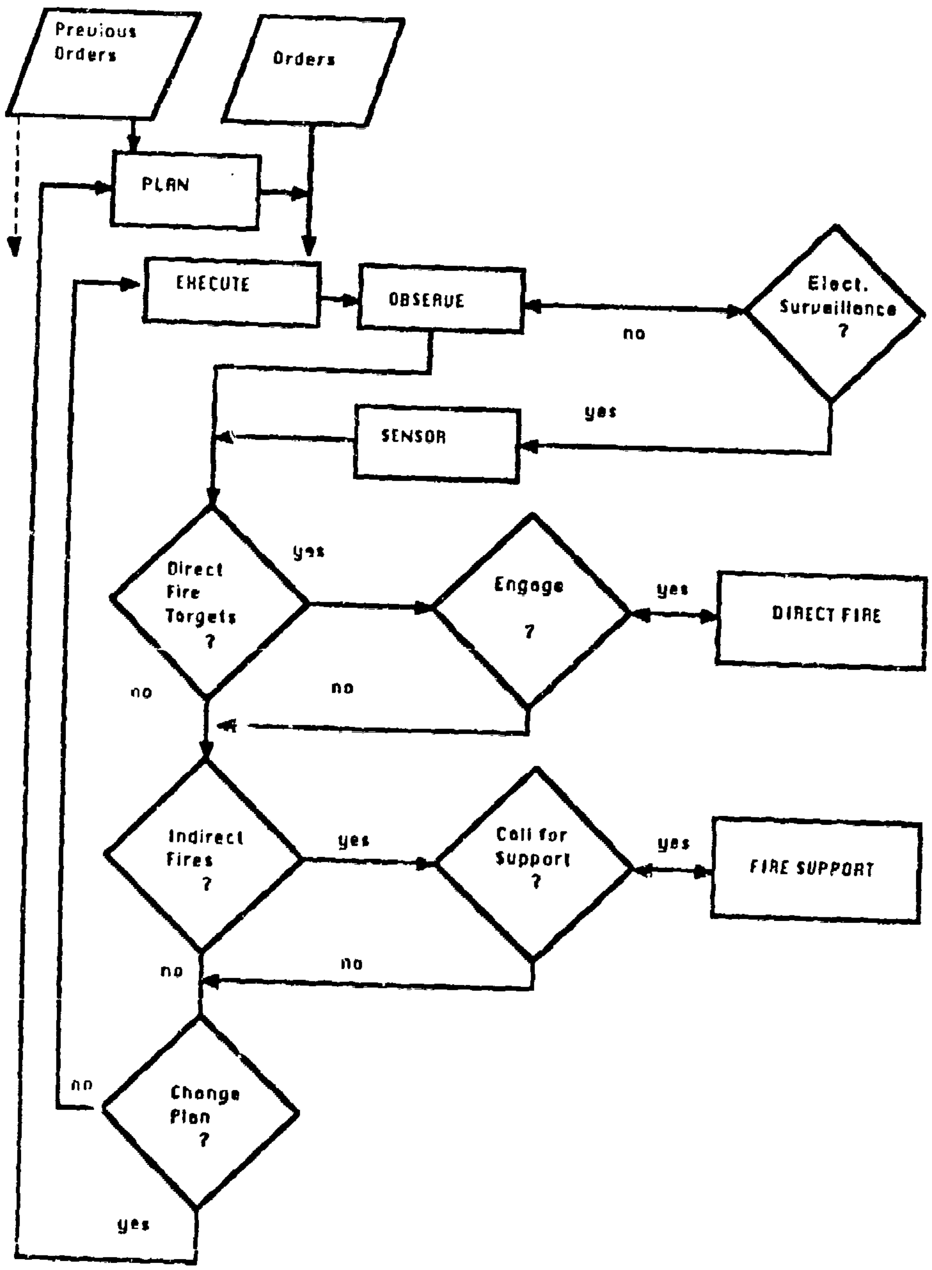


Figure 27. Process Flowchart, Top Level of Hierarchy from Pritchard (1977).

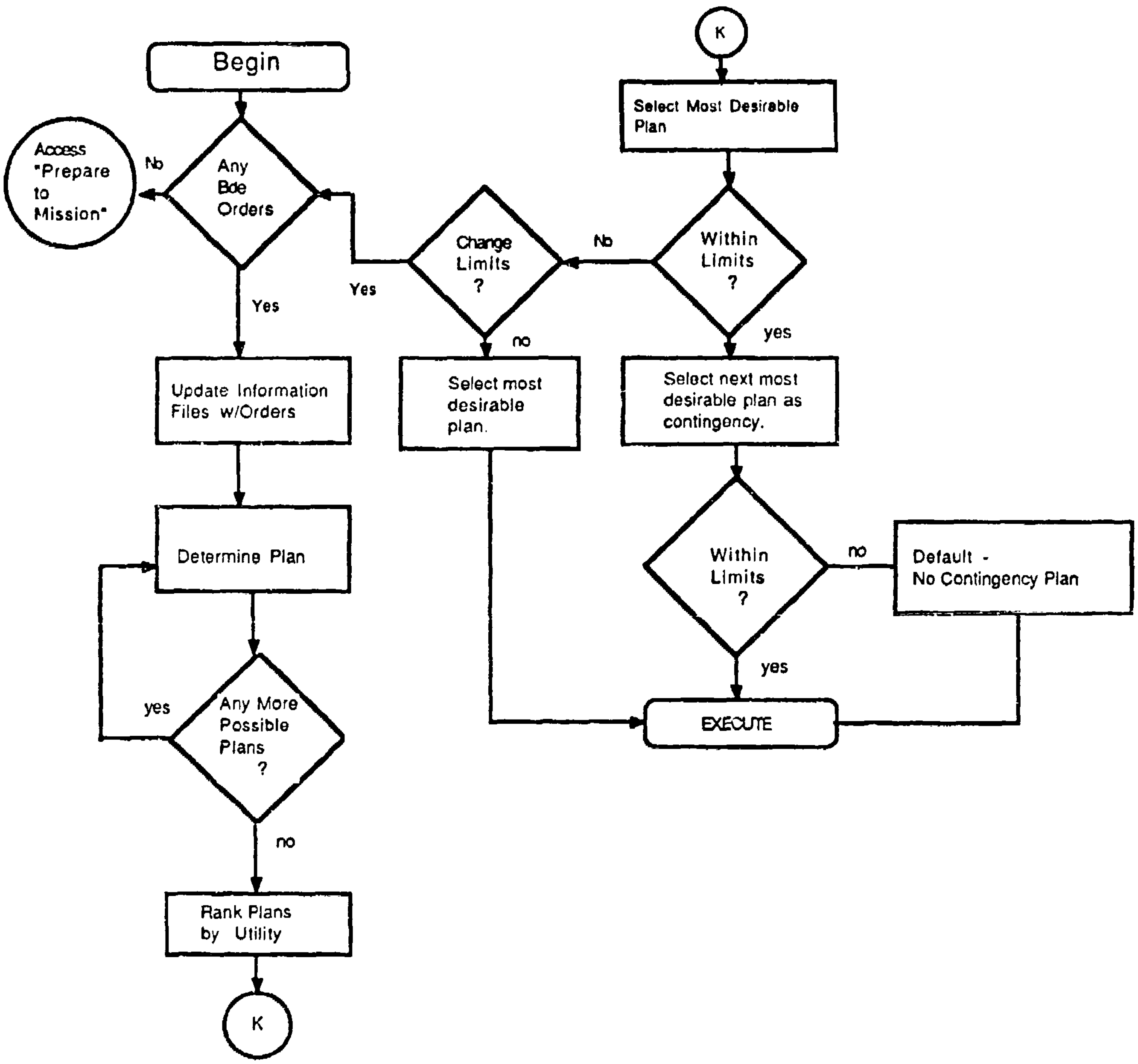


Figure 28. Flowchart of PLAN Process from Pritchard (1977).

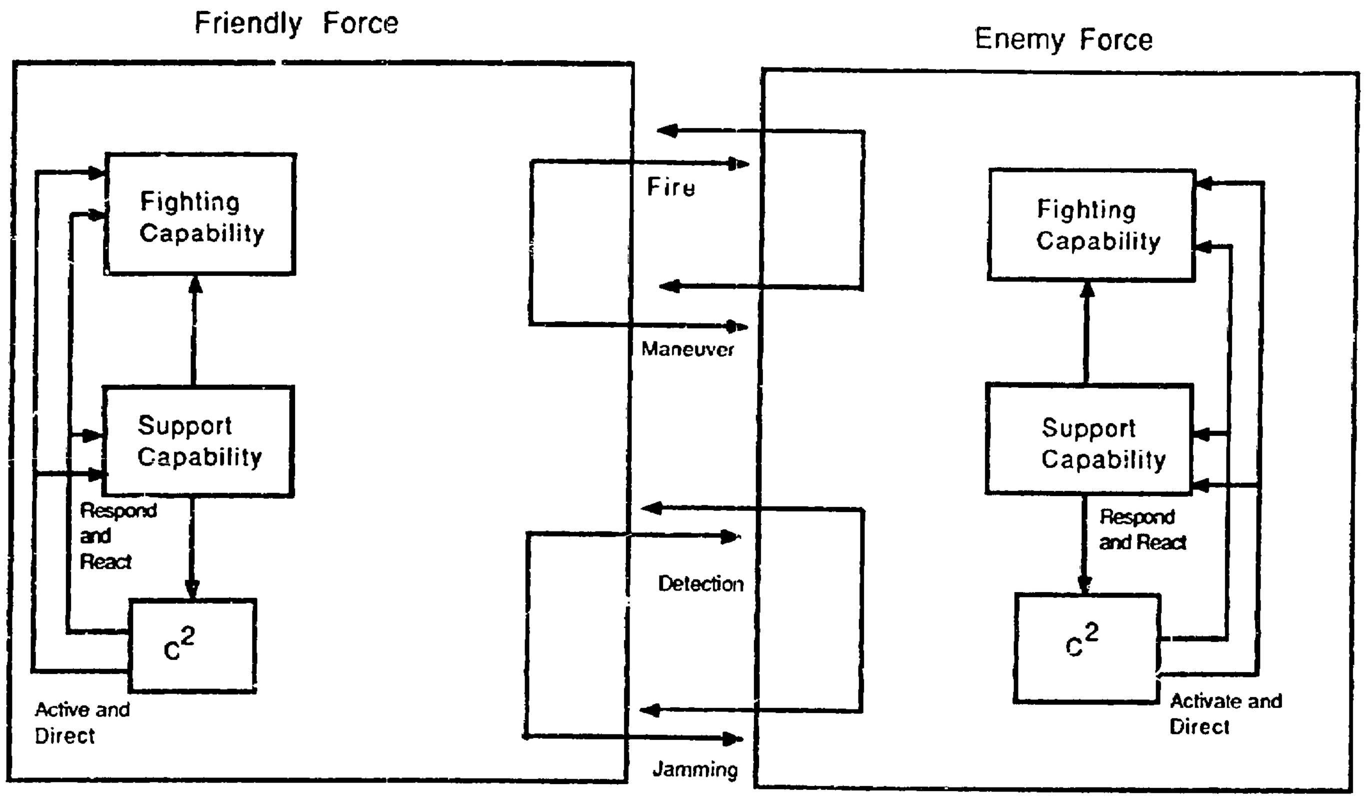


Figure 29. Interactions Among Selected Force Components as modeled by Witus et al. (1984).

The limitation of the model lies in its inability to deal with decisions outside of a restricted domain and its failure to deal with performance of specific behaviors, tasks, and activities that effect decision making performance. The model developed here is one in which command and control is decision making and in which only the decision making outcomes are input into the simulation.

The authors suggest they can develop a more flexible script with the use of a more specific taxonomy. Nowhere do the authors suggest the collection or analysis of specific task information, rather they suggest a taxonomy based on their own theorizing. This taxonomy, which itself implies a command and control model is presented as Figure 30.

Systems Oriented Models

Some models which appear to consider command and control from yet another perspective can be characterized as systems oriented. Some of these models tend to focus on information processing. Others go beyond mere theorizing and address the systems problems associated with the actual development of a specific command and control system. This latter type of model may be considered as architectural.

Systems Oriented, Information Processing Models

Wilcox, Slade, and Ramsdale (1983) provide an excellent example of how easily the command and control concept can be refocused, in this case, as communications. While emphasizing the importance of command and control, the authors suggest that communications "provide the backbone of a successful, coordinated command, control, and communications (C^3) policy." In fact, they reconceptualize command and control as nothing more than the "control of events and processes through the transmission and receipt of messages."

For these authors the command and control process consists of six stages. Their model of command and control is:

1. Surveillance
2. Communications
3. Data processing and management
4. Decision making
5. Communications
6. Action

The reader should note that the authors consider communications to be such an important part of command and control that communications is part of the command and control process twice: once to send a message up to the commander and once to relay decisions down to the field. This text focuses almost entirely on complexities of communication from a technical and mechanical perspective and in a sense the text, entitled Command and Control and Communications (C^3I) is a misnomer. The Wilcox et al. report appears to be primarily a communications text with limited application to the battlefield and it only illustrates the ease with which command and control can unwittingly be redefined.

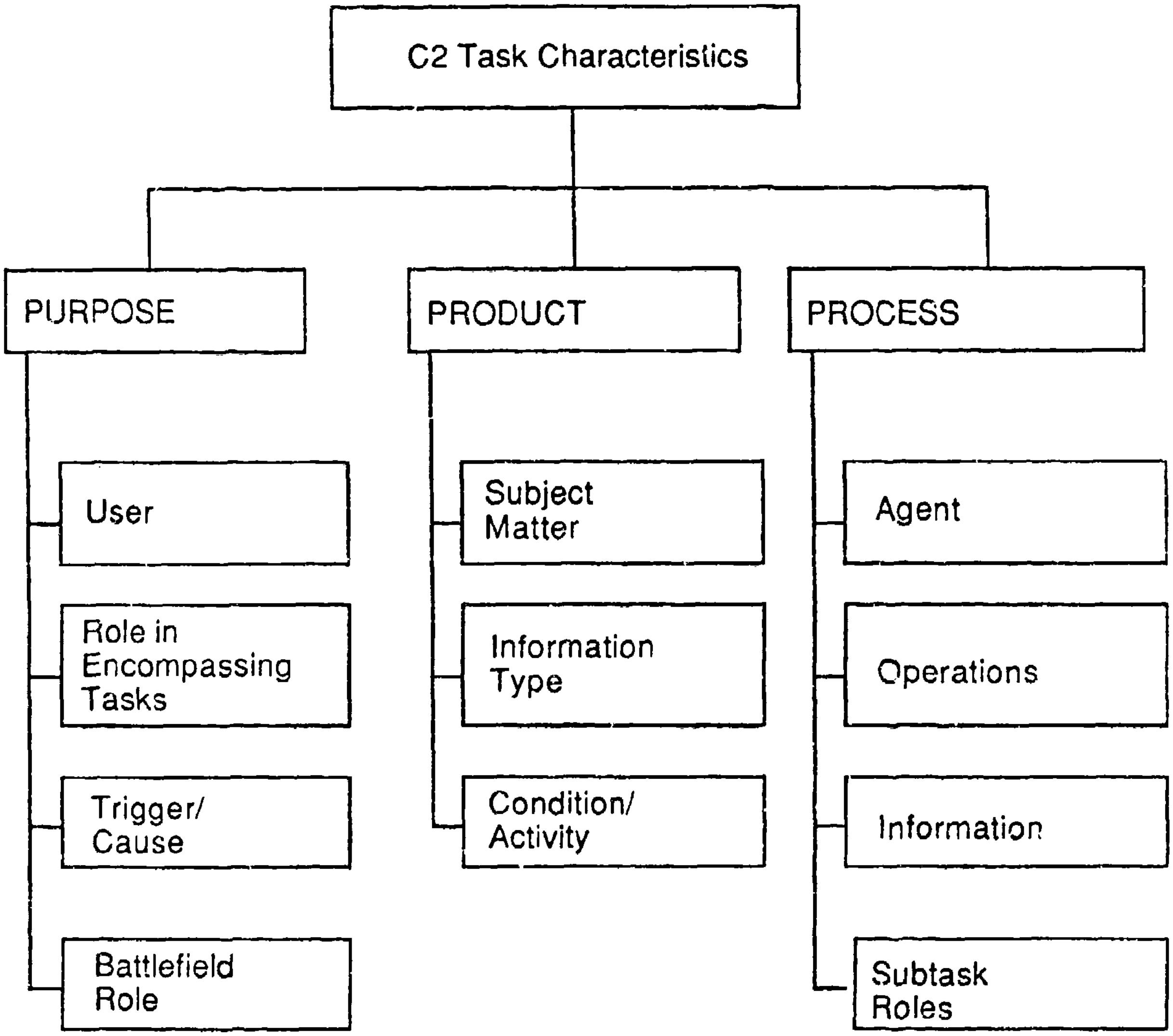


Figure 30. The Witus, et al. (1984) Taxonomy Overview.

A number of other researchers have used complex mathematical formulations and decision theories to model or evaluate command and control systems. It could be argued that these approaches tend to be obscure and to have limited applicability. Several researchers have evaluated the "timeliness" of command and control systems. The methodology appears to have been introduced by Bouthonnier and Levis (1984) and expanded upon by Cothier (1984) and Cothier and Levis (1985). In this methodology, the authors define a system and a mission. The system consists of components, their interconnection and the standard operating procedure for these components. Examples offered by the authors include a communication network and a fire support system although it appears that in a broader sense, a system could also refer to a decision making process or any set of organizational activities involved in completing a task or mission. Figure 31, from Cothier (1984) depicts the methodology.

The authors indicate that a mission can be defined as a set of objectives and goals. These goals are the things the system will be required to do and/or describe how the system must perform. The authors call these goals the "commander's needs." Both the mission and the system are defined by "primitives." Primitives are descriptive variables or parameters of the system or mission. For example, a fire support system can be defined by such variables or primitives as the kill radius, the probability of failure, the cannon battery accuracy and so on.

Attributes of the system and/or mission, are quantities that describe properties or characteristics and can be defined as a function of a set of primitives. Attributes of a command and control system might include such things as reliability, survivability and cost.

$$A_s = f_s\ (X_1,\ldots,X_k);\ s = 1,2\ \ldots\ S$$

describes an attribute for a system where $X_1 \ldots X_k$ are system primitives, and

$$A_r = f_r\ (Y_1,\ldots,Y_n);\ r = 1,2\ \ldots\ R$$

describes an attribute for a mission where $Y_1 \ldots y_n$ are mission primitives.

System and mission attributes can be defined using different scales and it may be necessary to transform the attributes to a common scale before comparison. When the attributes are expressed on a common basis, they are said to have been transformed into commensurate attributes.

Effectiveness is defined as a comparison between the system attributes (L_s) and mission (requirement) attributes (L_r). The specific comparison is called the loci of the attribute space. These loci are defined as the values that the compared attributes take as the set of possible primitive values.

Effectiveness is then: $E = V\ (L_s \cap L_r)/V\ (L_s)$, where V is a measure in the normalized attribute space and $\cap$ is the standard intersection operator.

According to the authors, this partial measure of effectiveness can be combined into global measures using a utility function:

$$E = u\ (E_1,\ E_2\ .\ .\ .\ E_k)$$

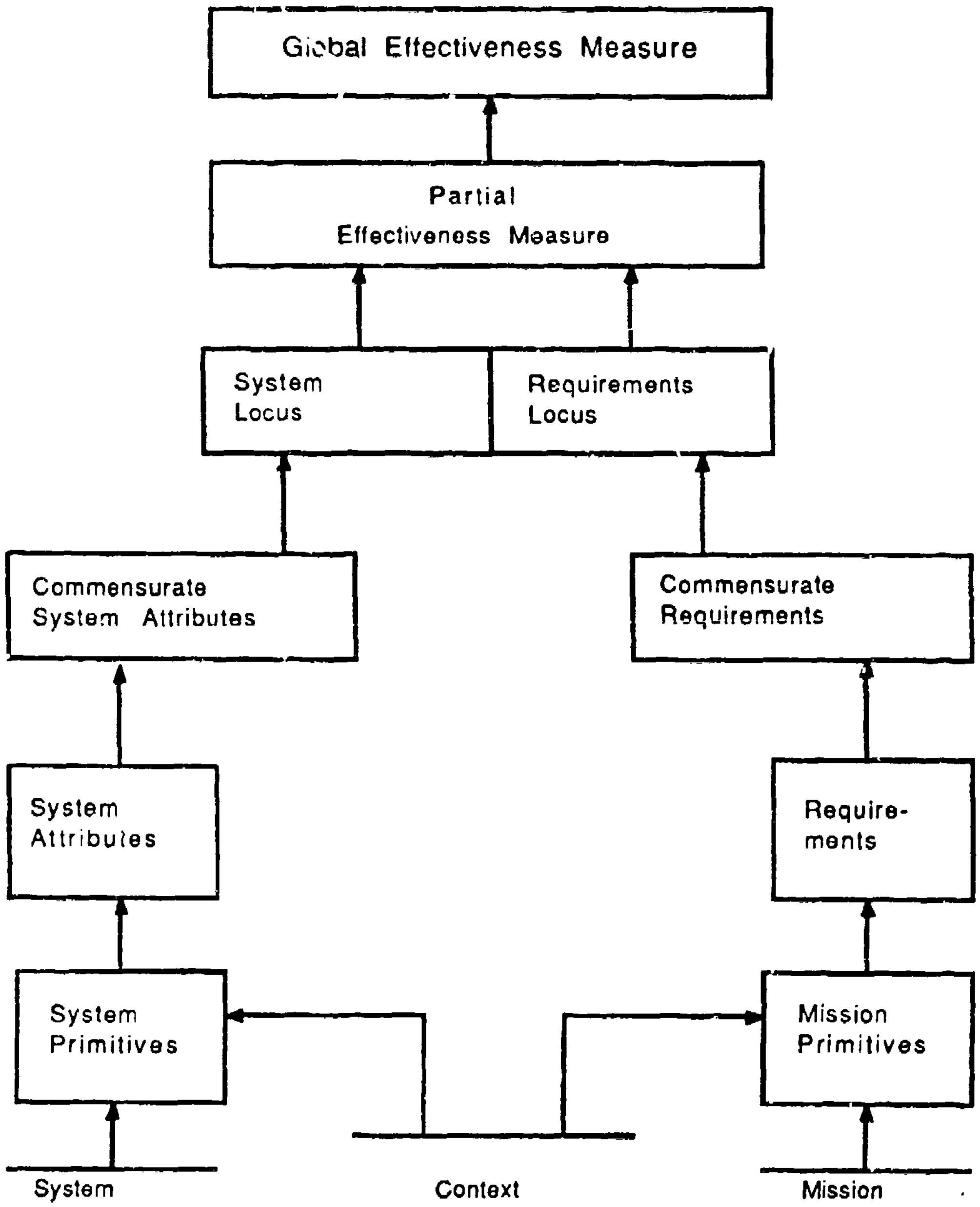


Figure 31. The Methodology for System Effectiveness Analysis from Cothier (1984).

These almost criptic insertions, taken from one of the documents referenced above, do not do justice to the researchers rather complex mathematical development of their command and control material. The material is included only to demonstrate how complex developments from adjoining fields can rapidly move beyond the availability of data to match to the theoretical developments.

Tomovic and Levis (1984) use a decision theory approach to mathematically model the information processing and decision making tasks of the command and control organization. The mathematics of the model are well beyond the scope of this paper. One of the more important points to make about this approach is that while the authors suggest they are analyzing or designing a command and control organization, their focus is primarily on information processing, which they call the most important characteristic of the organization. Indeed, they state, "The most important characteristic of the organization considered here is that their task involves information processing and decision making."

The model proposes a decision maker whose task is to receive data and then process it into an output. According to the model, the decision maker processes the data using specific algorithms. The model also allows for input between decision makers. The quality of decision making can be assessed based upon the mathematical derivations called "workload" and the "organizations performance."

Systems Oriented, Architecture Models

A considerable amount of outstanding modeling related work has been reported by researchers of the MITRE Corporation as work progressed on a long lasting project to support the Army in its development of computer based command and control systems. These systems, referred to during the period researchers were working as the Command Control and Subordinate Systems (CCS^2), were evolving systems intended to move computer technology into what had been purely manual command post operations. The intent of the MITRE work was clearly system developmental in nature and had as its goal the specification of equipment and software needed to design computer based C^2 systems.

This review section begins with consideration of a report by Bean, Ottenberg and Mukherjee (1983) which describes the conduct of a functional analysis of the maneuver control portions of Army command and control activities. The reader will note that the report could well have been considered in an earlier section - Organizational, Process (Taxonomy or Function) Models. It is instead covered here in order to preserve an obvious continuity between it and later MITRE studies. The Bean et al. (1983) report is one of five conducted by MITRE researchers, each of which considered one of the major battlefield operating systems. The reviewed report dealt with the Maneuver Control system. Other functional analyses which have been reported by MITRE researchers dealt with Air Defense (Singer, 1981), Fire Support (Bean et al., 1982), Intelligence and Electronic Warfare (Grinder, 1983), and Combat Service Support (Blondell and Hennings, 1984).

The major portion of the Bean et al. (1983) research deals with the identification of the tasks performed in corps or division command posts as the maneuver control function is performed. Maneuver control is the premier command and control system. Thus, it describes how the battlefield systems are integrated.

In their definition, or model, of the command and control process Bean and his co-workers consider that the mission of the maneuver control system can be stated as follows:

> The mission of the maneuver control functional segment is to plan, direct, coordinate, and supervise the combat activities of a combined arms force as it closes with and destroys the enemy by the use of fire and maneuver. More specifically, the segment provides for the command, control and coordination of the combat, combat support, and combat service support elements of the force in accordance with the commander's scheme of maneuver and provides for the command and control of maneuver elements in its execution.

Then the researchers develop a concept of functional areas which are "groupings of analytically similar command and control activities." These groupings focus on the processes of maneuver control. There are 15 of these functional areas. The first is "command" which is defined as the authority and responsibility for planning, coordinating, and controlling a combined arms force to accomplish an assigned mission. Command, according to the model, is exercised primarily by authority delegated through the chain of command, and includes:

Knowing the Situation
Deciding
Assigning Missions
Allocating Resources
Directing Forces
Sustaining Forces
Motivating

The second functional area is the "Executive/Chief of Staff" who provides direction, coordination and supervision of the command and control activities executed by the staff. The remaining 13 functional areas are:

Operations
Personnel
Intelligence
Logistics
Civil Affairs
Air Defense
Aviation
Fire Support
Engineering
Communications
Nuclear, Biological, Chemical
Airspace Management
United States Air Force Liaison

With this group "operations" is paramount and it performs the activities of:

Gathering Information,
Estimating,
Anticipating,
Informing,
Recommending,
Ordering (where proper authority has been delegated), and
Supervising.

In turn, then the activities are performed in order to supervise the following areas of the operations process:

Operations Estimating,
Resource Allocation Priority Setting,
Required Supply Rate/Controlled Supply Rate Determination,
Special Ammunition Requirements Determination,
Airspace Management,
Nuclear, Biological, Chemical Considerations,
Operations Order/Operations Plan Preparation,
Tactical Deception Planning,
Minefield and Barrier Planning,
Critical Communications Issue Identification,
Tactical Troop Movements,
Rear Area Protection/Rear Area Combat Operations,
Command Post Location, and
Task Organization of Subordinate Units.

The authors have provided two significant graphic portrayals which are models quite like military decision making models shown earlier. Figure 32 shows the maneuver control system's eight generic tasks in a form that resembles many of the various decision type models described earlier. Figure 33 shows the 15 functional areas that derive from the activities which constitute command and control in a manner that models the process from yet another view. Modeled from this perspective, the researchers provide a vehicle that shows the interfaces that exist between the functional areas as the command and control of forces is accomplished.

The Bean, Ottenberg, and Mukherjee (1983) report is a treasure trove of information and ideas for the command and control modeler. In later sections, the report provides detailed presentations of how the command and control process flows within segments of command posts, across functional boundaries, and from task to task. The report also provides a list of typical specialized command post reports along with excellent and illuminating discussions of command posts at various echelons.

The four subordinate system reports (Fire Support, Air Defense, Intelligence/Electronic Warfare and Combat Service Support) are probably equally valuable in their areas but are somewhat beyond the scope of a review that is intended to cover models that deal with the command and control of units in battle. The reason for the out-of-scope nature of the four "subordinate systems" is made clear as we consider a later report by Bigler et al. (1984).

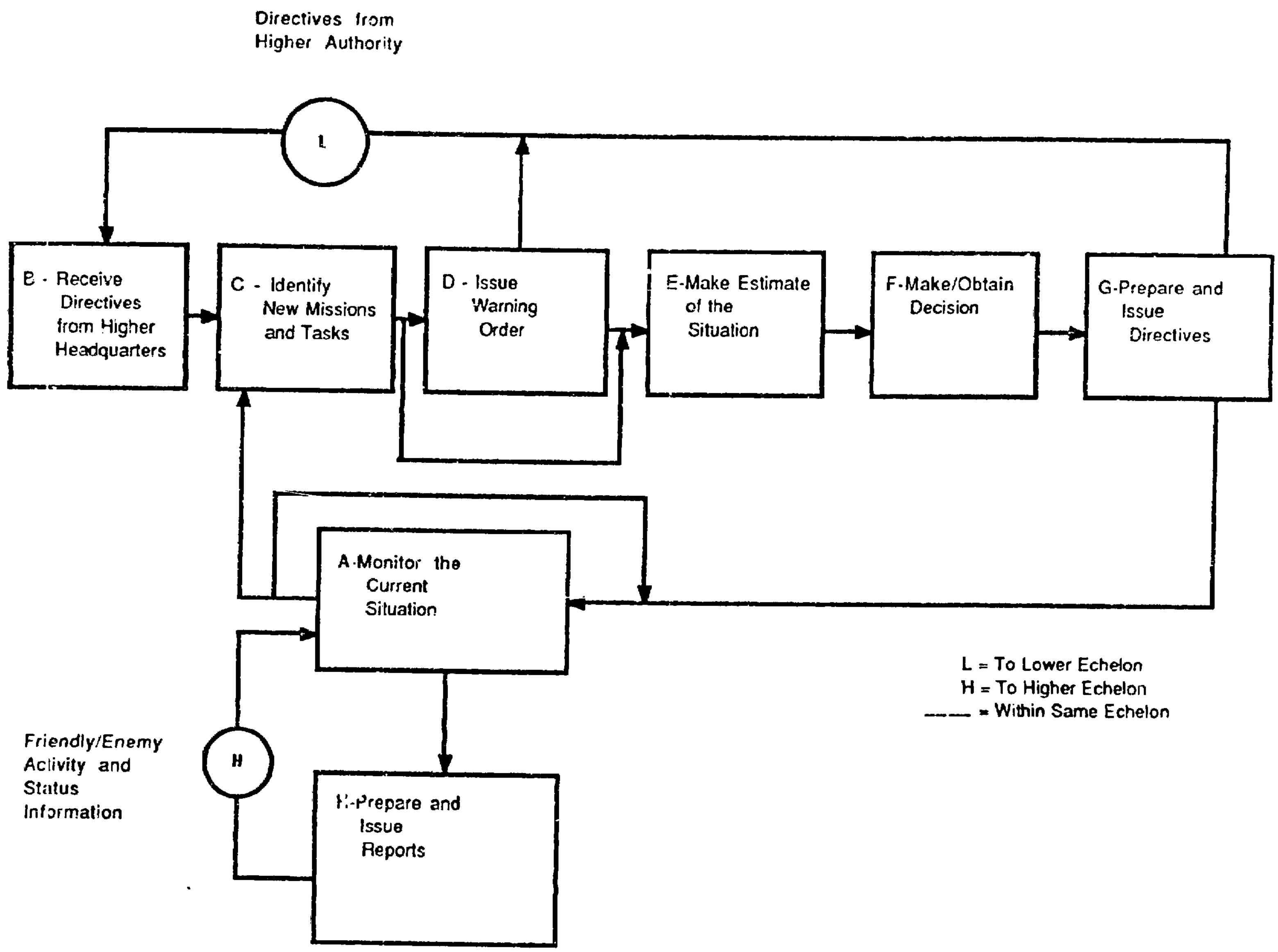


Figure 32. Maneuver Control Task Relationships from Bean et al. (1983).

MANEUVER CONTROL TASKS	Command	Executive/Chief of Staff	Operations	Personnel	Intelligence	Logistics	Civil Affairs	Air Defense	Aviation	Fire Support	Engineering	Communications	Nuclear, Biological, Chemical	Airspace Management	USAF Liaison
	MANEUVER CONTROL FUNCTIONAL AREAS														
Monitor the Current Situation	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Receive Directives from a Higher Headquarters	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Identify New Missions and Tasks	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Issue Warning Order	●	1/ ●	1/ ●				2/ ●		2/ ●		2/ ●	2/ ●	2/ ●		
Make an Estimate of the Situation	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Make/Obtain Decision	●	3/ ●	3/ ●	3/ ●	3/ ●	3/ ●	4/3/ ●	3/ ●	4/3/ ●	3/ ●	4/3/ ●	4/3/ ●	4/3/ ●	3/ ●	3/ ●
Prepare and Issue Directives	●	5/ ●	5/ ●	5/ ●	5/ ●	5/ ●	6/5/ ●	5/ ●	6/5/ ●	5/ ●	6/5/ ●	6/5/ ●	6/5/ ●	5/ ●	5/ ●
Prepare and Issue Reports	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

1/ In the name of the commander.
2/ Special staff sections do not issue warning orders; however, subordinate combat support units within the functional area issue warning orders to their own subordinates.
3/ Staff decisions are made within the limits of the commander's policy and delegated authority.
4/ Maneuver unit commander makes the decision.
5/ Coordinating and special staff sections only produce portions of and annexes to directives--e.g., Corps Aviation Staff Section produces the Aviation Annex to the Corps Operations Order.
6/ Subordinate combat support units within the functional area issue their own directives--e.g., Corps Combat Aviation Group Operations Order.

Figure 33. Maneuver Control Task and Functional Area Relationships from Bean, et al. (1984).

In the Bigler et al. (1984) report the five functional analyses previously completed form the basis for further architecturally based evaluation of the requirements for an integrated system consisting of a maneuver control system and the four subordinate systems previously noted. In this report the researchers extend the functional analyses in order to identify the interface requirements that must be considered if five CCS^2 systems need to work together in a computer-supported environment. The five systems, shown in Figure 34, were at the time of the Bigler et al. report known as the Sigma Star. The researchers revised some of the conceptualizations described in the Bean et al. (1983) report--and surely, also, some of those in the other four subordinate system functional analyses--and developed a series of command and control relevant concepts and models. The models provided are well supported by real world data on how the Army structures and operates its command posts.

The first of these concepts deals with a model that defines how command and control tasks may be classified and related to other tasks and other CCS^2 systems tasks. The researchers define four categories of tasks: System Integration, Subsystem Integration, Work-Specific, and Housekeeping. The four task categories are defined by Bigler et al., as follows:

System Integration. The highest level task is a system integration task performed by the Maneuver Control segment. This category of task harmonizes the work performed by all five segments and ensures that the scheme of maneuver is planned and carried out in accordance with the force commander's intent. This category of task is unique to the Maneuver Control segment.

Subsystem Integration. Within each segment, a single subsystem integration task is performed to unify the diverse efforts of the segment into a coherent whole. Each segment subsystem integration task is then merged with the other subsystem integration tasks within the Maneuver Control segment.

Work-Specific. In addition to its role as subsystem integrator, each segment accomplishes work unique to that segment but in support of the force as a whole. These tasks are called work-specific tasks, and their number varies among segments depending on the work needed to accomplish the segment mission.

Housekeeping Tasks. Housekeeping tasks deal with intra-segment communications, self-protection and self-sustainment.

The relationship of these four types of tasks is diagrammed in Figure 35, which has been modified from a figure in Bigler et al. (1984). When considered from a division command post perspective, the model assigns to the G-3 the system integration function and shows that each of the CCS^2 areas have tasks that permit the segment to control its subordinate parts and maintain a suitable interface with the maneuver control system.

A second paradigm developed by the researchers deals with information and develops a hierarchical classification scheme that enables them to show the flow and manipulation of data and information. In their scheme the researchers consider that data are representations of facts in a formalized manner. Information is the meaning a human assigns to data. The hierarchical relationship, therefore, begins with data. Data are communicated, interpreted, or processed

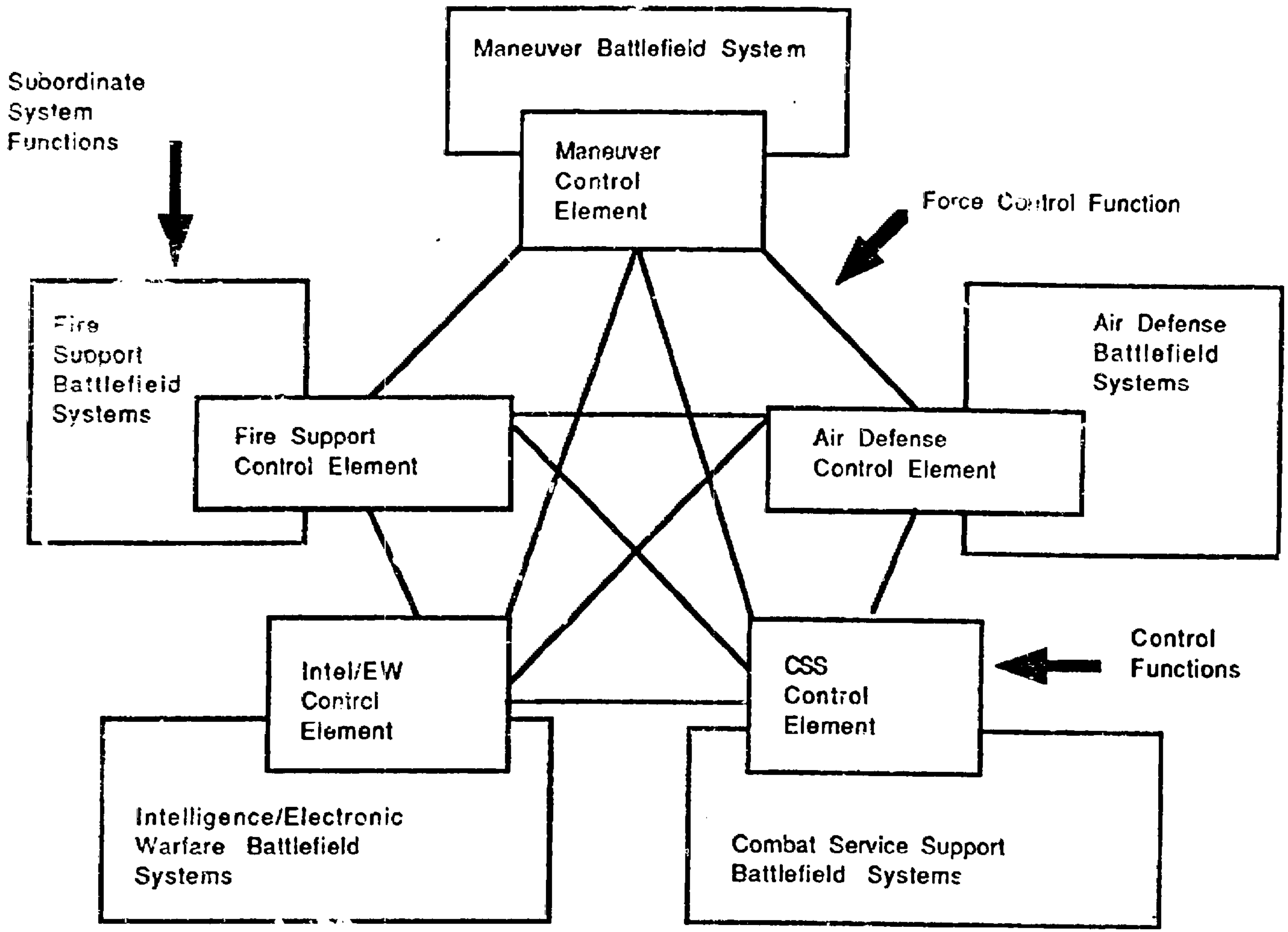


Figure 34. Command and Control and Subordinate System Architecture (the Sigma Star), from Bigler et al. (1984).

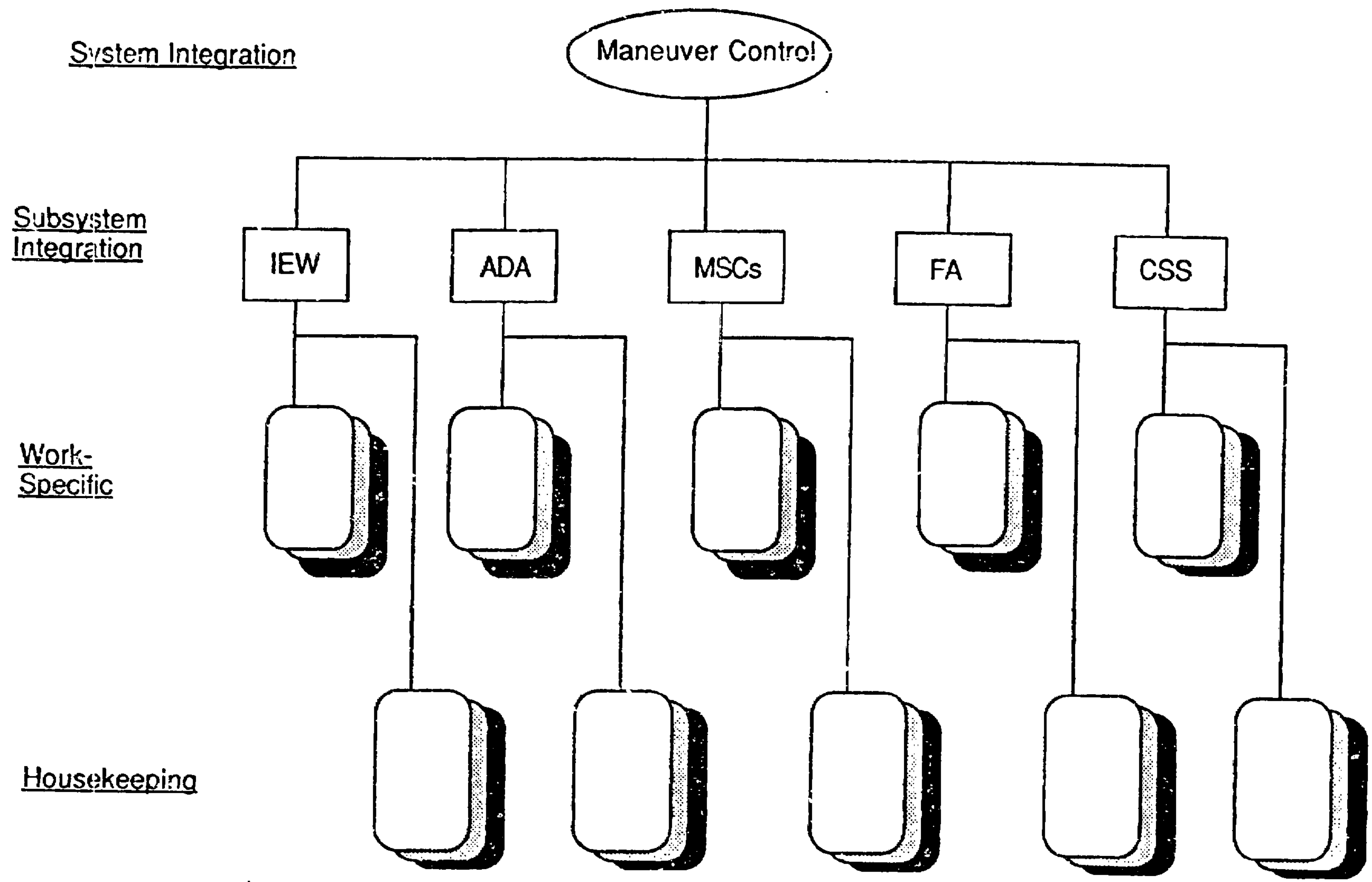


Figure 35. Hierarchy of command and control task types, modified from Bigler et al. (1984).

by humans or by automated means. Examples of data are unprocessed sensor outputs, inventory counts, air temperature, and notification that an item of equipment is no longer operational. The term information is used in the systems engineering sense to describe data transformed by humans performing the command and control processes: planning, coordinating, directing and controlling.

Technical Information. Technical information is the initial product obtained when meaning is applied to data. Examples of technical information are targeting information obtained from sensor outputs, requisitions for supplies or personnel, weather reports, and requests for maintenance support. Processing of data by humans or automated means is necessary to convert facts to meaningful information. Technical information is developed by units and exchanged with other units or higher echelon staffs to support command and control processes.

Staff Information. Staff information is that information product obtained from processing technical information that enables the staff to plan, coordinate, direct, or control resources under its cognizance. The targeting information provided to the fire support unit for example, when processed with other information, enables that organization to plan, direct, and control fire placed on the target using available resources. Staff information is used by the staff to perform its functional or organizational responsibilities, and the flow of staff information normally follows these channels. Staff information is also provided to the commander by staff members so that he can understand the battlefield situation and decide on appropriate action, and formulate directives for accomplishing his operational mission with resources under his control.

Command Information. Command information is derived by the commander from his assimilation of the staff and technical information he acquires through observation or report. This information is exchanged by commanders to convey the condition of their organization, the perceived situation, or other information needed by commanders to discharge their responsibilities. Command information may also be directive in nature, establishing the commander's desired situation. It originates with the superior commander when it is a directive and is provided to either his subordinate commanders or staff at that echelon. Command information flows in accordance with the organizational arrangement established by the task organization of the force.

Force-Level Information. Another classification of information used by the Army is force-level information. Force-level information is a selected set of technical, staff, and command information that has been identified by the Army as the information needed by commanders and staffs at any echelon to support the command and control of their forces.

Each of the four processes which are involved in the processing of data to increasingly more processed levels of information can, of course, be further sub-divided to identify specific methods employed. Thus:

Planning includes the (1) mission analysis, (2) definition of the work to be done, (3) organization of the assigned resources to accomplish the work, (4) scheduling the work, and (5) identifying constraints (resources and control measures).

Coordinating involves the exchange of information with higher, lower, and adjacent echelons as well as with organizations outside of the Army which also provide resources for the commander to employ. Coordinating includes: (1) resolution of constraints and (2) scheduling the application of resources during employment.

Directing is the process by which the commander formulates instructions and issues them to subordinates at lower echelons. These instructions form the basis for the desired situation the commander seeks to accomplish. "Execution" of these instructions is carried out at a subordinate echelon which in turn reports its status to the higher, directing echelon.

Controlling consists of: (1) monitoring and updating the perceived situation (the situation which available information collected or reported from the environment enables the commander and staff to evaluate); (2) comparing the perceived situation with the desired situation; (3) deciding on the action that is necessary; and (4) reporting the perceived situation to higher, lower, and adjacent echelons as necessary.

All of the specific tasks, which derive from the four processes, occur in a general situation (see Figure 36) in which the command and control system needs to maintain two major environmental interfaces. One involves the actions needed to assure that subordinate units execute and, thus, influence the environment; the other actions are taken to assure that subordinate units sense and report their situation in order to provide feedback concerning the environment. (See Figure 37)

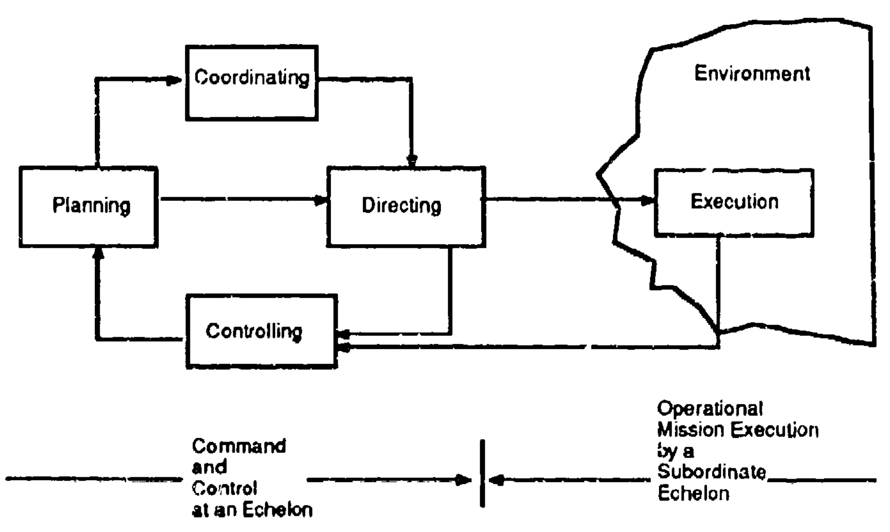


Figure 36. Command and Control Processes and the Environment from Bigl^r et al. (1984).

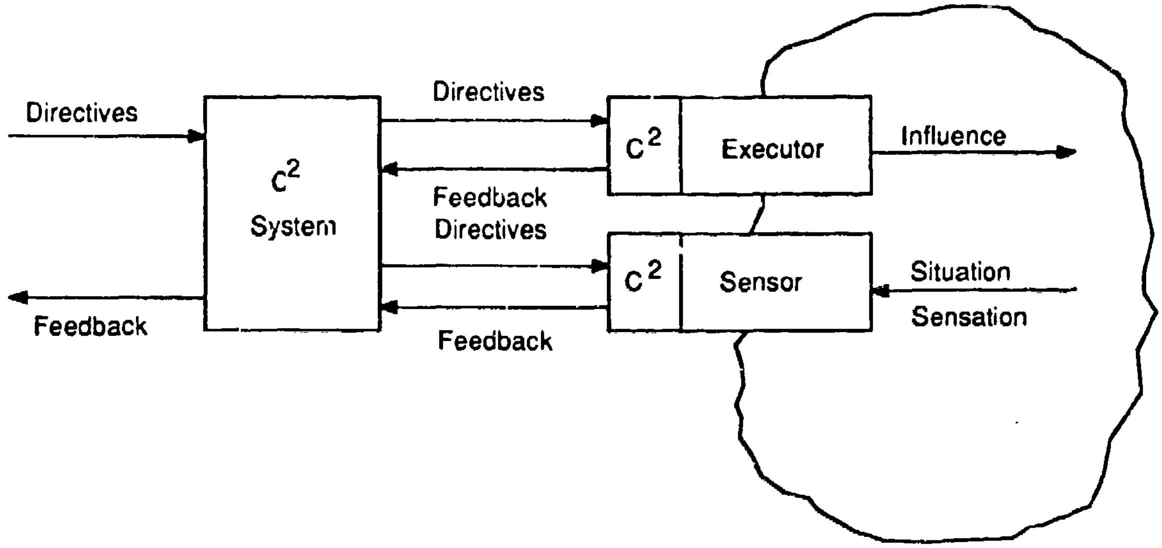
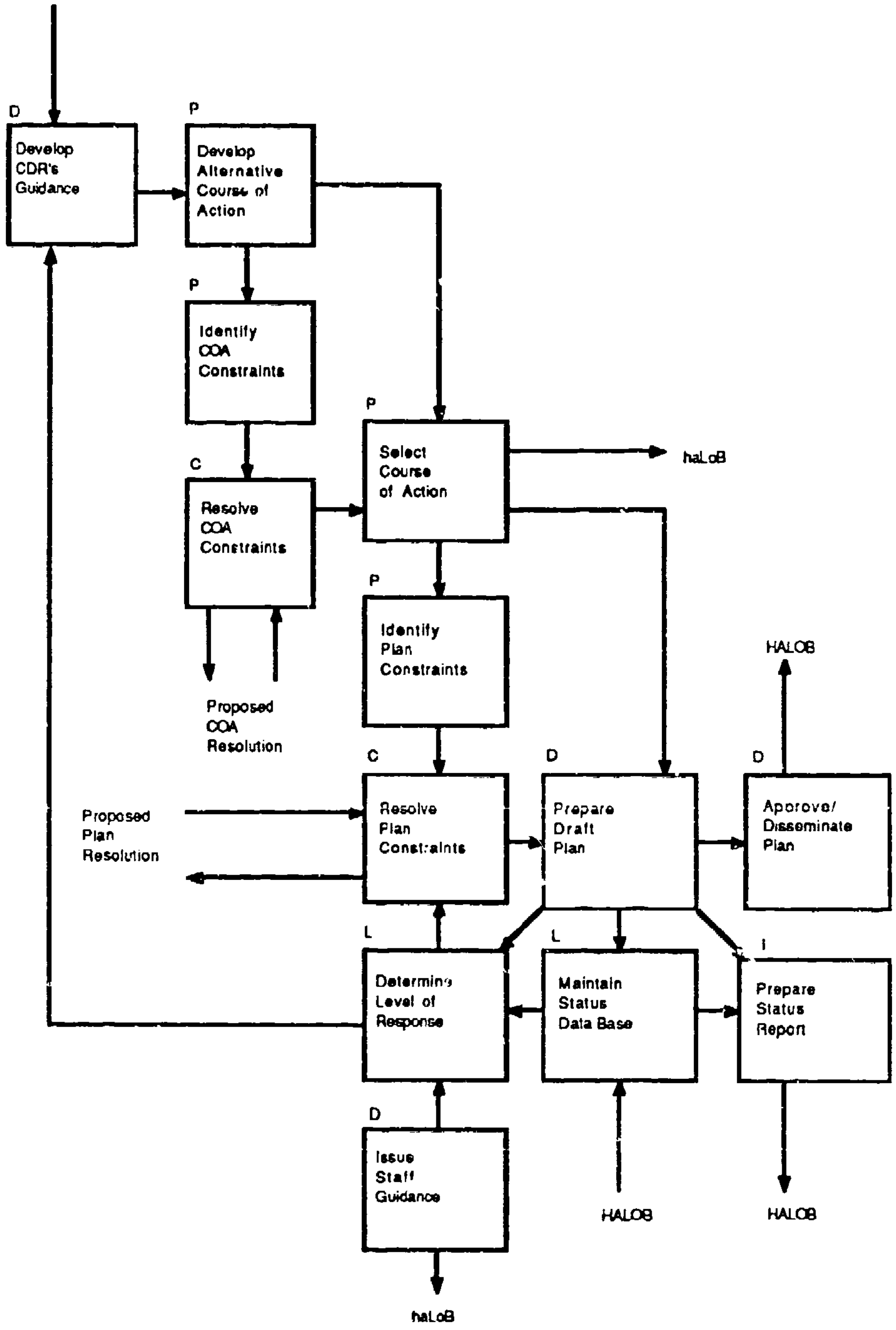


Figure 37. General Model of a Command and Control System from Bigler et al. (1984).

Ultimately the researchers provide three "levels" of command and control models. The levels vary in complexity and their complexity depends upon the situation that causes the command and control process to cycle through its sequence. The first level model (Figure 38) is more complex and defines how the system reacts when the command post, with its contained command and control system, needs to respond to a new situation created by orders (or approvals?) from a higher echelon commander. A second level model (Figure 39) describes how the system needs to react when the new mission is limited to planning to accomplish revised guidance from the commander of the echelon itself. The third level model (Figure 40) is a simpler, more truncated model which shows how a command and control system reacts when the plan to implement does not need to involve formal coordination with the commander at that echelon. All of these models are, of course, variants of the general model shown in Figure 41.

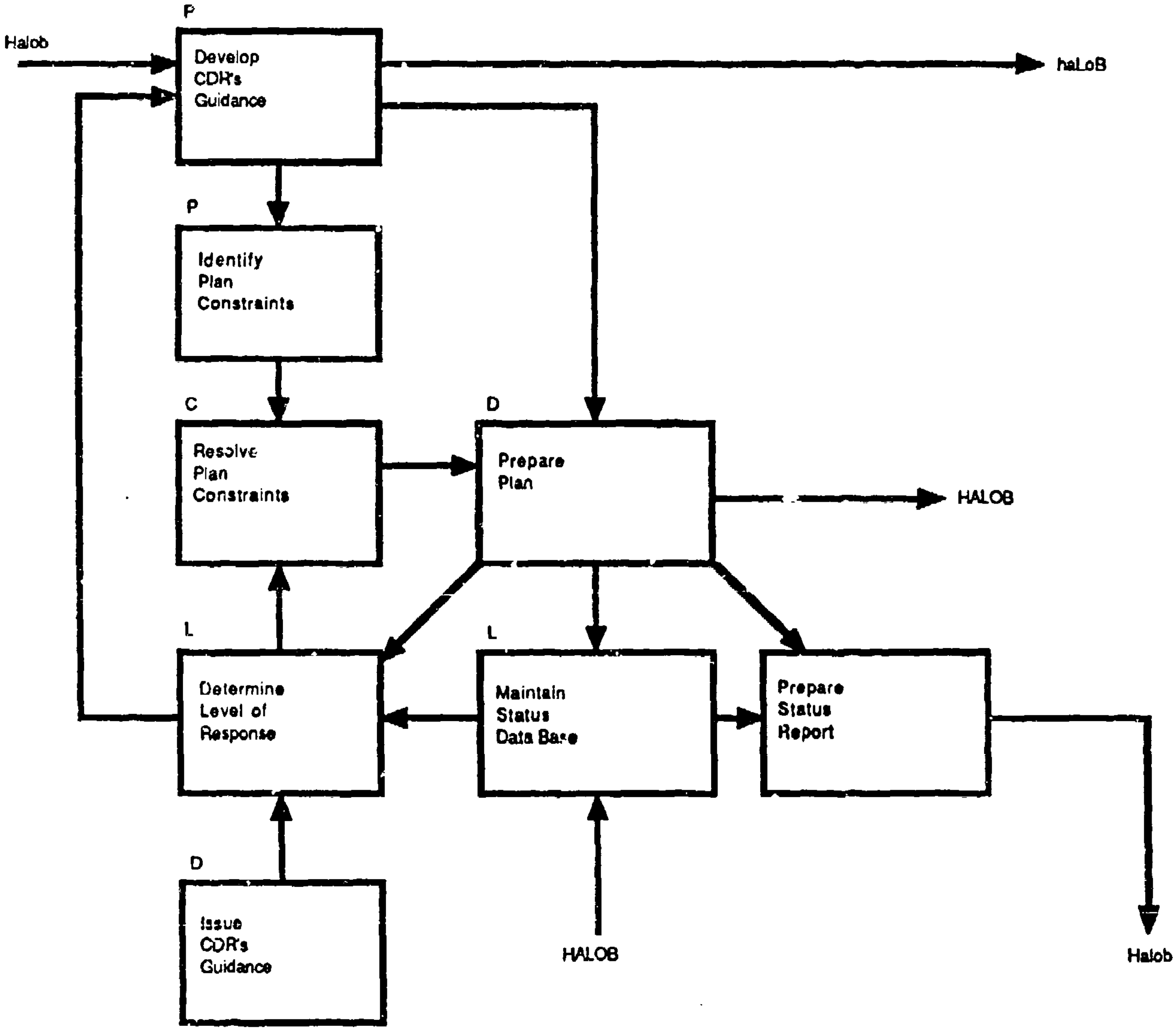
These reports by MITRE researchers are quite excellent. Almost unique among command and control modelers, they evolve their models and concepts on the basis of extensive analysis of how Army command posts, corps to brigade, actually operate. Also, since the intent of the work was to define a new command post architecture based on extensive computer support, the researchers were firmly anchored in the real world as they began and as they concluded their works. These reports are valuable as source documents and it is unfortunate that they have not had a broader distribution.



LEGEND:

h = Higher echelon; a = adjacent echelon; l = lower echelon
o = other service; b = battlefield system
Capitalization indicates involvement in information exchange

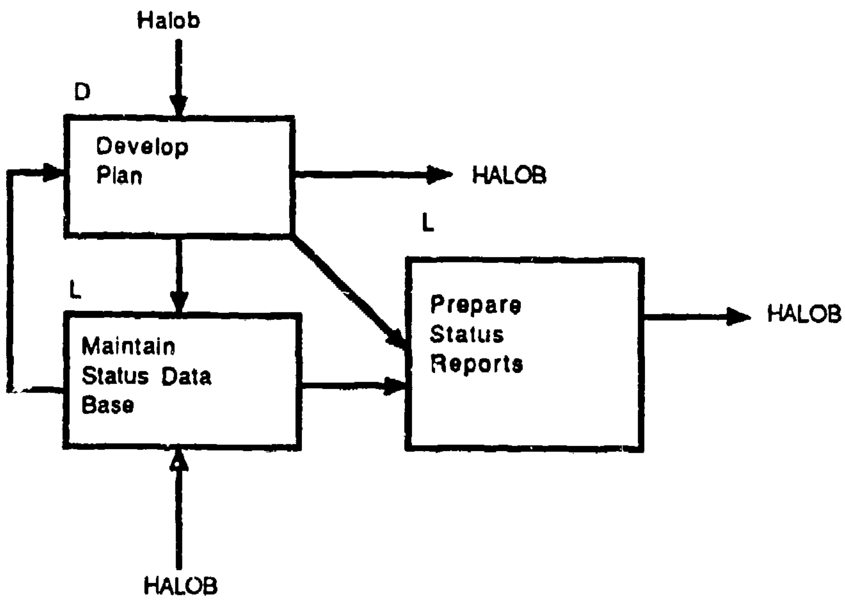
Figure 38. Model 1, A First Level Command and Control from Bigler et al. (1984).



Legend:

h = higher echelon; a = adjacent echelon; l = lower echelon;
o = other services; b = battlefield system
Capitalization indicates involvement in information exchange.

Figure 39. Model 2, A Second Level of Command and Control, Plan Prepared by Commander from Bigler et al. (1984).



Legend:

h = higher echelon; a = adjacent echelon; l = lower echelon;
o = other services; b = battlefield system
Capitalization indicates involvement in information systems.

Figure 40. Model 3, A Third Level of Command and Control Plan Prepared Without Coordination by Commander from Bigler et al. (1984).

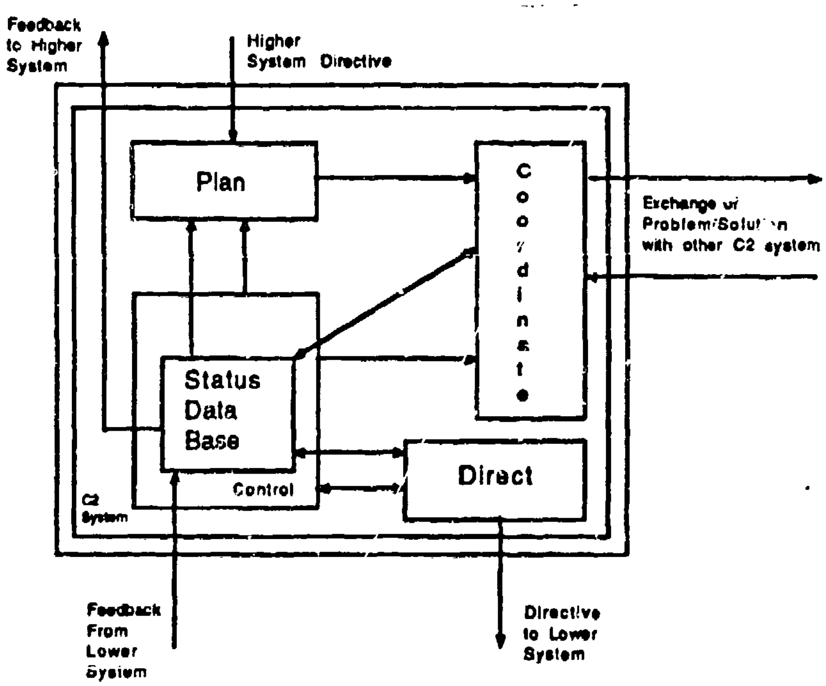


Figure 41. General Model of Command and Control Processes from Bigler et al. (1984).

Network Models

Network analysis techniques have had only a limited application to the command and control evaluation process. Certain rudimentary beginnings are demonstrated in work already cited. For example, Barber and Kaplan (1979) diagrammed the battalion command group ARTEP tasks in a generally time sequenced order that approximates a PERT chart. FM 101-5, Staff Organization and Operations, provides a "planning time discipline guide", see Figure 42, which portrays the planning cycle with time estimates for completion of major activities performed as an OPORDER is prepared. The guide also contains an affiliated matrix which shows how the various staff components contribute to the various operation planning activities.

The earliest application of a network analysis technique to the command and control process appears to be a Russian effort reported by Skachko, Volkov, and Kulikov in 1968. This study--not evaluated in the original--is available in the form of an unedited machine translation from the Air Force Systems Command, Foreign Technology Division (see Skachko, Volkov and Kulikov (1985)). The "unedited machine translation" is quite long, 331 pages, and untranslated material makes up major portions of Tables and Figures. The report is difficult to read and its major value is to establish what seems to be Russian primacy in this area, and to suggest that an interested researcher would do well to obtain the original and sit with a Russian proficient co-worker if a detailed review were required.

A more suitable source for the non-Russian reading researcher who is interested in network models is a book by Ivanov, Savelyev, and Shemanskiy published in 1977, then later translated and published under the auspices of the United States Air Force. In this book the authors discuss the application of a "strip chart" to define tasks, assign task times, and show task sequence data. Figure 43 shows the example, Preparing a Battalion Offensive Plan, used by the authors. Resemblances between Figures 42 and 43 are obvious. The authors of this book go beyond mere strip charting and discuss how the data in such a chart can be used to improve command and control procedures. In their discussion of the methodology the authors point out how inferences can be made concerning the impact of proposed changes by determining their effort on the total cycle time and utilization of staff. Later in their discussion of how to "scientifically organize" a command post the authors discuss the application of PERT charting techniques to command and control operations.

The authors introduce their discussion by noting the value of network analysis techniques and the command post characteristics that make these techniques especially valuable in command and control evaluations. The authors state their view as follows:

> Network charts are especially irreplaceable in determining the optimal alternatives of officers' work in organizing combat operations. As a rule, this work has to be done in a limited time. It involves a great many executive agents who are highly dependent on each other, and it therefore requires exceptionally clear-cut organization. At the same time, the main measures for organizing combat are based on certain norms

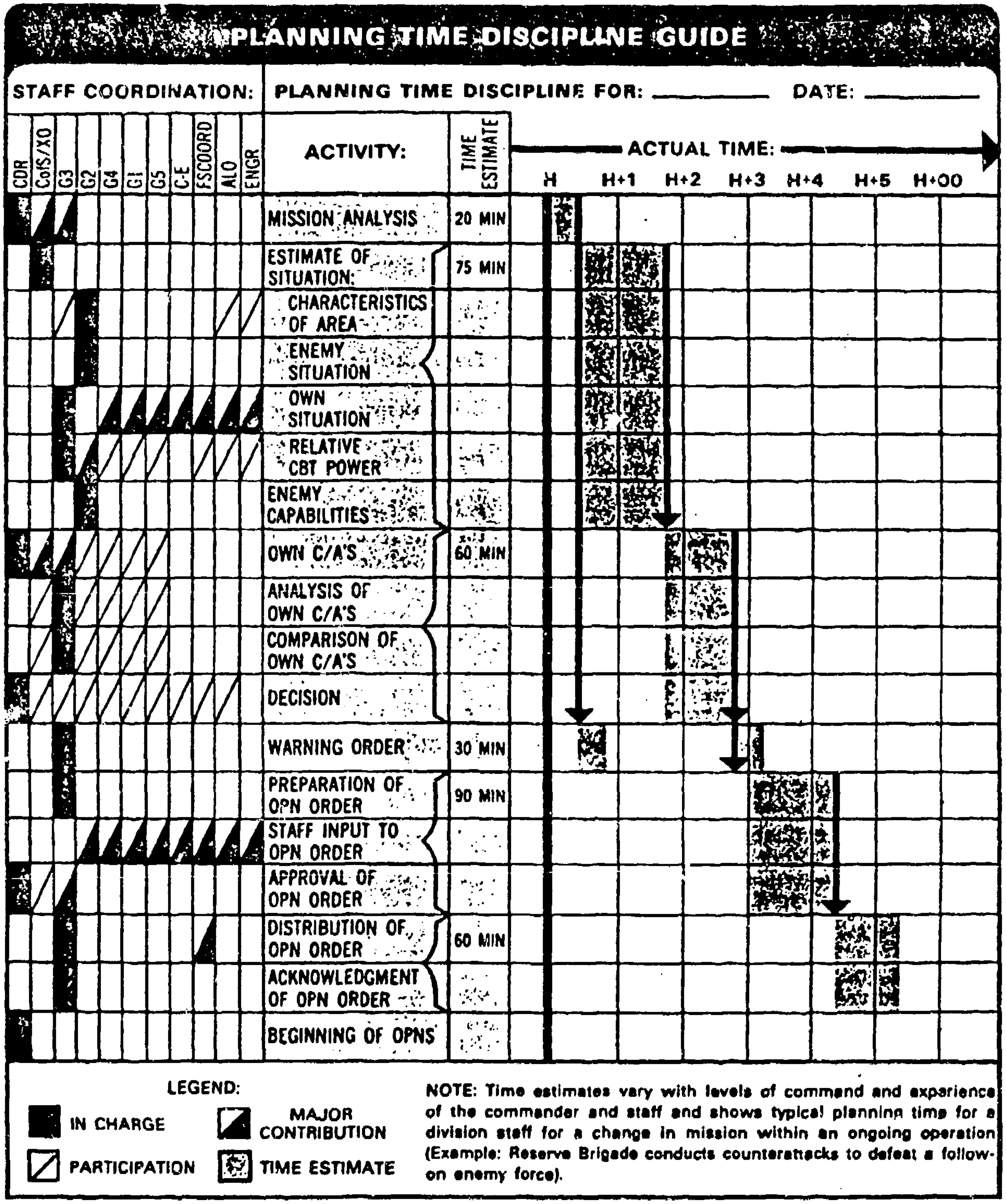


Figure 42. Planning Time Discipline Guide Adapted from FM 101-5.

Approved

Commander ____________

____

(rank, last name)

(date)

Plan For Preparation of Offensive

______________(subunit) from _______ to ____________

Time mission received ______________ Time ready for offensive __________

Sequence Numbers	Measures	Time frames for accomplishment hours/minutes							Executive agents	When accomplished
		1			2			3		
		20	40	60	20	40	60	20 etc.		
1	Analysis of assigned mission, taking into account the actual situation								Commander, chief of staff	
2	Dissemination of fragmentary orders								Staff, deputy commander	
3	Preparation of data and calculations required for making the decision and for planning								Staff, deputy commander	
4	Continuation of situation assessment, determination of the concept, issuance of preliminary fragmentary orders								Commander, chief of staff	
5	Completion of decision, assignment of missions to troops								Commander	
6	Report of decision to superior								Commander	
7	Performance of reconnaissance on the terrain in order to amplify the decision and organize coordination								Commander, staff officers	
8	Organization of the offensive at the company-platoon level								Subunit commanders	
9	Preparation of the routes and final organization of the jump-off position								Subunit commanders	
10	Advance and deployment in fire positions of artillery and mortars								Subunit commanders	
11	Advance of motorized rifle (or tank) subunits to assault position								Subunit commanders	
12	Replenishment of material reserves, repair and evacuation of defective equipment								Deputy commander	
13	Monitoring of the work of subordinates								Commander, deputy commander, staff	

Chief of Staff ____________________

(rank, last name)

Note: In the battalion, this plan does not have to be developed as an independent document, and all measures for preparation for the offensive are reflected by the chief of staff in the working notebook.

Figure 43. Example of strip charting, adapted from Ivanov, Shavelyev and Shemanskiy (1977).

susceptible to quantitative calculation, making possible completely objective judgments of the effectiveness of this or that alternative of work organization. The mathematical basis for the critical-path method is the network chart (PERT model, network) by which one can determine the scale of the operation, establish the most advisable sequence of actions, make the best distribution of duties among responsible personnel, and discover time reserves and means of reducing the time taken for organizing combat operations.

It is unclear how extensive a use the Russians have made of the network based models and PERT chart based analysis which they discuss in this volume. The authors do provide an example of a command post PERT network and the task data necessary to support critical path analyses. It is worth noting that in this volume there appears a reference to a 1974 report on command and control using network methods by Skachko, Kulikov and Volkov. Certainly the implication is that the application of network based techniques to command and control problems is at least past the exemplar application stage. Also it is likely that in the decade since this book appeared there would be further advances. Hence, a more comprehensive review by a qualified (read Russian reading) researcher might be in order.

In any event this book (Ivanov, Savelyev and Shemanskiy, 1977) and an earlier book by Druzhinin and Kontorov, 1972 (also translated and published by the U.S. Air Force) are good reading for the command and control researcher. Both volumes are available in the U.S. Air Forces, Soviet Military Thought series. Between them these books demonstrate the status of command and control and decision aiding thought in the Soviet Union a decade ago. Additional applications of network model and analysis techniques that have been conducted in the decade since these books were published may exist but the literature search that formed the basis of this review did not identify them.

Attempts to apply network analysis techniques within the English speaking research community have been quite sparse. Many of the computer simulations and wargame simulations purport to either model or evaluate the command and control process and some of these simulations allude to networks. However, the application or development of command and control models for computer simulations is beyond the scope of this paper. The reports which we have examined also define and model command and control in narrow and simplistic terms and, hence, they are not suitable for review here.

A report by Krupenevich (1984) illustrates this tangentially related area. The author notes that his purpose is to develop a generalized network methodology that can be applied to the further development of an existing simulation, the Airland Research Model. The author addresses two areas within this larger area; the development of a transportation model and the development of a command and control model. In his discussion of the command and control network Krupenevich describes his network as dealing with command and control <u>connectivity</u> rather than command and control. Thus, he actually addresses the communication portion of the broader area referred to as Command, Control and Communications or in an even broader way as Command, Control, Communications and Intelligence.

The researcher indicates that he wants to develop a network that provides a structure that: monitors information flow around the network, initiates events in the execution modules, assesses the quality of results of command and control planning, and investigates the details of the internal command and control process. In his model a message of some sort serves as the only input to a unit's processing algorithm. This message initiates actions within the receiving unit's planning module and often results in new messages being transmitted as the result of actions taken within the processing unit. Despite the authors broad goals the material actually reported deals almost exclusively with the communications aspect of the battle fighting problem.

In his report Krupenevich deals, with some rigor, with the network modeling of communications. For example, he addresses how the "connectivity" requirements change as task organization--the units assigned to subordinate commands--changes. He does not, however, appear to address the real command and control processes that occur within his network nodes. Indeed, his command and control network model appears only to define specific types of information and then identify how the information can be transported in the communication system. In the end he postulates that there are four types of command and control information: Orders, Requests, Reports, and Intelligence, and, given a command structure that can be identified, the command and control network (read connectivity network) determines "if a unit j, desiring to send a message of type i to unit k via mode of transmission l can actually do so."

There are numerous models that support simulations, analytic network models, and other types of models that fall outside the purview of this report. In many cases their exclusion results from their, sometimes explicitly stated, view that communications is the real essence of command and control. Such a narrow definition is clearly misleading and a theory or model based on such a view is not likely to be a major contributor to the advancement of the field.

A final modeling approach which may be directly relevant to command and control as it is performed by the Army is a methodology based on Petri nets. Petri nets were first described in the early 1960s to model computer systems. Since their introduction the technique has been extended and has been used to model various kinds of large, complex organizations and an assortment of aspects of these organizations (e.g., attributes, timing relationships, stochastic events). Relevant research has been reported by researchers at Alphatech, Inc. who have applied the technique to an Air Defense command and control problem. The work was funded by the Defense Communications Agency. An Alphatech, Inc. report by researchers Moore, Tenney and Vail (1986) describes both the Petri net derived methodology they used and the results of their application.

Since the Moore, Tenney, and Vail report deals with the modeling of an air defense mission the model itself is of little interest in the context of the Army command and control problem. The reason for this, of course, is that the command and control mechanisms involved in air defense are too narrow a subset of the more numerous functions performed by a corps, division, or even a brigade and because the model deals with command and control mechanisms that are intertwined much more closely with the events of the battle than is the case with Army command and control processes. Stated another way Army command and control processes are packaged by echelon with each echelon (package) interfacing with higher, adjacent, and lower--particularly next lower--echelons. Thus a division headquarters is usually separated from the actual events of the battle by brigade, battalion, and company command processes. A model that represents a division, therefore, can be looked at as a horizontal slice of the totality of the command and control systems involved in the battle. The air defense model developed by Moore, Tenney and Vail can be considered as representing a vertical system slice since it addresses command and control events on a continuum stretching from the engaged aircraft to higher echelon, land based, control levels.

For this report it is the methodology that is of interest. The researchers refer to their Petri net approach as using Stochastic, Timed, Attributed Petri Nets (STAPNs) and devote some 40 pages to a description of the method's basic concepts and related features such as mathematical constructs and mathematical-physical relationships. The following brief discussion, adapted from the Moore, Tenney and Vail report, describes the STAPNs technique, very cursorily, for the benefit of readers totally unfamiliar with the technique.

The STAPN technique uses five symbols to model objects, or products, that move in some real network. The five symbols are:

UNAVAILABLE TOKENS	○
AVAILABLE TOKENS	●
ARCS	→
TRANSITIONS	▮
PLACES	◯

Petri nets are based on a vision of <u>tokens</u> moving around an abstract network. Tokens are conceptual entities, meant to model the objects which move in a real network. In their simplest manifestation tokens can be in one of two states. When a token is created it is always in an <u>unavailable</u> state. After some time elapses, the token changes to an <u>available</u> state. After an additional time, the token is destroyed. The interpretation of the two states is that (a) when the token is unavailable, it exists and cannot be destroyed, and (b) when it is available, it exists and will be destroyed as soon as certain other conditions are satisfied.

The time a token remains unavailable is determined by a <u>timing model</u>. Timing models fall into four classes. The simplest models are deterministic: the duration of the unavailable state is fixed at one value, which may be zero. A more realistic model is stochastic. the duration of the unavailable state is random, but is always drawn from the same probability distribution. The randomness can be used to represent either actual physical uncertainity or known modeling imprecision. In a third case, times may depend on information carried by the tokens themselves. The fourth class of models allows the timing to depend on an external variable.

Finally, tokens may carry attributes along with them. Attributes are simply numbers, or other information encoded as numbers which accompany a token through its life. Values are assigned to the attributes of a token when it is created, and they do not change until the token is destroyed, after which they are irrelevant. Attributes may have continuous or discrete values, or consist of combinations thereof.

The abstract network through which tokens move consists of two types of elements. The first type is called a place. Tokens reside in places while they are unavailable and waiting to become available, or while they are available and waiting for conditions to arise allowing them to be destroyed.

The second type of element of which the abstract network is constructed is called a transition. Transitions determine how and when tokens are destroyed and created. Transitions evolve through three states: potentially enabled, enabled and disabled. Normally every transition is disabled; when certain conditions hold, a transition will become potentially enabled; if other conditions hold, it becomes enabled. In either case, the transition leaves the disabled state only for infinitesimal periods of time. After becoming enabled, the transition destroys some tokens, creates some others, assigns attributes to the new tokens, and immediately reverts to the disabled state.

The final abstract network elements are the connectors between places and transitions which are called arcs. Only one basic constraint restricts the placement of arcs in a STAPN: arcs can only connect places to transitions, or vice versa; they can never connect places to places or transitions to transitions.

These symbols, and a few additional rules, make it possible to create quite complex models. For example "places" can perform four roles. The four roles are:

> Storage: Tokens arrive in a place from one source and depart to one destination after they have become available and the conditions for their destruction have been satisfied.
>
> Confluence: Two or more streams of tokens flow together to proceed on to a single destination, after being stored.
>
> Divergence: One stream of tokens is broken into two or more streams, which proceed to different destinations after storage.
>
> Mixing: Two or more input streams combine, and then are broken down (usually in a different way) into streams which move to separate destinations after waiting.

In the case of a divergence or mixing there must be a way to determine which path any individual token will follow out of the place. To accomplish this a decision rule must be associated with every place. By invoking the decision rule for every passing token, the model can ensure that token behavior is always completely determined. These four place roles make it possible to model not only simple process steps but also flow junctures, separations and mixings which involve two, or more, flows. Thus, depending on the number of input and output connections, a place can play four roles as shown in Figure 44.

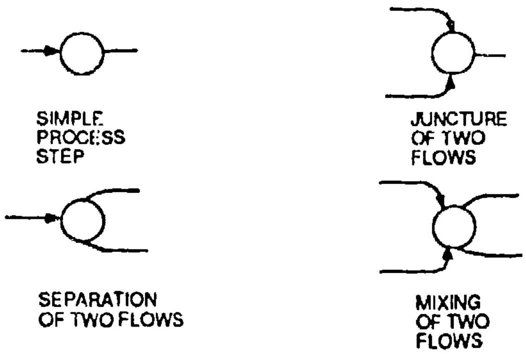


Figure 44. Place roles available for a STAPN diagram from Moore et al. (1986).

Transitions provide a similar opportunity for creating juncture, separation, or mixing representations. Thus, one, two or more arcs can terminate at a transition symbol, and one, two or more arcs can exit from a transition symbol. These symbols and simple rules, only some of which are discussed here, make it possible to model very complex systems. Figure 45 shows a simple STAPN that describes an equally simple exemplar system.

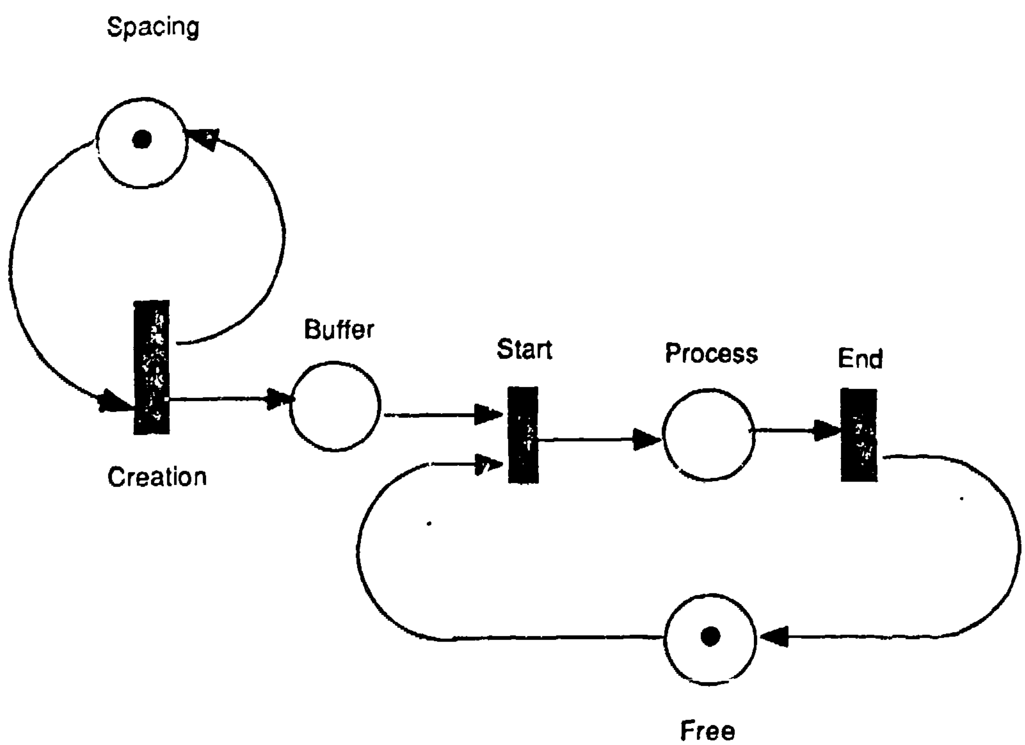


Figure 45. Example STAPN from Moore et al. (1986).

The system shown in Figure 45 operates as follows. The token in SPACING immediately enables CREATION, which places a token both in BUFFER and back in SPACING. If the timing model for this token is deterministically zero, then CREATION can fire immediately. More realistically, the timing will be nonzero, so the token rests in SPACING before enabling CREATION again. Once this happens, this cycle repeats and, thus tokens are intermittently deposited in BUFFER ad infinitum.

There is another set of events that are partially coordinated with the CREATION process. These begin when the first token in BUFFER becomes available. START fires, and when the token created in PROCESS becomes available, END fires and restores a token to FREE. However, if the time required for a token to become available in PROCESS is long compared to the time required in SPACING, more tokens will have arrived in BUFFER before the token in FREE becomes available. Alternatively, if the time spent in PROCESS and FREE is small compared to the time spent in SPACING, the FREE token will wait for the next arrival in BUFFER before firing START.

Neither of the network modeling techniques has been rigorously applied at corps, division, or brigade level but both PERT techniques and the STAPNs methodology hold great promise. Both suffer, however, because the data needed to apply them are not available, and the data are likely to be difficult to obtain in the quantity needed to make good use of such modeling techniques.

SUMMARY AND CONCLUSIONS

The state-of-the-art in command and control modeling is not well developed although it may be that some writers in the area have overstated the case. Earlier, in the Introduction, the reviewers quoted Fischhoff and Johnson (1985) who concluded that with regard to command and control theory:

> The stakes are so that that funders are willing to go with very long shots in hopes of producing some useful results. Yet, the complexity of the problem is such that many of its theories appear almost autistic, as though the attempt to make sense of it leads researchers down a path to convoluted and idiosyncratic theorizing.

In this review the validity of this statement is best demonstrated by material that the authors omitted from the review. Certainly there are a number of reports that deal with command and control so tangentially that it is hard to see any relationship beyond the title. Some reports do little more than demonstrate that algebra works. Other reports deal so completely with communications problems, computer technology, or control theory - in the physics and engineering sense - that it appears that command and control - in the Army sense - is either in the title by accident or added to broaden the apparent scope of the work being reported.[1]

There are, however, a number of publications that do make a contribution to command and control theory and a number that present material of value to model development. It might be more charitable, and more factual, to describe most theorizing as simplistic rather that autistic, and to note that the major problem in the field is not that it is "convoluted and idiosyncratic" but that too much of it lacks a clear focus. This review has demonstrated the broad domain and often disjointed nature of the work performed under the rubric "Command and Control Theory and Models". Sutton (1986), in a review of the more general literature - such as Military Review articles[2] - points out that there exists:

> . . . a tendency to address the subject (of command and control) in an unbalanced and piecemeal fashion. Some articles tend to emphasize the the importance of technology, both hardware and software. Other articles deplore the apparent fixation with technology and technical means, and urge a shift in emphasis to the role of leadership in C^2 systems. Another class of articles details the procedures, policies and techniques used by a certain unit in their command post system. Most of the articles are well worth reading, but one is soon convinced, to rephrase the old saw, that C^2 is defined by the senior man present.

Our review of the more research oriented literature certainly supports this view; except that command and control seems more often to be defined in whatever fashion most conveniently justifies the work rather than by the senior

---

[1] Names and references have been omitted to protect the guilty.
[2] Sutton draws his conclusions from a 27 item literature review virtually all of which were not of the type included in this review.

man present. Some of the problems associated with the relatively uncontrolled application of researcher fiat to the definition of command and control are apparent in this review even through its diversity was constrained by its rather narrow focus. Thus, the Behavioral System, Decision Making category tends toward research on how individuals make decisions rather than addressing how command and control decisions are arrived at in a specific command post environment; research classified as Behavioral System, Computer Technology tends toward discussions of how computer programs can be used - perhaps - to create a command and control model; and Systems Oriented, Information Processing material tends toward work that seems to deal more with recasting proven engineering analytic methods than with the command and control process.

The rather complex model classification scheme used in this paper may be overkill considering the state of the modeling literature but it does provide a framework for some conclusions. One set of somewhat general conclusions deals with how the different model classes place along a continuum anchored at one end by models created to help accomplish a specific command and control purpose and at the other end by those which appear to have been developed to support a much less specific - or even a tenuously related - command and control purpose. There is a clear trail of related research where models and theory have been created in order to support the development or improvement of the command and control measurement process. Clearly Field Manuals (FMs), Field Circulars (FCs), and Standing Operating Procedures (SOPs), which specify how command posts are set up and how battle staffs operate, are the foundation for the Army command and control process. It is equally obvious that Army Technical Evaluation Program (ARTEP) documentation and Army Mission Training and Evaluation Program (AMTEP) documentation represent a deliberate attempt to measure how well a command post, with its staff and equipment, performs.

Research efforts which appear to have evolved from the organizational research perspective and the work of management theorists certainly provide the best research bridge between extremes mentioned in the above paragraph. Olmstead and his various collaborators introduced the concept of an adaptive coping cycle to command and control research, and demonstrated that the effectiveness of a command post depended largely on the competence of the staff. Later researchers modified the Olmstead models and replaced them with variations of decision cycle based models. These type models led ultimately to the adaptive control cycle concept that forms the basis of the HEAT methodology and, with modifications, of the ACCES methodology. These decision cycle based Organizational Process research efforts have also been propaedeutic to the general acceptance of the cyclic decision making model within the Army, as witnessed by the various U.S. Army command and control definition documents that incorporate some variant of this model type.

The ultimate proof of the value of this organizational line of research is the fact that both HEAT and ACCES provide evaluative models which have been successfully applied at Army division level. A HEAT variant has been used to evaluate the contribution of the Maneuver Control System to the division command post and ACCES, itself a development from HEAT, has been developed and tested in division and corps level environments.

Behavioral System and System Oriented research has not been as influential in the command and control modeling and theory arena. What seems to happen to researchers who look at command and control from these perspectives is that they do not really deal with command and control. For example Behavioral System, Decision Making research tends to address how single decision makers make their decisions, and the studies tend to assume that the decisions worthy of study are those made when an order from a higher echelon is received and the units overall battle plan is developed. Thus, single decision makers replace the organization as the focus of the research and the rather rare event of planning in response to an order from higher headquarters replaces the twenty or thirty times more prevalent decision cycles that occur as the battle staff makes the decisions needed to actually fight the battle.

Behavioral System, Computer Technology oriented research, and System Oriented, Information Processing research, also tends to be less influencial and somewhat more tangential than Organizational oriented work. In these cases the cause seems to be the intent and the background of the researchers. Both areas are represented by work that attempts to show how a technology or analytic process, which is often complex, sophisticated and of proven value in some other area, can be applied to command and control. Too often it seems that the technology or analytic tool is well known to the researcher but command and control is poorly known with the result that not much is accomplished in melding the sophisticated to the little known.

This situation does not have to exist and the case against it is well made by those contributions which have been classified Systems Oriented, Architecture, and Network. Various MITRE researchers have applied well defined systems analysis tools to the command and control process, as it is done manually, in order to determine what needs to be done to make the system more computer based. The result of their efforts was that by program end the researchers knew command and control very well and could deal directly with the specific command and control issues they had identified from actual data collection at division level command posts. With a sound knowledge of how command and control operates in the Army the MITRE researchers were able to make contributions to both the model and theory area, and to the body of data concerning command and control.

Network based model efforts, though still not widely applied, represent a potentially successful way of modeling command and control in terms of work flow or some other process definition method. Time lines and traditional PERT charts have been used by several researchers, albeit more by foreign researchers than by our own. These approaches have been motivated to date somewhat more as Implementation models than as Evaluative models. Some of them, however, (FM 101-5 and the Russian literature) serve as a bridge between Implementation and Evaluation since, by providing times and work sequence material, they can also serve as standards creation mechanisms. It is obvious that Network models can be cast into a more analytic mold and that greater contributions are clearly possible. PERT-like models which contain exit paths which differ according to some stated contingency have been used for many years (see Crumley and Wilson, 1966 for an example) and could describe upper echelon command and control processes very well if the data were available to create them.

The model and theory development literature reviewed in this report seems to support the following conclusions:

1. Models and theory which support a purpose beyond a mere discussion of the model or theory itself are more productive than products which derive from attempts to develop models or create theory independent of a specific application.

2. Generally, research which is based on an organizational or management theory perspective has been more productive than research evolving from other research perspectives.

3. Research which considers decision making as the role of a command post is more effective when it does not artificially, and incorrectly, limit the decisions it considers to those implied in the military decision making model used to define how orders from next higher headquarters should be developed into orders at the echelon which receives them.

4. No extant model is sufficiently well developed and well enough supported by data that it can be used in a predictive or analytic fashion.

Beyond these conclusions, which clearly evolve out of considering the literature itself, there are other goals, or model and theory requirements, which should be adopted to provide guidance for the development of better Army applicable models. These conclusions are partly drawn from the literature and partly the result of considering, in a broader fashion, the problems associated with the potential acceptance and utilization of command and control research. These ancillary conclusion are:

5. Models should deal with a specific organizational structure.

6. Models should be based on observable tasks, processes, or behavior.

7. Models should be constructed so that the data which support them and the models' outputs can be easily related back to the tasks, processes, or behavior on which they are based.

8. Models should be supported by at least the potential for a theoretical development which defines how the command and control function relates to battle outcome and, thereby, permit research concerning command and control to be of value in showing how battle staff activity contributes to unit fighting effectiveness.

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