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ONR ltr dtd 27 Jul 1971

TM-WD-227/000/00

CONCEPTS FOR COMMAND AND CONTROL SYSTEMS

23 DECEMBER 1965

PREPARED FOR: ADVANCED WARFARE SYSTEMS DIVISION,
NAVAL ANALYSIS GROUP, OFFICE OF NAVAL RESEARCH.

TM-WD-227/000/00

TECHNICAL MEMORANDUM

(TM Series)

The research reported in this report was sponsored by the Office of Naval Research, Advanced Warfare Systems Division, Naval Analysis Group, Contract Nonr 4923(00), ONR Contract Authority Identification No. NR-278-021.

Final Report

CONCEPTS FOR COMMAND AND CONTROL SYSTEMS

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TABLE OF CONTENTS

ABSTRACT

"Command and control system" is "defined" by: (1) outlining a tentative model of the embedding "military process" consisting of five "functions" (sense, analyze, decide, act, communicate) at command points, with emphasis on the interfaces between these functions; (2) describing eighteen military command and control systems in operation or under development; (3) noting how analysts have categorized this kind of system; and (4) indicating resemblances between this kind of system and two non-military organizations. It is thereupon suggested that the methodology for improving the derivation of concepts for command and control systems can be improved by profiting from past experience concerning five interrelated "trouble-points" originating in the concepts for such systems: interfaces at function and system boundaries, data input at the front end, interaction of noise and data conversions, consideration of the "anti-system", and system exercising. Two of these "trouble-points" are examined in some detail to show how such analyses might contribute further to an improved methodology. Optimization of "enabling conditions" could also result in such improvement. These include participation of the user, learning the task of conceptual design, managing that task, and letting the system evolve. It is recommended that the Navy continue this study in-house by assembling further information about trouble-points so that designers can learn from problems encountered in the past and their resolutions or continuing challenges.

I. PREFACE AND SUMMARY

This task was performed as part of the Naval Command Systems Research Program, sponsored by the Advanced Warfare Systems Division, Naval Analysis Group, Office of Naval Research, under the direction of Mr. Ralph G. Tuttle, ONR Scientific Officer. The objective of this program is to provide a scientific and technological base on which system planners can make improved decisions in the development, design and implementation of improvements to Naval command and control systems.

The information contained in this document reflects, in part, the results of a study effort which was directed toward the following objectives:

1. Define "command and control system" -- The goal of this task was one of describing the essential characteristics of command and control systems rather than preparing a new, pat definition of one or two sentences. In other words, the goal was one of performing a relatively basic analysis of that process which manifests itself as, and is or could be implemented by means of, a command and control system.

2. Prepare a superior methodology for deriving concepts for Advanced Naval Command and Control Systems -- In general, the purpose of this task was to develop a methodology or methodologies for specifying system operational requirements, that is, to suggest or outline improved methods for developing command and control system concepts.

3. Identification of Future Areas of Investigation -- The purpose of this task was to identify specific steps and methods that the Office of Naval Research might undertake as part of a long range program directed toward further refinement of the methodologies resulting from this study.

Personnel from four contractor organizations were chosen to undertake the work outlined above. These organizations, The Auerbach Corporation, Human Sciences Research (HSR), The Stanford Research Institute (SRI), and the System Development Corporation (SDC), decided on differing but mutually supporting approaches to the study tasks. Two of the organizations, HSR and SRI, joined in developing a single approach. The approaches chosen differed primarily in perspective, one being deductive, another being inductive, and the third approach incorporating elements of both. Early in the study a triangle of abstractions, or tree structure, emerged as a way of representing the overall patterning of the study. If such a triangle of abstractions or tree structure is imagined, then the deductive approach would consider the structure in successively lower levels of abstraction. The inductive approach, operating in an opposite fashion, would consider the structure in successively higher orders of abstraction. The third approach can be imagined as initiating at some mid-point in the triangle and concurrently engaging in ascending and descending exploration.

The report associated with each of these approaches interfaces with each of the others. Each report does stand on its own in that it does not depend on the other reports for complete understanding. As such, the separate reports are not to be likened to chapters of a book, but rather to books on the same subject, all having a common goal. The viewpoint differs but the subject remains the same. Also, as a "book" the present report can best be read as a set of interrelated essays rather than as a document with a single focus or theme.

By no means can any of the reports be regarded as representing a completed study. During the three months of participation in the study by each of the authors of the present report, much of this effort was expended in interacting with the personnel of the other contractors, in interpreting the various task requirements and in collecting a great deal of information about command and control systems. Essentially, this report records selected portions of that information, the kind of analytic approaches adopted, and some initial attempts at analysis. Obviously, much more could be done to elaborate the analytic concepts, to bring them into greater coherence and to organize more compactly the results of our exploration.

Since there was a requirement to devote 50 per cent of the effort to "defining" what a command and control system is, the reader should not be surprised to encounter, in the next section of this report, an extended attempt to satisfy this requirement, along more than one channel. Readers who may be interested in an abstracted view of the overall military context may wish to examine the first part of that section. Those who would like to look at actual systems will find eighteen of them described in the second section. If one is also concerned with the manner in which various analysts have categorized such systems, one may wish to read the third section. In addition, if one can be intrigued by resemblances between command and control systems and other organizations, one will turn to the first Appendix, which treats certain aspects of a daily newspaper and a labor union.

For readers who are already familiar with the field and are more concerned with developing new command and control systems, the second section of this report and the next three Appendices may have more appeal. This material attempts to provide some guidance for deriving the concepts on which command and control system design is based. It makes no pretense of clothing old guidelines in new dresses or of furnishing a comprehensive checklist or set of cookbook recipes. Rather, an attempt is made to improve "methodology" by singling out a number of areas where past experience indicates there is much room for improvement.

These areas consist, first, of a set of "trouble-points" in command and control systems, where designers have and can run into trouble. Five interrelated trouble-points consist of (1) interfaces between system or function boundaries; (2) the input of data at the front end of the system; (3) the interaction between noise and conversion of data; (4) the role of the "anti-system"; and (5) exercising the system by simulating the interfaces, the anti-system, the input data and the conversions. An attempt is made to indicate how inadequate or faulty concepts concerning these five trouble-points can degrade the command and control system's eventual performance. Two of the Appendices elaborate on the problems of input data and interaction between noise and data conversion.

Second, it is suggested that the methodology of deriving concepts for command and control systems can be improved by improving the "enabling conditions", that is, the circumstances under which such concepts are derived. In particular, some analysis is devoted to the problems of "participation of the user" in the concept derivation process, of "learning the task" of deriving system concepts, of managing that task, and of system "evolution" as an enabling condition for improving concepts of command and control systems (the idea that actual experience with a system will generate better concepts for system growth). "Evolution" is discussed in an Appendix, which includes the views of a number of analysts who have written about this somewhat amorphous concept.

Finally, in responding to a request for recommendations about continuing the study, it is proposed that the Office of Naval Research undertake an in-house program of assembling additional information about trouble-points in command and control systems originating from the concepts on which the systems were based. This program could lead to an ONR Center of Command and Control System Research, which could support all parts of the Department of Defense concerned with developing such systems.

II. DEFINITION OF "COMMAND AND CONTROL SYSTEM"

As indicated in the foregoing preface, the System Development Corporation's approach in this study can be characterized as inductive, in the sense that it rests on an empirical rather than a theoretical base. With such an approach the first step is to look at the actual military world in which command and control systems operate and at the actual command and control systems which are in operation or development in this real world, and then generalize from this examination. To this procedure one can apply the term "descriptive analysis". This descriptive analysis constitutes the "definition".

This section of the report contains the descriptive analysis. It is divided into two major portions. First, there is a simplified outline or "model" of the "military process" in which present command and control systems are imbedded and in which future systems must also be imbedded. Second, eighteen systems are briefly described, in a sort of annotated catalog, to provide some degree of factual anchorage in what can otherwise be a sea of terminological confusion. In addition, this section will take note of some of the classificatory schemes which people have advocated for categorizing command and control systems. With this same empirical approach it would also be possible, of course, to scrutinize organized entities within and outside the military realm that have not been called command and control systems but which have something in common with them. An exploratory venture along this line can be found in Appendix I.

What has been the rationale for adopting an inductive approach of this nature for the definition task of this study? A major aim is to furnish clarification. In their infancy, new semi-technical terms in human discourse tend to acquire diverse usages or meanings because new users tend to extend their application. The term "command and control system" is no exception. Some new users have a tendency to apply it to everything and anything. There are even variations in structuring its components, such as "command control system" and "command/control system". However, for it to retain any discriminative usefulness one must, for purposes of discussion, establish limits of some kind, so there will be some commonality of usage in that discussion. Such limits need not, of course, constitute a constraint, since one may well decide that they should be extended. So the descriptive analysis may provide clarification by roughly indicating boundaries.

Even greater tendencies exist to generalize the term "command and control", that is, omitting "system". It is fortunate that a definition of this term was not what the study task required. And there is also widespread temptation to generalize the term "system", by affixing it to any organized or semi-organized activity. Such usage not only degrades its discriminative value but hides the principal purpose of its application in military procurement in recent years, namely, to specify a set of interacting elements the development, production and installation of which can be handled better if they are handled together, under a common label. In this descriptive analysis, "system" has this meaning and will not be applied randomly or capriciously.

At this point one may ask what the purpose is in defining "command and control system" at all, whether through a descriptive analysis or in some other fashion. The purpose is to assist in accomplishing the second main task of the study, that of improving the methodology of deriving command and control system concepts. In conducting a descriptive analysis of actual command and control systems and of the military process in which they are imbedded, one comes across a considerable array of lessons which one can apply to concepts for future systems and to the methodology for for deriving them. To be sure, to make reference in the descriptive analysis to all specific items discovered concerning particular systems would require that this report be classified. Instead, these "lessons" will be covered in a more general manner in the section on "Methodology".

A. THE FUNCTIONAL STRUCTURE OF THE MILITARY PROCESS

Introduction

Command and control systems comprise a relatively new kind of capability. However, they play a role in a process which has long existed, the control of military forces. This process in turn plays a part in what can appropriately be called the "military process", and more and more thought is being given to the extent to which this larger process can or should be implemented by a command and control system or systems. While current command and control systems fall far short of having the scope necessary to implement the overall military process, this is not to say that they never will have, or that they will not at least attain a wider scope than they have. In order to show where they fit now, or might fit, it was deemed worthwhile to begin to establish a functional structure of the military process. In deriving this functional structure, emphasis has been placed on exploring the properties of interfaces which exist between functions as well as exploring the properties of the functions themselves.

The Approach to Structuring the Military Process

The approach taken in structuring the military process is based on the following criteria and assumptions:

- The approach is function oriented,* i.e., persons, places and things are considered only if it can be shown that they act to support or constrain the performance of a given function.
- It is assumed that world-wide military forces are involved in the military process and that such forces are not autonomous, i.e., some form of command hierarchy exists.

* A function-oriented approach has also been taken in the HSR-SRI report, which presents a different model of the overall context within which to view command and control systems.

. It is assumed that existing organizational structures or procedures need not be considered, and similarly, the current or anticipated state-of-the-art of our technology is not a constraining factor.

. It is hypothesized that the military process is made up of the following basic classes of functions:

Sensing

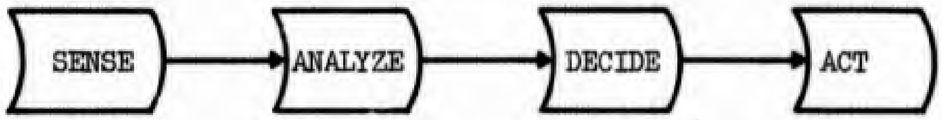
Analysis

Decision

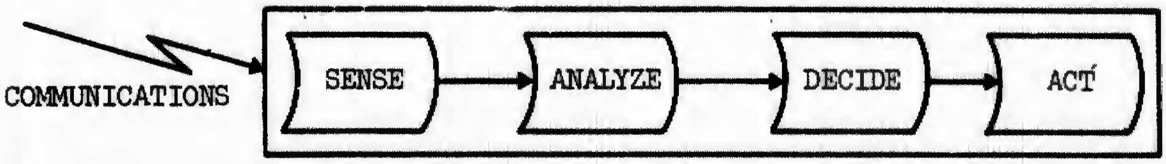
Action

The Basic Functions

Based on the above hypotheses, and treating the basic functions in the most general sense, the process may be diagrammed as follows:

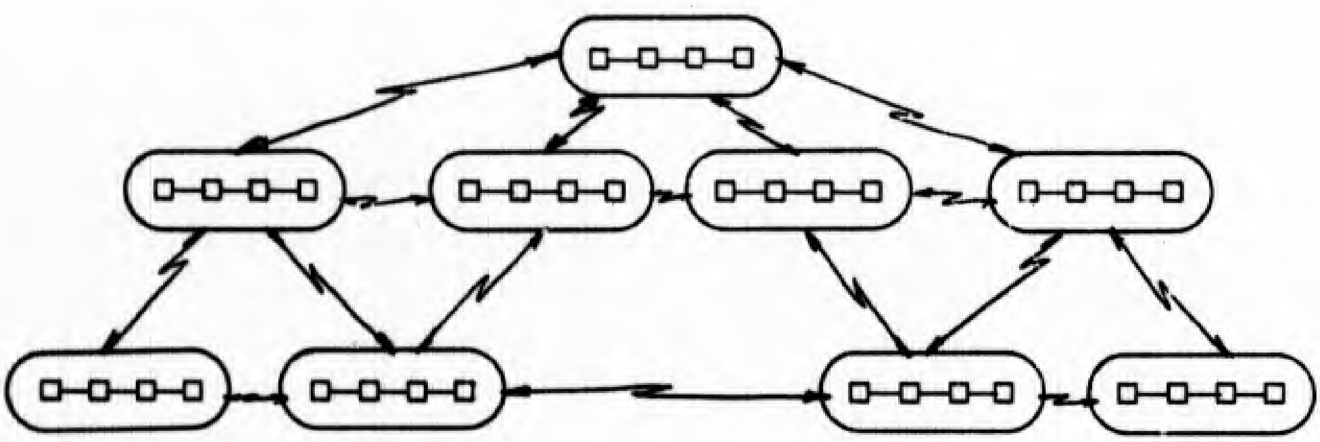


Aside from the apparent need for communicating in its generic sense, since it is axiomatic that world-wide forces are not co-located, an additional basic function, communications, is necessary in order that separate forces be able to communicate one with another. As such, the diagram may be expanded to look as follows:



Overall Force Structure

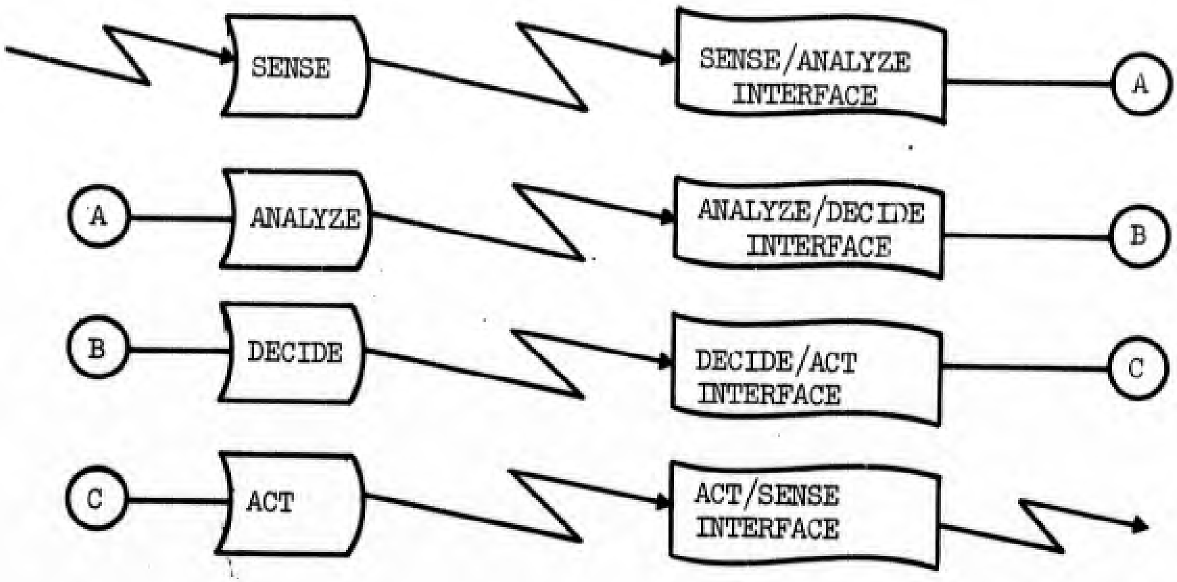
At this point it is worthwhile to establish an overall force structure which permits examination of representative functions without regard to the command level at which such functions are performed. This can be done most simply by creating a structure within which the basic function set is presumed to exist at each separate force command point. Since no particular structuring of the forces has been assumed, a force command point may be any organized group of individuals or even an individual. As such, a schematic representation of the overall structure would appear as follows:



In essence, the overall structure is made up of separate command points, each of which performs the basic function set. Communications may exist upward, downward or laterally between the separate command points.

Expanded Basic Function Set

To return now to any given command point, the picture that reappears is the basic four-block diagram with certain refinements. For one, communications are shown to exist between each of the separate functions -- this would be true if the functional process was being performed within an individual as well as by a group of individuals. Two, interfaces between each of the basic functions are shown to provide additional points of analysis. As such the revised diagram appears as follows:



Taking each basic function and basic function-interface in turn, their characteristics will be explored.

<u>Basic Function, SENSE</u>

In general, sensing may be accomplished by one of two means, human or machine. Types of <u>initial</u> sensing are:

- An object (or array of objects) being observed by a human or a machine.
- A phenomenon being observed by a human or a machine.
- An action being observed by a human or a machine.

In essence, all data results from human or machine observation of an object(s), a phenomenon, or an action. Subsequently, such observations are represented graphically, orally, or by electrical signal. As such, that which is being sensed by any given command point is represented by data which has been transduced one or more times. This point will be explored further when considering the SENSE/ANALYZE interface.

Sense Object Points

Any given command point may sense one or more of the following sense object points:

- superior command points
- parallel command points
- subordinate command points
- the environment

Superior Command Point Sensing. Superior command points are sensed in order to obtain information and/or instructions (orders, directives, and policy guidance are terms synomonous with instructions).

Parallel and Subordinate Command Point Sensing. Parallel and subordinate command points are sensed in order to obtain information.

Environment Sensing. The environment is sensed in order to obtain information. By environment is meant all objects, actions, and phenomena which exist in the direct surveillance area of the command point.

Direct vs. Indirect Sensing. Direct sensing is that sensing which is accomplished by means integral to the force command point regardless of the number of times the data is transduced or converted in form within the command point. Indirect sensing is that sensing of data which is received from an external force command point. As such, sensing the environment is invariably accomplished by direct sensing, and all other sensing is accomplished by indirect means.

Direct Sensing. Direct sensing is accomplished by persons or equipment which are integral parts of the force command point. Thus, it offers the advantages of sensing flexibility and effective control of the observation elements, and affords an opportunity to assess and correct data errors which result from form-conversions which the data is subjected to within the force command point. Its limitations lie in the scope of coverage it may afford, and since subordinate as well as superior and parallel command points may be sensed only by indirect means, direct sensing comprises a relatively limited sensing means.

Indirect Sensing. In addition to data form-conversion problems which are common to both direct and indirect sensing, indirect sensing introduces the following additional problems:

- Time delays
- Additional form conversions required
- Data not complete
- Data missing
- Superfluous data acting as "noise" thus making separating out the needed data more difficult

- Data available but not made known to command point needing the data.

Summary. Sensing provides the means of obtaining information and/or instructions. Sensing is accomplished initially by a human or machine and requires that that which is initially sensed be converted one or more times into other forms before the derived data becomes available for use. Indirect sensing, which becomes necessary under all circumstances other than those in which the means of accomplishing the observing comprises persons or equipment integral to the force command point, introduces still further constraints.

The SENSE/ANALYZE Interface

This interface provides a point at which one may examine the properties of the data which are made available for analysis.

The sources of potential differences between the data and the facts from which it was derived are explored below as well as other basic properties of the data which provide the input to the analysis function.

The Information Moods. The following indicates "moods" that may characterize information at the time it is received for analysis:

- Planned
- Expected
- Probable
- Actual
- Estimated

Taking these in order, the following contextual examples are provided to clarify the meanings of the separate moods:

- An air strike is planned (against point "X") for launch at 0900 hours tomorrow.
- The weather is good this morning; it is expected that the launch will occur at 0900 hours as planned.
- It is now 0910 hours, no information has been received to the contrary, it is probable that the launch occurred as planned.
- The aircraft (actually) launched at 0900 hours.
- An aircraft was reported down; it is estimated that the pilot survived.

Timing of Information as Function of Mood. Information in the Expected mood may be received prior to or following the event. Information in the Actual mood will invariably be received for analysis with some period of time elapsing between the time of the event and the time of receipt of data describing the event. If direct sensing is employed, whether by human or equipment means, the time may be very short but in all instances is finite and may be very long.

Information in the Probable mood is subject to the same time constraints as is information in the Actual mood, i.e., it invariably does not become available until some finite period of time has elapsed following the planned time of occurrence of the event. This information mood, as well as the Expected and Planned information moods, have no meaning except with respect to planned-for events.

Information in the Expected mood is derivable only in the time period immediately preceding the event and may be received for analysis prior to or following the planned time of occurrence of the event.

Information in the Planned mood is derived in the time period preceding the event and may be received for analysis prior to or following the planned time of occurrence of the event.

Forms of Information. Information may exist in the following forms at the SENSE/ANALYZE interface:

- Narrative
- Controlled Format Narrative
- Formatted
- Coded Formatted

Narrative Information. Narrative information is defined as that information which is not controlled as to format. The contents, however, may be required to conform to specified reporting requirements. Narrative information is free from constraints insofar as the general means of expression is concerned and thus, potentially at least, is higher in information content than the several formatted means of expressing information. Its disadvantages lie with the increased difficulty involved in identifying and selecting those portions of the information of interest to the recipient. Further, the increased flexibility of expression inherent when information may be expressed narratively affords an equivalent opportunity to omit items of interest.

<u>Controlled Format Narrative</u>. This form of information is defined as that information which is controlled insofar as the general subject sequence is concerned. It offers advantages similar to narrative information, suffers little in flexibility and presents itself in a way which makes it somewhat easier for the recipient to locate information of interest. Increased difficulty is encountered, however, by the person who or equipment which prepares the information for submission.

<u>Formatted</u>. This form of information is defined as information which is controlled as to both subject sequence and order of information items within each subject. Generally, its primary utility is in presenting information of a routine, repetitive nature, and presents such information in a way which makes it easy for the recipient to locate items of interest. It is more difficult to prepare for submission and does not provide for unanticipated information requirements.

<u>Coded Formatted</u>. This form of information is defined as information which is controlled as to both subject sequence and order of information items within each subject. Further, the items of information are expressed employing various codifications methods. Its characteristics are similar to the Formatted form of information. Its advantages derive from message brevity but are accompanied by increased difficulty of both preparing the information and interpreting it at the time of its receipt.

Information Conversions. Subsequent to the initial observation of a human or a machine, information is converted one or more times before it becomes available at the SENSE/ANALYZE interface. Such conversions are unavoidable in order to represent that which was initially observed in an information form.

Types of Information Conversions. The following types of information conversions may be required:

Quantizing. This type of information conversion entails the converting of any value, which is a member of a group of values, into a value representative of the group. Examples of this type of conversion may be found in existing radar practices wherein the time of pulse return is converted into a "range" value, under circumstances which require that one of a limited set of values be chosen as representative of the actual range. All of the analog to digital conversions currently associated with converting radar output provide examples of quantization as an information conversion process. Additional examples are to be found wherever a "unit of measure" is implicit when expressing the information, whether the units be tens of miles, hundreds of tons, seconds, tenths of degrees, or any other.

Classifying. This type of information conversion causes that which was actually observed to be classed as a member of a class of things. Examples of this type of conversion are:

"light bomber", "small arms ammunition", "Essex-class carrier", and "governing officials". In certain instances the size of aggregates of objects or the size of a phenomenon is expressed by stating a size class, e.g., "a small task force", "a horde of Chinese", and "light resistance". Similarly, a state or condition may be expressed by stating a status class, e.g., "the Combat Readiness Rating is C-2".

Naming. This type of information conversion is the means by which specific observed objects or phenomena are assigned separate entities, e.g., the "CVA-59", the "2nd Battalion of the 112th Infantry Regiment", "Capt. Jones", "Hurrican Agatha", and "Operation Mickey Finn".

Action Interpreting. This type of information conversion is the means by which an observed action is assigned a describing word or words, e.g., "attacked", "kidnapped", "assassinated", "searched", "deployed", "dispersed", etc. In essence, this type of information conversion is the means by which the action word, or verb, is created in the description of that which was observed.

Other Considerations. In addition to the above, and while not information conversion, per se, the information may be converted in form several times before it becomes available to the ANALYZE function. Each such form conversion increases the probability of modifying the information meaning or content.

Summary. The information emanating from the SENSE/ANALYZE interface will vary as to mood, timing, and form and will be expressed in a fashion which incorporates the relative vagaries of quantization, classification, naming, and action interpreting. Further, the information may have been modified as a result of form conversions.

Basic Function, ANALYZE

This function provides the means of deriving salient information from the data provided by the SENSE function. Two major sub-functions are engaged in when performing this function, Selection and Correlation.

Sub-function, Selection. In order to perform any analysis, it is necessary, first, that that data deemed to be of significance to a given analytic procedure be selected from the totality of data available, or potentially available, to the force command point. In essence, the first question which must be answered is, "What factors are of significance to this analysis?" Or stated another way, "What parameters of data should be taken into account which, when properly correlated, will make available an informative description of the situation?". In general, the steps that are taken in answering this question include the following:

1. Determining the purpose of the analysis.
2. Determining what is needed to be known.
3. Determining what is known.
4. Determining what is not known.
5. Determining what data will directly provide needed information.
6. Determining what data derivative will provide needed information.
7. Finally, determining the sufficiency, timeliness, dependability, and quality of data which can be obtained and thus determining the limitations on the scope and quality of information which will be made available following correlation of the available data.

Implicit in step 3 of the above procedure is the notion that certain data needs may be anticipated and such data caused to be available from some form of memory, or data storage, prior to conducting the analysis. To refer to this kind of data as "static" data would be misleading, for all data changes, at least to some extent, with time. As such, it is believed useful to consider the two kinds of data which enter into the analytic process as Pre-analytic and Intra-analytic. The characteristics of these kinds of data are as follows:

- Pre-analytic. This kind of data has the following characteristics:
  1. It is obtainable prior to its need for analysis.
  2. While its age may affect its quality, it is data which is not feasible to obtain at the time of, or during, analysis.
  3. It may represent estimates and forecasts as well as "factual" information. A relatively simple example of the data differences that may exist in this regard would be:

     Factual: known characteristics of U.S. aircraft or naval craft.

     Estimated: intelligence estimates of the characteristics of enemy aircraft or naval craft.

- Intra-analytic. This kind of data differs from pre-analytic data in the following ways:
  1. It is not obtainable prior to its need for analysis, e.g., while the characteristics of an enemy submarine may be known

with some degree of certainty before U.S. forces engage the submarine, its position or positions at the time of the engagement are data obtainable only during the engagement and consequently only during the related ASW tactical analysis.

2. While generally based on observations of objects, phenomena, and actions which were observed or occurred during the analytic process, the resulting data is nevertheless "after the fact". That is, some period of time elapses between the time of the observation and the time the data becomes available for analysis.

3. Whatever its quality, intra-analytic data represents "factual" information. For example, data regarding unanticipated force deployments, which are observed during the process of the analysis, and which act to modify intelligence estimates derived in the pre-analytic period, should be afforded (with due consideration for the quality of the data source) the increased weighting of "factual" data.

Sub-function Correlation. This sub-function provides the means of creating higher order information from the selected data. Correlation may entail any arithmetic or logical process, singly or in combination, and be performed by men or machines or both.

In keeping with a premise of this paper, that is, that no particular structuring of the forces has been assumed, this sub-function may manifest itself in very sophisticated ways, or in very simple ways. For example, an individual in combat senses his environment, gives verbal representation to what he sees, selects the "data" he deems to be of significance, and correlates such "data" to derive conclusions such as "there are six enemy tanks", or "my flanks are still protected". He is engaging in the sub-function, correlation, as much as the computer-supported system which provides output indicating, for example, that "252 medium cargo aircraft are available and operationally ready within a 200 mile radius of Poo Bow".

Note that in neither example has a decision to take an action been made. The individual had not decided to advance or retreat and the computer-supported system had not "decided" to effect the evacuation, if such was the decision that required being made. As indicated earlier, the correlation sub-function acts to create higher-order information from selected data and as such supports decisions regarding actions to be taken but does not of itself enter into the decision-making process.

It is believed to be extremely important that this clear-cut distinction be made between the analysis function, with its related correlative properties, and the decision-making function, per se. The meaning of either word, i.e., "analyze" and "decide", could easily be imagined to be applicable to both functions. Certainly one who is "deciding" is "analyzing" the facts. However, word meaning is not the issue here. What is important is that a positive distinction be made between those activities which are directed toward deriving a picture of the situation, and those activities which are directed toward determining what, if anything, to do about the situation.

The applicability of such reasoning is relatively easy to grasp in the command decision-making sense, but what about the control decision-making process? For test purposes, examine a surface-to-air missile control environment. The actions taken to observe and establish tracks of airborne objects fall clearly within the Sense and Analyze functional areas. Further, some action must ensue to enable a determination to be made that the object being observed and tracked is hostile. This action in turn is one of Analysis, i.e., it is an action which results in a "description" of the situation. Assuming a decision is made (by either a man or a machine) to destroy the hostile object, the description of the situation (altitude, position, and velocity of the hostile object) is provided to whatever means, or combination of means, is employed to effect guidance of the surface-to-air missile to its target. The missile, once launched, may be compared to a subordinate force command point with the attendant capabilities of sensing commands, or the position of the object it is pursuing, analyzing such data and making "decisions" which result in actions being taken by control elements of the missile.

Such reasoning could be employed, but to little avail, to describe the processes associated with the separate reactive elements of the missile. The important consideration here is that there is a valuable distinction to be made between the processes associated with describing the situation and those processes concerned with determining what to do about it.

The ANALYZE/DECIDE Interface

This interface provides a point at which the properties of information which form the basis for a decision may be analyzed. Three general properties are of interest:

- The timeliness of the information
- The quality of the information
- The quantity of the information

Information Timeliness. Referring to the preceding discussion relative to information moods, it is clear that the information which is made available on which to base a decision may vary substantially with respect to its currentness. This factor, in turn, suggests that the total set of information which is made available may, if not properly managed, present a misleading picture by failing to distinguish between the absolute "ages" of the information which is being presented. If the total sense-analyze-decide cycle is relatively short and the situation which will exist in the immediate future is fairly predictable (as is generally the case in various weapon control and fire control applications), this problem is somewhat minimized. However, when the events on which the information is based occurred hours or even days prior to the time of the decision, it becomes increasingly important that the information make clear its mood or moods, and further, be presented in a way which facilitates a summation of the total information content.

Information Quality. The quality of information may be examined by exploring the following properties:

- Completeness: a general measure of the consistency with which all salient information is made available.
- Accuracy: the extent to which the information being presented agrees with the actual facts.
- Ambiguity: the extent to which information may be interpreted more than one way.
- Dependency: the extent to which tables, lists, and other information are required to interpret the information which is being presented.

Quantity of Information. The term "quantity" as it is used here refers more to the total quantity of detail rather than the amount of information content. Since the information which results from analysis must be presented or "displayed" either graphically or orally, this facet of the ANALYZE/DECIDE interface is, in essence, concerned with the general problem of presenting the maximum amount of information utilizing the minimum amount of data. In other words, the goal, in considering quantity of information, should be one of saying the most in the shortest, most comprehensible way. To accomplish this requires substantial judgement on the part of the person or persons responsible for determining the most useful level of detail. The general concepts of communications theory are of value when making such determinations, and fortunately these concepts are based on just good "common sense". For example, the entropy concept of communications theory suggests that the entropy of information increases as the uncertainty as to what the information will convey increases. This concept suggests the "common sense" rule, "If you want to provide information, don't tell the man what he already knows". This concept, in turn, may be applied to the general problem of redundancy of information. That is, to say the same thing more than once, albeit in different ways, is not going to increase the amount of information being conveyed.

Basic Function, Decide

While certain decision processes may be automated to some extent, the majority of the decisions which must be made in a command and control environment depend on the pattern-recognition capability of a human coupled with the "stored" knowledge that a human is capable of calling on in a random fashion. The particular approach that is to be employed will depend in large part on the nature of the decision which is required. Of course, a choice must be made between having (1) the human make the decision, (2) the machine make the decision, (3) the human make the decision aided by the machine, and (4) the machine make the decision aided by the human. The general subject of decision making has been addressed in substantial part in the work performed by Human Sciences Research and Stanford Research Institute. Accordingly, the reader is referred to the companion document co-authored by these two organizations.

The Decide/Act Interface

This interface is concerned with the orders, instructions, or directives which communicate the nature of the action decided on to the component responsible for taking the action. As such, the major question that arises here is "how well does the expression of the required action reflect the action that has been decided on?" Some significant work has been done in the general area of conveying commands. The reader is referred to "The Language of Command" by Dr. T. G. Belden of the Institute for Defense Analyses for further insight into this important facet of the Decide/Act interface.

Basic Function, Act

Two general types of actions are considered here, operational and administrative. Operational actions are those actions taken to actually engage the enemy or transport supplies or personnel and in general are directly concerned with the utilization and/or flow of equipment or material. Administrative actions, on the other hand, are those actions taken to order or request a subordinate command point to take a required action. In other words, the final action taken by a given command point may be one of ordering another command point to take an action. Under the latter circumstances the command point issuing the order is, in essence, acting as a sense object point to the command point required to take the action. The command point receiving such orders will in turn operate to sense, analyze, decide and act. The sensing is of an order issued by a superior command point. The analysis is concerned with interpretation of the order and the instructions contained therein. The decision process relates to determining the actions required of the force command point; and the action it in turn may take may be either operational or administrative, depending on whether it is directly taking the operational action required or acting as a relay point of command for force command points subordinate to it. Since the ultimate objective of any decision entails an operational action, administrative actions may be interpreted as amplifying or relaying actions. Looked at in this way, and borrowing from the general concepts of servo-mechanism theory, it is important that the fidelity and "gain" of administrative actions be taken into account when considering the overall military process.

Act/Sense Interface

Any decision to take an action is based on a real or imagined need for the action. Accordingly, there is an equivalent need to know the result of the action. Even an administrative action which comprises ordering a subordinate unit to take the action required carries with it an equivalent need for a positive indication that the order has been received, understood and (eventually) followed. In many instances actions can be designed to provide automatic feedback reflecting the result of the action taken. While the need for feedback will vary depending on the possible consequences of the actions which have been decided on, to fail to provide for feedback implies "open loop" operation which is inherently unstable. Moreover, where it is considered that the enemy and/or the environment will in many instances operate so as to prevent feedback, or deny the requisite information, the feedback process, of itself, becomes an important and integral element of the overall military process.

Communications

Implicit in much of what has been set out in the preceding paragraphs is the need for effective communications. Certain previous papers on command and control have described communications as the "glue" of command and control systems and in a sense, at least, such comparisons are valid. It is worth noting that advances in communications have created additional roles and tasks for non-communications functions directed toward the command and control of military forces. For example, tactical control at the national level would simply not be feasible without present day communications capabilities. As such, it is to be expected that communications will never be good enough, for as our ability to communicate improves so will our horizons of communications applications expand. This perspective is undoubtedly true of all facets of the military process and as any capability improves what must be sought out is the related need for change that such improvement both enables and engenders in other areas of the military process.

B. COMMAND AND CONTROL SYSTEMS

Introduction

Beginning with SAGE, a considerable number of what their developers have called "command and control systems" have been placed in operation or reached a state of advanced development during the last eight years. They have been developed by the Navy, the Air Force, the Army and special agencies of the Department of Defense. The brief descriptions which follow cover 18 of these. These descriptions necessarily vary in extent. In the present study it was not intended to make an examination in depth of any system, nor have classified sources been used, so the descriptions simply are intended to present an overview based on readily-available information. Even such an unclassified overview of the total domain, however, seems to lack precedent, at least in the documentation familiar to many persons involved in developing such systems.

Included are only those systems which have been called "command and control systems" by their developers. Although this seems like a neat operational definition, it is not quite as clean as one might wish, since even the developers have sometimes varied their terminology. However, it has served as an adequate if approximate method of generating a representative sample. It will be noted that the sample has little representation of systems concerned exclusively with logistics or intelligence. Although large computer-based systems have been developed for these activities, the term "command and control" has been rarely applied by their developers; and in any case it would be difficult to provide adequate information from unclassified sources about intelligence systems. Automated systems for the management of military personnel have also been omitted.

An attempt has been made to include some information under the following descriptors for each system: using organization, primary purpose supported, primary functions, structural composition, operational environment, type of conflict, technology introduced, and developmental circumstances. No attempt is made to specify development agency, contractors, cost, effectiveness, schedules or details of equipment and computer programs.

Air Force-Developed Systems

Prior to the formation of Air Force Systems Command on 1 April, 1961, replacing the Air Research and Development Command, there was a "Command and Control Development Division" as part of ARDC. Certainly by 1960 C^2D^2 was describing the electronic systems it had under development, its "L" systems, as "command and control systems." The Winter Study Group which it established late in 1959 explicitly used the term as an overall label. However, one can deduce that the term had not achieved universal usage early in 1960 by the fact that it did not appear in an extensive Aviation Week review of L systems in March, 1960. A complicating factor since then has been the appellation of a large number of strictly communication systems as "L" systems. In one 1965 listing these were included indiscriminately under "command and control systems", whereas Lieutenant General James Ferguson, Deputy Chief of Staff of the Air Force for Research and Development, listed the communication "L systems" under "command and control systems" but categorized them separately under "communications". (Ferguson, 1965) Still later in 1965, Major General John W. O'Neill, commander of AFSC's Electronics Systems Division (the successor to CCDD), stated: "The words 'command and control', which appeared in an earlier mission statement, did not supply a clear or comprehensive understanding of what we do at Air Force Systems Command, Electronics Systems Division." He noted that the new term was "information and communications systems." (Data, 1965). Although this terminological note has been injected at this point to explain the exclusion of Air Force communications L systems from this report's "command and control system" catalog, it also suggests how fashions in terminology are subject to change.

Ten Air Force "command and control systems" are described, in ascending order of their "L system" numbers.

407L -- Tactical Air Control System (TACS)

Using Organizations: Composite Air Strike Forces (CASF), which are the Tactical Air Force "suitcase" air forces that accompany Army elements on Strike Command-directed missions; United States Air Force Europe (USAFE) tactical air forces; and Pacific Air Force (PACAF) tactical air forces.

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis and Communications for air weapons control, direct air support, air traffic control, and command communications. (Sensing is accomplished mostly by means of associated radars.)

Structural Composition: Various mixes of the following: Control and Reporting Center, Combat Reporting Post, Air Traffic Regulation Center, Tactical Air Control Center, and Direct Air Support Center. There is also a Tactical Air Command Center, the focal point of the system, as well as a number of other elements. All modules of the system are mobile, i.e., air transportable. The aircraft or helicopters which will carry them are not considered integral parts of the system, at least in initial procurement, apparently, nor are the heavy radars which will provide the surveillance data. An Army Tactical Operations Center, also outside the system boundaries, is closely associated with the Direct Air Support Center. First equipment procured for 407L consists of jeep-mounted communications gear.

Operational Environment: Mobile ground-based installations for air operations in a limited (battlefield) area transportable to various locations, one complex for each location (and a number of complexes); possibly also airborne units.

Type of Conflict: Presumably limited war primarily. Since the centers are not hardened, they would not survive under nuclear attack in global war. The system can also use such features as air-sea rescue, reconnaissance, airlift and air refueling operations under cold war conditions.

Technology Introduced: "The initial system will be manually operated. Eventually the system could consider lightweight computers, automatic display equipment, and data links" (Ferguson, 1965). At first, the system will lean heavily on off-the-shelf components for communications and display. This system appears to be the only "L system" for command and control which does not include a digital computer in initial design.

Developmental Circumstances: 407L was not listed, generally, at least, among ESD command and control system prior to 1964. It appears to constitute a reaction to the increased importance of limited war and the awareness thereof, and to the Air Force's structuring of its role in battlefield operations. New capabilities may be added, step by step, possibly including a proposed "Advanced Tactical Command and Control System" (Armed Forces Management, July, 1965). An airborne command post for 407L has been envisioned. Requirements for tactical air command and control systems have recently come under intensive scrutiny by DDR&E.

412L -- Air Weapons Control Systems (AWCS); also occasionally called Quickdraw.

Using Organizations: United States Air Force Europe (USAFE) and West German Air Force. Also, some testing has been conducted by Tactical Air Command.

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis and Communications for air surveillance, identification and control of interceptor aircraft (subsystems). Some Sensing (radar). Some delegated Decision-making, i.e., by humans selected and trained as system elements. With respect to the Action function, the controlled weapons were not developed as part of the system.

Structural Composition: Various combinations of subsystems and subsystem elements are netted in a single complex. Radars which existed in the preceding manual system have been integrated into the system; but also new radars have been planned as part of 412L.

Operational Environment: Fixed, ground-based locations for defense of the airspace over a substantial portion of West Germany against manned aircraft. Originally there were also plans for a mobile version for other areas.

Type of Conflict: Presumably global war; limited war also in the unlikely event that there would be limited war involving West Germany.

Technology Introduced: Automatic data processing components in the surveillance and intercept control subsystems are provided by the AN/GPA-73, involving both wired and programmed computers. I/O equipment includes special consoles. Communication equipment includes data links.

Developmental Circumstances: Under a concept of high concurrency, this system was produced and installed before testing was completed, so some development actually occurred on site after the scheduled operational dates. Some concepts resemble those on which SAGE has been based, while others differ, including some related to function allocation between man and machine and human intervention in the data transformation process. Plans for transportable versions and use for tactical air operations other than air defense proved to be optimistic. A system training program was created but some difficulties resulted from failure to generate and implement concepts for simulation capability along with the rest of the system concepts.

416L -- Semi-Automatic Ground Environment (SAGE). Sometimes called "Basic" because there is another 416L for an Alaskan Air Command Processing and Display System.

Using Organization: Operationally, North American Air Defense Command (NORAD). Administratively, Air Defense Command (ADC) and, in Canada, Royal Canadian Air Force. Commanders of SAGE Sectors and Divisions for ADC and RCAF are also Commanders of equivalent NORAD areas.

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis and Communications for air surveillance, identification and control of interceptor weapons; also forward tell to NORAD headquarters.

Re: Sensing. Only the secondary, gap-filler radars were developed as integral to SAGE. Long range radars in the preceding manual system and some more recent long range radars developed under separate projects are used by SAGE and now are regarded as part of the system, in an operational and administrative sense (see Israel, 1965).

Re: Decision-Making. A number of decision-making features were integral to SAGE in its development, delegated to humans selected and trained as system components, with some automatic data processing support. This decision-making includes identification of hostile or friendly aircraft, and selection, dispatch and guidance of interceptor weapons.

Re: Action. The controlled weapons -- interceptor aircraft, Bomarc missiles and (via Army channels) Nike Hercules -- were not originally developed as part of SAGE.

Structural Composition: There is a network of 15 (formerly more) Direction Centers, each responsible for a sector of the United States or Canada many hundreds of miles wide. Each of a small number of co-located Combat Centers is responsible for a sub-net of Direction Centers. The DCs are tied by voice and by data links to many scores of long range radars and gap filler radars in an overlapping fashion and to weapons bases. Surveillance, identification and control are performed principally at the Direction Centers. Two-way voice communications link DCs to manned interceptor aircraft, and one-way data link provides further communication from ground to air. DCs and CCs are netted by data link and voice.

Operational Environment: This is primarily a fixed, ground-based, multi-site system to control the airspace over the continental United States and parts of Canada. It includes airborne elements, consisting of AEW&C aircraft, for surveillance of the airspace over the ocean areas near the Atlantic and Pacific coasts.

Type of Conflict: The system was designed to operate in global war but not one involving nuclear-armed ICBMs, and also to provide continuous surveillance during cold war conditions.

Technology Introduced: Data processing at the Direction Center is performed both manually and by the duplexed AN/FSQ-7, an early tube computer, and at the Combat Centers manually and by the AN/FSQ-8. A large number of complex consoles provide input-output for operators. Photographic rapid-processing and projection equipment furnishes multi-viewer displays to the battle staff. Automatic communications include ground-ground and ground-air data links. The AN/FST-2 converts analog to digital data at the long range radars. The ground-air communications directly control Bomarc missiles and provide data for visual and auditory presentation to pilots of interceptor aircraft and to airborne computers.

Developmental Circumstances: Original concepts of SAGE stemmed from efforts to find applications for the very early Whirlwind computer. For several years there were two competing developments: SAGE at M.I.T's Lincoln Laboratory, and the Air Defense Integrated Systems (ADIS) at the University of Michigan's Willow Run Laboratory. The latter placed surveillance and tracking operations at the long range radars, utilizing the AN/GPA-23 analog tracking-computing equipment already designed by Columbia University's Electronic Research Laboratories. Both systems envisioned centralized locations for weapons direction, and SAGE design also centralized the computation for surveillance. Earliest SAGE concepts contemplated fewer computation centers, i.e., more centralization, than eventuated. SAGE surveillance concepts were feasibility-tested in the "Cape Cod system" The Air Force selected SAGE instead of ADIS, except that the Bomarc missiles, which had been under development as part of

ADIS, were adopted for use with SAGE at some locations. Early estimates of the required extent of computer programming were over-modest. SAGE was installed incrementally in area pieces, over several years, accompanied by a system training program. Although the hardware remained essentially the same, the computer programs went through a series of many changes, the larger of which were originally called "models", to deal with such considerations as new weapons, geographical redistributions and electronic countermeasures. Various early concepts of full automaticity, some of them implemented, were later modified to require considerable operator intervention (see Israel, 1965). The scope of some of the projected testing was also reduced, but one series of tests was conducted within a large area, under wartime conditions simulated by real aircraft, although not for comparison with the replaced manual system. After it became clear that many Direction Centers might be destroyed in nuclear war by Soviet ICBM's carrying nuclear warheads, especially those located near SAC airbases, it was proposed to create hardened "Super" Combat Centers (with solid state computers) which could take over control of forces from the Direction Centers. This expensive project was discontinued after considerable development. The relationship between SAGE's capacity and the airbreathing threat was questioned in a RAND Corporation report (Aviation Week, 1963): "Not only has the threat for which the system was designed failed to materialize in the magnitudes visualized, but the system performs the tasks necessary to defend against the lesser threat less effectively and at a greater cost than potential alternative systems." Publicized rationales for SAGE (e.g., Saturday Evening Post, 1959) have usually emphasized, without much validity, that lightning-fast computer calculations were needed to match the speeds of newer aircraft. Rather than aircraft speeds, early system concepts actually resulted from concern about (1) the amount of data which would have to be handled in a large raid, and (2) the problem of netting sensors, directors and interceptors where interceptor range had increased more than radar range had increased, so interceptor aircraft would be traversing a number of radar reception areas.

416M -- Back-Up Interceptor Control System (BUIC)

Using Organizations: Same as SAGE

Primary Purpose Supported: Same as SAGE

Primary Functions: Same as SAGE, taking over air defense operations in case a SAGE Direction Center is rendered inoperable in an attack.

Structural Composition: The Buic facility is emplaced at one or two of the long range radar sites within each SAGE sector and is netted to all the radars as well as to the Direction Center in that sector, by voice and data link communications, which also connect it to air bases.

Operational Environment: Same as SAGE, except for the AEW&C elements.

Type of Conflict: Global war, including nuclear attack. Vulnerability is diminished through dispersal and geographical disassociation with SAC bases. SAGE continues to hold responsibility for cold war surveillance.

Technology Introduced: Solid-state AN/ASG-51 (D-825) computers, consoles for I/O operations, ground-ground and ground-air data link and voice communications.

Developmental Circumstances: "BUIC-2" is an interim configuration which supplanted "BUIC-1", a manual version, and is being followed by "BUIC-3", which possesses expanded target capacity through added memory storage (*Aviation Week*, September, 1965). A program for System Exercising for Training and Evaluation (SETE) was developed concurrently with BUIC-2.

425L -- North American Air Defense Command (NORAD) Combat Operations Center.

Using Organization: North American Air Defense Command

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis and Communications concerning (1) air-breathing attackers; (2) missile attackers (ICBM's); (3) nuclear hostile detonations; (4) damage to own bases and facilities; (5) intelligence; (6) status of own interceptor aircraft and anti-aircraft missiles; and (7) status of 425L communications, computers and support equipment.

Structural Composition: 425L is a single, hardened center inside a mountain, with supporting communications by which sensing information is received from other systems and locations and such information and control instructions is sent to other systems and locations.

Operational Environment: This is a fixed, ground-based system at Colorado Springs with responsibility for the airspace over the North American continent and approaches to it.

Type of Conflict: Global, nuclear war. In addition, 425L analyzes airspace surveillance during cold war.

Technology Introduced: Equipment, much of it off-the-shelf, includes one Philco 2000/212 and two Philco 1000 computers, together with peripheral memory units and buffering equipment, 15 console displays, a multi-viewer display, a switching center and hardened communications both underground and microwave links with hardened antennas (Aviation Week, February, 1965).

Developmental Circumstances: Original plans had called for growth through a number of phases involving on-site testing. There has been some testing and familiarization in a "soft" facility nearby. The using organization has been brought into design participation, although there has been considerable turnover in command and operator personnel since design began. An austerity policy narrowed the scope and objectives of the computer programs; the number of consoles was also reduced.

433L -- Weather Observing and Forecasting System.

Using Organization: Air Force Air Weather Service.

Primary Purpose Supported: Information Collection and Analysis.

Primary Functions: Sensing and Analysis of operationally significant weather information for forecasting, display and dissemination.

Structural Composition: From easily available sources it is not entirely clear what comprises this "network of weather sensors, computers and transmission equipment" (Aviation Week, January, 1962). The main receiving station for all weather data from a number of subsidiary 433L stations appears to be the Air Weather Service's Global Weather Station at Offutt AFB, Nebraska.

Operational Environment: This is a fixed, ground-based multi-unit system which may have airborne sensors and which may be or become global in extent of coverage.

Type of Conflict: All types, including peacetime.

Technology Introduced: "Thirteen different types of equipment are involved, varying in complexity from portable tactical sensors to radars" and the system "encompasses improved meteorological techniques expressed in computer programs for SAC Hq., NORAD, and the National Weather Central" (Ferguson, 1965). The AN/FMQ-5 Automatic Weather Station is "a computer-keyed device for weather data-gathering, processing and distribution," which "computes and issues almost instantaneous summaries of rainfall, peak wind gusts, mean wind speed, magnetic wind direction, sea level barometric pressure, altimeter setting, free air temperature, dewpoint temperature, runway visual range and approach light contact height" (Aviation Week, 1962). There are also data displays and a radar cloud height detector.

Developmental Circumstances: "The 433L system is an evolutionary plan to modernization with system improvements phased into operational use as they become available. The overall system plan is best described as a 'building-block' concept. Individual 'blocks' enter operational use under an orderly time-phased plan within the operating patterns of the weather service" (Ferguson, 1965). Originally 433L was planned as a joint military-civil weather system involving Federal Aviation Agency and the U.S. Weather Bureau as well as Air Force but after a couple of years FAA began instead to develop its own system "in close technical coordination" (Aviation Week, 1962).

465L -- Strategic Air Command (SAC) Control System

Using Organization: Strategic Air Command

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis and Communications for developing war plans, assessing force readiness, alerting and executing the force, and conducting force exercises (Aviation Week, 1964).

Structural Composition: Hardware and displays are located at four SAC bases, including SAC headquarters. These are netted by dual communication lines. Headquarters has two large computers, and another alternate headquarters base has one. All four have electronic data transmission communication centrals for routing communications, data storage facilities and multi-viewer displays. By means of a remote communications center every SAC airbase is connected with the system via the nearest communications central, for sending and receiving messages.

Operational Environment: This is a fixed, ground-based, several-unit system which links headquarters centers with bases worldwide, for control of airspace attack vehicles.

Type of Conflict: Primarily global, nuclear war; but also usable for limited war and for cold war exercising.

Technology Introduced: The three computers are AN/FSQ-31Vs originally developed for the SAGE Super Combat Centers (see 416L). An IBM 1401 computer acts as a buffer. The computer program contains more than a million instructions (Aviation Week, 1964). Displays include printed messages and seven-color wall displays (Ferguson, 1965), and are quite numerous as to content. The remote communications centrals consist of an electric typewriter, high-speed printer, cryptographic equipment and digital conversion equipment. The Jovial compiler was created for producing the computer programs. The multi-viewer displays, four at each principal base, are 16x16 screens fed from projection-type display generators.

Developmental Circumstances: "Hindsight suggests that SAC, with little previous experience in the capabilities and limitations of computers, go carried away in establishing what the system was to provide, possibly the unwitting victim of overly enthusiastic industry presentations, according to one Air Force official. While there is no limit to what an automatic data processing system can do, if there is no limitation on time and money available, the latter qualifications may not have been stressed sufficiently to top SAC officials. At the time that the 465L specifications were drawn, the ICBM seemed far in the future and SAC's entire inventory consisted of manned bombers, many of them based at bases scattered around the globe. Thus, the original 465L specifications provided for global coverage and made no provision for today's vast network of strategic missiles, according to ITT spokesmen. System requirements not only had to be revised because of the shifting nature of SAC's inventory, but also because of new personnel in key SAC jobs who changed the operational concepts, according to some observers" (Aviation Week, 1964). Conceptual planning proceeded on an iterative basis and, prior to a limitation on funding, also provided for more than one configuration phase. Development of the system brought to light some of the problems related to participation of the using organizations in deriving system concepts such as the need for (1) their early and intimate involvement; (2) reconciling a fractional and operations approach with the more system-oriented views of the designers, which might include conceptualizing through functional analysis; (3) resolving the problems of introducing a new system on-site while the preceding system must still operate as well as possible, especially when considerable debugging is inevitable; (4) preparing for the possibility that the new system may have an effect on the user's organizational structure; (5) obtaining specifications of objectives and criteria by which to judge whether the performance of the proposed system would sufficiently surpass that of its predecessor to justify building it; and (6) estimating realistically the time required to develop and install the system, its cost, and the scope of the computer programming which would be required.

473L -- Headquarters U.S. Air Force Command and Control System

Using Organization: U.S. Air Force Headquarters

Primary Purpose Supported: Resource management.

Primary Functions: Analysis in behalf of resources monitoring, situation monitoring, operations monitoring, plans evaluation and plan generation/modification (Armed Forces Management, 1964). The system compares plan requirements with forces available and/or operationally ready, evaluates the effect of implementing a given plan or plans, monitors the movements of aircraft during deployment operations to evaluate the effectiveness of deployment planning, and evaluates effects of planned deployments on air-base facilities. It also evaluates (1) large-scale transport movements, (2) feasibility of a mission in terms of aircraft capability, and (3) effects of a plan or group of plans on selected resources. Files which it maintains contain such things as contingency plans, force status, exercise schedules, airfield facilities and aircraft and missile characteristics.

Structural Composision: A facility in the Pentagon includes an operations center with display devices and consoles, a computer facility and office/

conferencing areas. It receives reports from and sends messages to Air Force elements worldwide principally through a circuit of teletype facilities and the Automatic Digital Network (AUTODIN), which generally is not considered an integral part of 473L, although on occasion this is unclear (Ferguson, 1965). There is also an undisclosed site (Aviation Week, 1964).

Operational Environment: This is essentially a ground-based, fixed facility concerned with worldwide ground and airborne elements.

Type of Conflict: All types.

Technology Introduced: The Pentagon site's nerve center is the AN/FYQ-11, duplexed Librascope L-3055 computer, together with mass disc memory files, a buffer processor group connecting to AUTODIN, a "uni-record" subsystem of peripheral equipment, seven "integrated" consoles and a multi-viewer multicolor display. The consoles include a combined electronic typewriter and TV-tape display, a multicolor slide projection display, photographic black and white hard copy of that display, and a high-speed printer. The electronic typewriter includes a matrix of control and logic pushbuttons, the functions of which can be varied by means of keyed overlays.

Developmental Circumstances: "The 473L system has been developed on an 'evolutionary' basis, with improved techniques and equipment gradually phased into operation" (Ferguson, 1965). Originally it started austerely with a leased IBM 1401, then was integrated into an IBM 1410 as programs increased, to provide an "Operational Training Capability." Improved query and display methods have accompanied the advance to the third, larger and faster computer. 473L has been described as "an extension of the staff planning process", whose "open-end character ...evolutionary growth make a C&C system which Pentagon planners cite as an example of the trend in the future" (Armed Forces Management, 1965).

492L -- USSTRICOM Command and Control System

Using Organization: United States Strike Command

Primary Purpose Supported: Operational control of forces

Primary Functions: Analysis and Communications

Structural Composition: There are three major, separate elements, each a command post: the Command Center at Strike Command headquarters; the Joint Airborne Communications Center and Command Post, "JACKPOT", which is an air-transportable module; and the Joint Operations Center, at Joint Task Force headquarters in the field.

Operational Environment: One component part of 492L is a fixed, ground-based facility to deal with command-wide information; another is mobile and either airborne or ground-transportable (wheel-mounted) for short-term, en route operations of a Joint Task Force Commander; and the third is transportable and ground-based, for that commander's operations in the field.

Type of Conflict: Limited war.

Technology Introduced: USSTRICOM's war room possesses a display board and is supported by a computer facility containing an IBM 1401 (Armed Forces Management, 1965), together with communications equipment and a TV set. The air-transportable component contains communications gear, no computer. The Joint Operations Center for field operations "will have computers and display equipment" (Ferguson, 1965).

Developmental Circumstances: The Headquarters component first used an IBM 1401 for computation. It is expected that the current 1410 will give way to larger and faster computers, since the system is taking an "evolutionary" approach (Armed Forces Management, 1965).

496L -- Space Track. Recently, 474L -- Ballistic Missile Early Warning System (BMEWS) has been listed jointly with 496L.

Using Organization: Air Defense Command.

Primary Purpose Supported: Information collection and analysis.

Primary Functions: Sensing, Analysis and Communications for registration of orbiting objects (and in the case of BMEWS also of intercontinental ballistic missiles).

Structural Composition: 496L radar and photographic observation stations are linked with a Space Defense Center containing 496L data processing and communications equipment at Colorado Springs. The BMEWS system has three sets of detection and tracking radars, in Alaska, Greenland and England, with some associated data processing. BMEWS-processed data are transmitted also to Colorado Springs, ICBM data going to 425L and space data to the Space Defense Center, which in totality is part of the NORAD Space Detection and Tracking System (SPADATS) that incorporates the Navy's SPASUR System as well as 496L.

Operational Environment: These are ground-based, fixed installations conducting worldwide surveillance of high-altitude airspace.

Type of Conflict: 496L is primarily a peacetime operation. 474L also operates during the cold war to detect the onset of global, nuclear war.

Technology Introduced: For 496L, "key equipment in improving our detection and observation capabilities are a 13-story-high phased array radar at Eglin Air Force Base, Fla., and an optical surveillance system, combining telescope and electronic techniques, at Cloudcroft, N.Mex." (Ferguson, 1965). Data are processed by computer.

Developmental Circumstances: A hurriedly-established space tracking network was initially operated by 496L personnel until ADC could take over operations, and now "496L provides research and development to improve sensor capabilities, systems accuracy, computer programs, and also contributes to astrophysics studies" (Ferguson, 1965). In the development of BMEWS, the logic which evaluated radar returns failed to take into consideration a certain natural phenomenon, so shortly after BMEWS became operational the system indicated that an ICBM launching had occurred, although it was actually the moon rising.

Other Air Force Systems

A number of other (non-communications) systems have been called "command and control" systems at one time or another by Air Force developers, including the following.

410L -- Area surveillance control system; an automatic radar system to be used in lieu of 1300 Air Police to protect SAC Titan II sites against penetrators.

413L - Distant Early Warning (DEW) Line.

416N - Sea-launched Ballistic Missile Detection System, providing to NORAD and SAC a warning of a missile attack on continental North America.

431L -- Traffic Control and Landing Systems, a program to develop and produce air traffic control, navigation and communications equipment.

438L -- Intelligence Data Handling System, for high-speed processing of world-wide intelligence data. Not publicly listed in recent years.

466L -- Electromagnetic Intelligence System, a worldwide system for collecting intelligence by electromagnetic means and processing for transmission to users.

477L -- Nuclear Detonation Detection and Reporting System (NUDETS) to provide information on nuclear detonations in North America. Discontinued (<u>Aviation Week</u>, 1965).

482L - Emergency Mission Support, a system to provide air-transportable air traffic control, communications and navigational aid facilities in support of emergency air operations.

481L -- Post-Attack Command and Control System, to provide the SAC commander with a capability to control his forces if his normal headquarters operation is destroyed (Electronic News, 1964). Not generally listed.

The "command and control system" label apparently has not been applied to the Bomb Alarm System, which detects and reports nuclear explosions; to logistics systems such as the Combat Logistics Network (ComLogNet), which links about 450 air bases, stations, depots and civilian suppliers through switching centers; or to some non-communication "L" systems, such as 463L -- Materials Handling Support System, which includes cargo handling equipment. At one time 480L -- Air Communications System or Airspacecom was classed as a command and control system, but more recently it has disappeared and been replaced by a number of communications systems which were formerly included in it.

Army-Developed Systems

For various reasons the Army apparently started to develop command and control systems later and in much smaller number than the Air Force. The Army has a headquarters system composed of the Army War Room in the Pentagon and an automatic data processing and communications facility called "Autoprobe". Also, it should be understood that an Army commander of a Unified Command, such as STRICOM, may employ a command and control system developed by another military department, for example, 492L. The Army does not seem to have applied the "command and control system" label to its air defense data processing complexes, Missile Master and BIRDIE (Signal, 1965). Its principal venture explicitly in this kind of system has been CCIS-70.

CCIS-70 -- Command Control Information System--1970. Recently this has been renamed "Automatic Data System for the Army in the Field" (ADSAF), but the earlier title is used due to its greater familiarity.

Using Organization: Field armies.

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis and Communications for (1) tactical operations, that is, control and coordination of maneuver elements (G-2, Intelligence and G-3, Operations); (2) tactical artillery fire direction; and (3) combat service support (logistics and personnel and administration). All Sensing is to be accomplished by personnel, who presumably will not have to be developed (selected and trained) integral to the system.

Structural Composition: Actually, this is a project which consists of several separate or "semi-independent" systems plus data link and other inter-communications. The tactical operations system is expected to function at Division, Corps and Army levels, perhaps with initial emphasis on the first. The tactical fire direction system at first will be concentrated at the battalion level with digital links to artillery batteries, forward observers and the Division Artillery Fire Direction Center, but later it will also be integrated into the Division Center and finally implemented at the Corps artillery level. The combat service support system will function, at least initially, at the Corps level. Thus, the different systems will vary in number within a field army, and each field army may have a complex of these systems.

Operational Environment: In a very broad sense, the battlefield.

Type of Conflict: Limited and global war. Also, the combat service support system may operate in peacetime and the other two during peacetime for exercises.

Technology Employed: A "family" of "Fieldata" computers was initially developed: BASICPAC, INFORMER and MOBIDIC, together with various arrays of I/O equipment, as well as the MSQ-19, Army Tactical Operations Central. More recently the Field Artillery Digital Automatic Computer (FADAC) M-18 was introduced for the tactical fire direction system. A follow-on to FADAC is envisioned for this system at the battalion level, and a TACFIRE computer composed of modules of this follow-on is tentatively planned for the Division and Corps levels (Armed Forces Management, 1965). Computers for the other systems have not been specified. It is expected that printers, card readers, teletypewriters and flexowriters will be associated with the computers and their software, which will include extensive data banks.

Developmental Circumstances: The Army conducted a study in 1956-57 which "concluded not only that automatic data processing equipment would be feasible on the battlefield in the 1965-70 time frame, but could also make the difference between victory and defeat" (Shoemaker, 1964). The CCIS-70 project which resulted was highly equipment-oriented, as indicated by the development of the Fieldata computers. "Experience in this project showed that the first definition of a requirement by a user is considerably different than the programs which will be capable, flexible, and responsive enough for field use. It was necessary for the user and the technical personnel to actually see the programs running on machines, to jointly test, manipulate, and modify them to achieve the refinement necessary" (Shoemaker, 1964). At first CCIS-70 was to consist of five systems: fire support, intelligence, personnel and administration, logistics, and operations centers. By 1964 it had "been determined that a complete Army-wide system in each of these functional areas represents too large an initial step," so "initial fieldable systems" were defined for the first four. In 1965 the name of the total complex was changed, as noted above, and component systems were recombined to total three. Meanwhile, an "experimental, austere Operations System" using off-the-shelf equipment was prepared for testing in the Seventh Army in Europe (Shoemaker, 1964). "The testbed system to be used by 7th Army will provide commanders and their staffs at Division, Corps and Army levels with an automated experimental system" (Armed Forces Management, 1965).

Navy-Developed Systems

The Navy has developed "strategic" command and control systems generically called OPCONCENS (Operational Control Centers) in two categories, "major" and "subordinate", and "tactical" command and control systems, of which there are currently three. In addition, the Navy has a headquarters system, consisting of Flag Plot and the Navy Information Center (NAVIC), the Navy's Automatic Data Processing Center, which supplies automated information to Flag Plot. "NAVIC is currently being expanded with the addition of another computer which will permit the utilization of a direct, remote query device from Flag Plot to obtain high-priority data directly from disk file storage. The addition of automated or semi-automated displays is being studied but space and cost will preclude extensive use of these devices for some time" (Data, 1965, quoting Rear Admiral David Lambert). In addition, at the strategic level, there has been some planning concerning a Command Ship Data System (CSDS) and a Fleet Flag Data System (FFDS). The latter, which would serve the four numbered fleet commanders, is "still under study and no firm plans have been made for the use of any specific system" (Data, 1965, quoting RAdm. Lambert). Additional tactical systems which have been under study include a Tactical Flag Data System (TFDS) and a Small Ship Combat Direction System (SSCDS). Queried whether the SSCDS concept was still valid, Admiral Lambert commented that "the results of this study will be used in further work in the small ship data system area" (Data, 1965). "Our goal is a world-wide integrated network of automatic data systems linked by the necessary communications to facilitate control of forces under the JCS" (Data, 1965, quoting RAdm. Lambert).

MODS -- Major Operational Control Center Data Systems

Using Organizations: CINCPAC (Commander-in-Chief, Pacific), CINCPACFLT (Commander-in-Chief, Pacific Fleet) and COMHAWSEAFRONT (Commander, Hawaiian SeaFrontier); CINCLANT (Commander-in-Chief, Atlantic), CINCLANTFLT (Commander-in-Chief, Atlantic Fleet) and CINCWESTLANT (Commander-in-Chief, Western Atlantic).

Primary Purpose Supported: Resource management and, for Unified Commands, operational control of forces.

Primary Functions Performed: Analysis and Communications for logistics, e.g., POL (Petroleum, Oil and Lubrication), climatology, communications, movement of ships at sea, reports about unidentified aircraft, reports to higher headquarters, war gaming, and a number of other tasks.

Structural Composition: There are two locations, Hawaii for the FOCCPAC (Fleet Operations Control Center, Pacific), and Norfolk for the corresponding Operations Control Center for the Atlantic. The latter is composed of number of component spaces, such as the Movement Report Center, Early Warning Barrier Plot and Command Post (Armed Forces Management, 1965).

Operational Environment: These are fixed, ground-based installations for handling activities ashore, afloat and in the airspaces above the oceans, in the Pacific and Atlantic areas.

Type of Conflict: All types.

Technology Introduced: At the Atlantic installation, which is said to have considerable resemblance to the one in the Pacific but has been developed on a different schedule, two CDC 1604A and four CDC 160 A computers were being installed during 1965 (Armed Forces Management, 1965). An IBM 704/1401 system had been handling 55 programs on the 1401 and 50 on the 704, while two Univac computers had been programmed earlier to do a sea surveillance job. Further equipment expansion may occur in 1967. Addition of 25 computer programs per year is a target. The Jovial compiler and Oasis utility system are utilized for both the Pacific and Atlantic installations. Closed-circuit TV systems are planned.

Developmental Circumstances: Development has been incremental. Responsibility has been shared among several Navy agencies. "One of the foremost critical hardware problems is the development of reliable on-line computer-driven visual display devices," according to RAdm Lambert (Data, 1965). The "biggest" OPCONCEN problem is "getting and retaining experienced people" (Armed Forces Management, 1965). The computer programs for the OPCONCENS have been characterized by diversity of contents and objectives, with consequent requirements for coordination. The OPCONCENS have been created to serve both intra-Navy and unified command operations, with resultant concern with priority and emphasis.

SODS -- Subordinate Operational Control Center Data Systems

Using Organizations: Sea Frontier and Area Commanders. Potentially, Subarea and Sector Commanders.

Primary Purpose Supported: Resource management.

Primary Functions: Analysis for the naval control of shipping, ocean surveillance, movement of naval forces and emergency actions such as search and rescue.

Structural Composition: COMWESEAFRON (Commander, Western Sea Frontier) has the prototype installation, at San Francisco. Alternatively this is called COMNAVDEFEASTPAC (Commander, Naval Defense Easter Pacific), since the commander wears two hats. Potential other locations would be the equivalent location for the Atlantic and the Marianas, Philippines, Japan and Caribbean.

Operational Environment: These are fixed, ground-based installations for handling activities ashore, afloat and in the airspace above the oceans within relatively large geographical areas.

Type of Conflict: All types.

Technology Introduced: Austere computer and EAM facilities with considerable manual operation, including manually-controlled displays.

NTDS -- Naval Tactical Data System

Using Organizations: Pacific and Atlantic Fleets.

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis and Communications for air surveillance, identification and control of interceptor weapons in anti-air warfare.

NTDS provides CIC support to a commander's Decision-making. Sensors (radars) and weapons (aircraft and missiles) implementing Sensing and Action were not developed as integral parts of NTDS. Additional goals of NTDS include its use in integrated surface operations, air traffic control, electronic warfare and anti-submarine warfare.

Structural Composition: An NTDS complex is designed for shipboard installation, one per ship, with netting between ships. One of the system goals is inter-force netting between NTDS-equipped vessels. "Only six ships now in the fleet are equipped with NTDS, including the nuclear-powered aircraft carrier USS Enterprise and guided missile cruiser USS Long Beach. The carrier Kitty Hawk is also being fitted with the equipment as is the new attack carrier USS America. Current plans call for all major U. S. warships to be so furnished. This will involve about 14 attack aircraft carriers, 35 frigates and about ten cruisers" (Armed Forces Management, 1965).

Operational Environment: Shipboard installations responsible for the airspace above the ocean within localized areas, with some responsibility also eventually for surface and undersea operations within these areas.

Type of Conflict: Limited or global war.

Technology Introduced: Consisting of computers, display consoles and data links, an NTDS complex includes up to four Univac USQ-20 computers, the larger ships carrying four, the smaller ships two. Data links are both ship-to-ship and ship-to-air.

Developmental Circumstances: NTDS, to some extent, was originally an outgrowth of the British analog-computation Comprehensive Display System. Analog techniques for aided tracking were incorporated on an interim basis. Development, production and installation have been spaced over an extended time-period. Sophisticated shore-based training facilities are presently being introduced. Implementation of some NTDS objectives has been deferred while the system has undergone a period of testing, which has led to design changes. "For example, a particular part of the new system may be in trouble at the outset. Massive efforts are required for a jury rig to effect basic repairs and redesign. Eventually, the level of design performance is attained, the jury rig removed. But, under these circumstances, we most often find that the level of activity declines only slightly. These efforts may have shown only too clearly that, by continuing redesign, new and theoretically better levels of performance could be attained. The process of development, originally conceived as an essential but time-limited repair process, continues almost unabated and so does the consequent uproar" (Stroud & Irwin, 1965). NTDS has also revealed what the introduction of automatic data processing may do to the military command structure and what new requirements and problems it imposes concerning skilled programming personnel and their training (Stroud & Irwin, 1965). Much of the NTDS programming has been undertaken "in-house", especially shipboard programming. There has been considerable discussion about compatibility, or the absence thereof, between NTDS and land-based automated air defense systems (e.g., Air Force's SAGE). Also, there has been testing of the compatibility between NTDS and ATDS and MTDS; and compatibility may be required between NTDS and the OPCONCENS.

ATDS -- Airborne Tactical Data System

Using Organization: Pacific and Atlantic Fleets.

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis and Communications for air surveillance, identification and control of interceptor aircraft in anti-air warfare. Possible Sensing; information is not readily available whether radars were developed integral to the system. ATDS can be used also for air-sea rescue.

Structural Composition: ATDS has been designed for operation in AEW&C (Airborne Early Warning and Control) aircraft operating with a task force, to extend the coverage of NTDS.

Operational Environment: Mobile, airborne installations covering localized airspaces above the ocean.

Type of Conflict: Limited and general war, with some application in peacetime for reconnaisance and navigational support.

Technology Introduced: Airborne AN/USQ-54 computer displays, and data link.

Developmental Circumstances: See NTDS concerning compatibility testing.

MTDS -- Marine Tactical Data System

Using Organization: Marine expeditionary forces.

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis and Communications for anti-air warfare (air defense) and en route air control, i.e., for "combat air operations." Radars and aircraft or missiles have not been developed integral to the system.

Structural Composition: Principal components are equipment complexes for two of the centers provided for a Marine amphibious operation, the Tactical Air Operations Center (TAOC) and the Tactical Air Control Center (TACC), which coordinates a small number of TAOCs. Sets of equipments are housed in various huts. Compatibility is required with ATDS and NTDS.

Operational Environment: Transportable ground-based installations for handling airspace operations in a relatively small area.

Type of Conflict: Limited and general war.

Technology Introduced: Radar data converters, digital computers, display consoles, voice communications, data link communications.

Developmental Circumstances: MTDS development has extended over about eight years and included testing at Marine Corps establishments.

Department of Defense Special Agency-Developed Systems

Among systems created by special agencies of the Department of Defense and at one time or another called "command and control" systems were the DODDAC (Department of Defense Damage Assessment Center) and the DCS (Defense Communications System). DODDAC has been merged essentially into the National Military Command System. Communications systems, such as the "National Communications System" (NCS), established in 1963, and the Department of Defense's global, automatic switching systems, AUTOVON for voice and AUTODIN for digital messages, are no longer alluded to as "command and control" systems (Signal, 1964 and 1965). One finds references to a "World Wide Military Command and Control System" but this appears to be more a generalized concept than an entity in development. The principal system to be considered, then, is NMCS.

NMCS -- National Military Command System

Using Organizations: Joint Chiefs of Staff (JCS) and the National Command Authority (NCA).

Primary Purpose Supported: Operational control of forces.

Primary Functions: Analysis (and Communications via the JCS Digital Network) for maintaining an overview of current actions being taken by worldwide military forces, of the deployment and status of these forces, and of plans for their use in both contingency situations and general war; also, for assisting the several directorates of the Joint Staff to meet special analysis requirements of the NCA.

Structural Composition: The following facilities are included in NMCS: the National Military Command Center (NMCC) in the Pentagon; the National Military Command System Support Center (NMCSSC) in the Pentagon and also at the ANMCC; the Alternate National Military Command Center; the National Emergency Command Post Afloat (NECPA) in the USS Wright and USS Northhampton, Navy-developed installations; and the National Emergency Airborne Command Post (NEACP) in modified C-135s, Air Force-developed installations. Elements of the JCS Digital Network link the NMCS with the Unified and Specified Commands.

Operational Environment: This sytem has fixed, ground-based facilities, plus mobile airborne and seaborne installations as backup, for coverage of worldwide military activities in all media.

Type of Conflict: All types.

Technology Introduced: Automatic data processing is provided by IBM 1410s at the NMCC and ANMCC. Both facilities also have access to CDC 1604As and 160s. There is special-purpose message formatting and routing equipment.

Developmental Circumstances: While the NMCS became an administrative fact at a particular point in time, the system has largely been fashioned from elements which predated it. Relatively far-reaching plans for automatic data processing capabilities were prepared during the initial development period. However, such capabilities are being implemented on a step-by-step basis, with each subsequent step being taken at a time when prerequisite actions have been satisfactorily accomplished rather than in accordance with a predetermined schedule. Separate groups sharing the responsibility for design and representing (1) the using organization, (2) the specifiers of functional requirements and (3) the hardware designers have sometimes held differing views concerning the system's scope and evolutionary tempo (<u>Armed Forces Management</u>, 1964).

C. TERMINOLOGY

As noted earlier, application of the term "command and control system" has not been characterized by consistency or scientific rigor, and this is even truer of "command and control". For example, one even comes across such statements as: "Every man functions as part of many systems for command and control, in his home, in his city, state, nation, on his job, in his lodge, church and social group. He plays different roles in each; he is himself an example and a prototype of the systems of which he is a part" (Jacobs, 1961). Turner (1965) has noted that "command and control" has at least five different meanings, depending on whether the speaker is a computer programmer, the OSD comptroller, a scientist, a manager or a military commander.

The difficulties to which such loose usage can lead are discussed at some length in Appendix II. Perhaps it has been because of the growing tendency to apply the term "command and control" to essentially everything new on the military scene that military authorities have attempted to formulate short, authorized definitions, at least of "command and control system". This has not always been easy. According to Major General John B. Bestic, USAF, Deputy Director for NMCS, it required 33 meetings for a top-level Department of Defense group to grind out a definition that the members could agree on (Data, 1965).

Others have simply become indignant. "Command and control is in danger of becoming a catch-phrase, a shibboleth, a gimmick expression, a technological counterfeit", an anonymous critic wrote in Armed Forces Management (1965), suggesting further that it has been "shrouded with the jargon of a technically-trained, experience-limited elite -- experts in search of a field of expertise..." However, fortunately, according to a JCS official, "every year people are learning more and more about command and control." (Possibly when enough people learn about it, the term will vanish.) A more restrained comment is that "the term 'command and control' has become popular and is used to describe a general capability relating to the direction of Armed Forces" (Kroger et al, 1961).

Nominal Definitions

Possibly the best brief definition of "command and control" is one attributed to an unidentified "Defense expert": "Command and control is running the show." (Armed Forces Management, 1965).

Apparently that expert was not Dr. Eugene G. Fubini, at the time Deputy Director of Defense Research and Engineering, since he provided a longer one: "Command and control is the complex of procedures, doctrine and devices which supplies an operational, logistic or administrative commander with the information that he or his staff requires to make decisions and to implement them through subordinate units after these decisions have been made.....It doesn't differ from the usual command structure at all" (Armed Forces Management, 1965).

Our real interest is in the nominal definition of "command and control system", not of "command and control". One of the first attempts to achieve such a definition was the Working Group on Command and Control at the 7th

Military Operations Research Symposium in 1961 (Weiner, 1962). Two definitions were accepted as a basis for discussion: (1) "A command and control system is an information-handling system which assists in the exercise of command and in control of resources (forces);" (2) "A command and control system is an information-handling subsystem whose function is to achieve desired relations between itself and the environment." Further, the Working Group decided that a command and control system had the following functions: event sensing; situation evaluation; situation projection; comparison of situation, system objective and response potential; action selection; and action implementation.

More recently, a nominal definition has been formulated at the highest military level. Presumably it is the authoritative definition throughout the Department of Defense. The Joint Chiefs of Staff have formally declared that a command and control system is "a system consisting of those facilities, equipment, communications, procedures and personnel which are under the personal control and direction of the commander and are essential for planning, directing and controlling operations of assigned forces pursuant to missions established by higher authority" (United Actions Armed Forces -- UNAAF -- Publication No. 2, JCS).

Earlier, the Navy had adopted a slightly different definition of command and control system: "...a systematic arrangement of personnel, facilities, and information acquisition, processing and distribution systems employed by a commander in directing and controlling his forces" (Opnav. Inst. 03300.9A). (Of course, either definition requires further definition of the terms "directing", "controlling" and "forces". But the Navy definition's emphasis on "information" has considerable appeal.)

The Air Force had defined command and control system as follows: "A composite of equipment, skills, and techniques which, while not an instrument of combat, is capable of performing the clearly defined function of enabling a commander to exercise continuous control of his forces and weapons in all situations by providing him with (a) the information needed to make operational decisions and (b) the means for disseminating these decisions. A complete system includes all subsystems, related facilities, equipment, material, services, and personnel required for operation of the system, so that it can be considered a self-sufficient unit in its intended environment" (Air Force Regulation No. 375-1(2.(3)), January, 1961).

A somewhat more comprehensive description of "command and control system" was offered later by General Ferguson (1965): "To make the vital decisions for the employment of weapons and forces, aerospace commanders must, first of all, have four services rendered for them by their command and control systems: the gathering of data on the activity of both friendly and enemy weapons, the transmission of the data to a central location, the processing or analyzing of the data, and the display of the processed data. Once decisions have been made and the action orders issued, four additional services must be rendered by the same or related command and control systems: the transmission of orders to the forces and weapons in the field, the conversion of those orders into weapons activation signals, the transmission of signals for the control of the weapons in action, and the return transmission and processing of reports on the activities and accomplishments of the weapons."

Apparently the Department of Defense and its component departments have felt a need to define "command and control system". Accordingly, one must infer these systems are something new, in spite of such statements as "The military has always used command and control systems" (Jacobs, 1961). Perhaps inadvertently, the same author indicates what's new: (1) these systems were based on the introduction of "automatic equipment (computers, communications, and so on)", and (2) "these systems are packaged for management convenience. They can be described by the military and understood by the industry. They are small enough to be handled as entities by many industrial organizations, but they are not so small that the context within which the design should be done is entirely lost." Not merely from these comments but from the actual history of the term, it is clear that "command and control system" had been adopted for the integrated <u>development</u> of <u>projects</u> which are <u>military</u>, which are <u>large</u>, and which are undertaken to introduce new, <u>automatic equipment</u>, namely computers and associated I/O equipment and communications (and sometimes radars).

Of course, the fact that this is <u>why</u> the term "command and control system" has been adopted does not enforce this as its "meaning" or "definition". Speech is free. But it may be the only definition or meaning on which one can achieve general agreement -- if one excepts the statement, "command and control system is a mixture of two verbs, a noun and a conjunction." Attempts to achieve agreements on definitions of "command and control" or "command and control system" are as vain as they are unproductive, as participants of the Military Operations Research Symposia have learned

(Steger, 1962). Fortunately, of course, as indicated at the start of this report, no effort is being made to put together a new, brief definition of "command and control system". The foregoing material was assembled essentially for historical or etymological interest. What does have somewhat closer bearing on the purposes of this report is the section which follows on methods of system classification.

Classification Schemes

One approach to classifying command and control systems has been to dichotomize, i.e., strategic vs. tactical, or command vs. control. The Navy has drawn the distinction between strategic and tactical from the start, in the Chief of Naval Operations directives which established the framework for the development of such systems.

Rear Admiral Lambert has stated the difference between strategic and tactical command and control systems as follows: "As a generalization, one might refer to tactical command and control systems as those systems in which combat direction, through direct control of tactical units, is performed. These are normally ship, aircraft, or transportable installations operating in real-time. Strategic systems are those which normally support a major shore-based commander, and the operation of which in real-time is not an absolute requirement" (Data, 1965). Classification according to "real-time" and "non-real-time" criteria has become another approach with some popularity.

Benington (1964), in distinguishing between "strategic command" and "tactical control", cautioned against differentiating between tactical and strategic wars, "for these terms do not distinguish wars; they distinguish two essential aspects of managing any conflict or crisis".

Classification of systems according to command vs. control is implied by the overall term itself. One can suggest that the "command and control" component of "command and control system" is a disjunctive concept which has been adopted because of what "command" and "control" have in common. What they have in common includes a relatedness to a system labelled a "command and control system". Further, the fact that both the word "command" and the word "control" appear in this label suggests that such systems are related to the activities of both "command" and "control".

However, the importance of "command" and the importance of "control" may not be equal in any one system. Some analysts have emphasized the differences, for example, Kroger (1964), who said, "I find it quite helpful to separate the command functions in the phrase 'command and control' from the control functions. Even though not all systems can be neatly categorized as being discretely either a command system or a control system, because most have elements of both, it is helpful in examining the problem of automation to differentiate between command functions and control functions. One way of defining the difference is to state that if the decision element is a man, we will call it a command function; but if the decision is made by a computer, we will call it a control function. This means, then, that command functions involve the broader problems like planning, assessing capabilities, and allocating resources. These functions require the gathering of large amounts and many classes of information, aggregating it, and processing it so that it can be presented to a man to help him in making knowledgeable decisions. Control functions, on the other hand, usually involve the direct control of action by a computer. A control system functions like a servo-mechanism; that is, it pursues a fixed objective in a changing environment. A good example of a military control system is the automated air defense direction center business as typified by the SAGE system. Another is the guidance and control system of a ballistic missile."

(Of course, anyone who really knows the SAGE system would hardly call it "automated", suggest that the computer directly controls the weapons, or liken it to the guidance and control system of a ballistic missile. Perhaps this is a good illustration of the value of looking at the real world before offering generalizations.)

An earlier report along the same line by the same author (Kroger et al, 1961) took a slightly more liberal view of control functions, saying they operate "in situations where, although the volume of information is large, it can be categorized in a relatively few classes. Objectives are fixed and the problem is to maintain action toward the objectives through error detection and corrective action. The operation of an air defense direction center is a typical control function because the system elements have parameters which can be reduced to specific values, and both the rules for the employment of system elements and the relationships among the elements are well understood..... At lower levels of command, for example, a SAGE direction center, the control function is a dominant factor. On the other hand, at higher levels, the command function dominates..."

(Even this view can be misleading. In the first place, uncertainty can be introduced into a "control" system and reach a level perhaps equal to that of uncertainty in a "command" system, and it will be so introduced in wartime when a hostile force tries to blind or confuse the control system, e.g., with jamming or chaff or decoys. In the second place, a system like SAGE may have substantial "command" elements, e.g., activities of the sector commander and his battle staff, and virtually the entire operation of the Combat Center.)

In a lecture on "Operational Context of Command and Control", Scherer (1964) also has distinguished between "control" and "command". "Typical military problems" related to "control functions associated with tactical levels of organizational structure," he noted, "are missile and air defense, alerting and committing of offensive forces, anti-submarine warfare, multiple satellite operations, and coordination of battlefield reconnaissance with close air support." On the other hand, the "higher levels of command" are concerned with "evaluation, planning, strategy formulation and execution."

N. P. Edwards, of DDR&E Weapons Systems Evaluation Group, has likewise tried to differentiate command from control (1964). He divided command and control systems "into two different groups based on how the effectiveness of the system can be determined." Control systems are illustrated by aircraft autopilots and missile guidance systems; one is justified in trying to eliminate the human. Command systems are composed of data gathering and command transmission subsystems, the performance of which one can measure, and a data analysis subsystem -- "the heart of a commander's personal mode of operation" -- where measurement is not feasible.

Failure to distinguish between command functions and control functions may be unfortunate. Craig (1965) has called attention to the possible effects of word-association in discussion of command and control, with the result that techniques useful for command, such as centralization, may seem appropriate to control, when decentralization might be better.

The report of the Air Force's Winter Study Group separated command and control systems into four groupings (Aviation Week, 1960): Command, Control, Sensors and Support. A year later a listing of 14 AFSC command and control systems had five groups: Command, Control, Intelligence, Warning and Support (Missiles and Rockets, 1961). (Incidentally, the same article reported that "ESD and Mitre are planning the integration of all of these and future Air Force command and control systems into one worldwide Aerospace Command and Control System.")

General Ferguson (1965) listed command systems separately from control and electronic systems (and, as noted earlier in this report, both separately from communications). General O'Neill subsequently pointed out that ESD's equipment-oriented projects were organized under three deputates, the Deputy for Command Systems, the Deputy for Surveillance and Control Systems, and the Deputy for Communications Systems (Data, 1965).

Christie (1965), who restricts his usage of the term system to an electronic data processing system rather than including all equipment, organization and procedures, places "command" in a hierarchical relation to "control", in that "command" is exercised over "control". He divides command and control systems into control systems, which are electronic data processing systems that carry on surveillance and control operations, and headquarters systems (short for headquarters information management or headquarters information systems), which are electronic data processing systems to assist in the management of information fcr use at a headquarters. To Christie, control systems can be called special purpose systems (even though they may use general purpose computers), while headquarters systems are general purpose.

Somewhat similar binary classification schemes have emerged with the use of the terms "sensor-coupled" to describe control or tactical systems, and "capping" for command (headquarters) or strategic systems. The latter are less directly tied to such sensors as radars. They exist at the higher echelons of the command structure. Further, it can be seen that "tactical" and "control" tend to be used more or less synonomously, in contrast with "command" or "strategic" or "headquarters" systems.

In addition to the general schemes reviewed above for categorizing command and control systems, they can be classified along various other dimensions. Some of these dimensions have been indicated in the annotated catalog of command and control systems in the preceding section of this report. Obviously, one consists of the parts of the military structure which are the developing organizations. Another consists of the parts of the military structure which are the using organizations.

The catalog has employed a descriptor called "primary purpose supported", composed of "information collection and analysis", "resource management" and "operational control of forces". This dimension and the subdivisions therein were developed from a functional examination of the systems in the catalog. Hopefully it provides a useful set of categories. (Of course, the assignment of each system to only one of the three does not mean that the system may not also possess one of the other purposes; it merely defines which of the three is primary for that system.) The particular three purposes simply emanated as a preferred, limited set, once purpose had been differentiated from function in the functional analysis. (One can look at function as a process or subprocess with a purpose. It seemed desirable to employ the term function as synonomous with subprocess.)

The rationale for the particular categories along the dimension of "primary functions" in the catalog has been presented in the section of the report on "The Functional Structure of the Military Process". These classes, namely, sensing, analysis, decision-making, action and communications, had been derived from an examination of the actual overall military process.

Although each function exists at every command point, as "The Functional Structure of the Military Process" specifies, this does not mean that each exists there in equal strength with the others. Quite the contrary. Accordingly, attribution of certain "primary" functions to a command and control system means that such functions are dominant within a command and control system at some command point. If a function plays a minor role, it is excluded. For example, if the system did not include weapons, the action function would not be listed.

"Operational environment" was introduced as a complex dimension which includes the medium in which the system itself operates (e.g., land, air, sea, undersea); the medium in which the activities (e.g., combat operations) for which it is responsible occur (again, land, air, sea, undersea); the scope of geographical area of such activities (ranging from a localized area to world-wide); and the scope of the location of the system itself (ranging from a single installation to a large number of installations and varying between fixed and transportable).

"Type of conflict" constitutes a bow in the direction of analysts who like to classify systems according to the type of war or level of conflict for which the systems are designed -- ranging from peacetime or cold war through limited to general or global war (with or without nuclear weapons).

One could also categorize along additional dimensions, such as (1) medium in which the adversary force operates; (2) types of weapons controlled; (3) types of data processing technology introduced (both hardware and software); (4) cost of the system; (5) number of personnel for operation and maintenance of the system, etc.

Still another potential scheme consists of a "model" which distinguishes among (1) "computer-oriented" systems "built around a computer capability which is a major determinant of its operating characteristics;" (2) "organization-oriented" systems where "existing command organizations, responsibilities and doctrine are major determinants," (3) "single-function" systems which have "a primary mission or task;" and (4) "continual-function" systems which "have several missions and are required to function over an extended period of time under a variety of operating conditions" (Weiner & Taylor, 1962). These four types of emphasis may be combined in various ways.

However, it seemed doubtful that these would add much to the general overview, which was the objective of the catalog. The dimensions which were used, however, did seem to facilitate this overview, if only to indicate the diverse nature of actual command and control systems. Very few could be located together at the same locations on more than a few dimensions. One could say that such systems "cluster" rather than possess common dimensional categories. As a consequence, when one looks at them in the mass, so to speak, and notes where they fall on various dimensions, no clear pattern emerges.

III. METHODOLOGY FOR DERIVING CONCEPTS FOR COMMAND AND CONTROL SYSTEMS

As indicated in the Preface, another major task of this study was to suggest improvements in the methodology for deriving command and control system concepts. This methodology should be applicable to future Navy command and control systems.* "Deriving concepts" was generally understood to mean "specifying operational requirements." However, "methodology" has been variously interpreted. The task can be restated, "What has to be done to generate system concepts or requirements, and how can it be done better?" For this report it was felt that a fairly broad interpretation was most useful, and this portion of the report proceeds accordingly. It has appeared that generating system concepts is a complex endeavor, and that its execution might be improved in a number of ways.

One method, which shall be called the algorithmic approach, is to produce a comprehensive checklist or dictionary of all the variables and parameters which must be taken into account in conceptualizing all possible future command and control systems. This approach, however, confronts some potential problems:

An itemization at a fairly crude or coarse-grained level may not represent any improvement over current methods of deriving requirements. These methods call for specification of such variables as the future threat (enemy forces, weapons, strategies and tactics); new technology (one's own weapons, sensors, electronic data processing -- both hardware and

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* It may be noted that the question being addressed in this study basically is "What should the system be?" not "Should there be a system?" Also, no distinction has been made between (1) a second-generation system which might replace one already developed, such as MTDS; (2) a first-generation system for a current problem, such as anti-submarine warfare; or (3) a first-generation system for some future, unheralded problem, such as selective raising and lowering of the ocean level.

software, communications, etc.); one's own forces and their organization, objectives and doctrine; environmental influences, such as geographical and metereological factors; current effectiveness of information sensing, flow and processing and of command dissemination; and cost, scheduling and other constraints involved in a new system. At the start of the study it was made clear that what was needed was an improvement on this methodology, not its replication. One way to improve on it might be to make the variables fairly fine-grained, perhaps through a functional analysis, so a rather detailed guide would be available. However, a possible difficulty here would be the applicability of such a guide to a particular system. The survey of command and control systems earlier in this report demonstrates their considerable diversity. There seems to be no such thing as a "typical" command and control system. In particular there have been major functional differences, except perhaps at a gross level, between command or headquarters systems and control or tactical systems. Could any requirements guide be detailed enough to represent an improvement over current methodology, yet be tailored to fit a particular system or type of system?

But there is a bigger problem. The most difficult aspect of current methodology seems to be one of <u>prediction</u>. It does no good to take parameter values and characteristics found in present systems and inject them into the concepts for a future system. One knows they will have changed by the time such a system could be created and installed. Yet for the purpose of conducting feasibility and cost/effectiveness or cost/benefit analyses, as well as for selecting among system concepts, one must make such predictions. It has been stated that a major drawback of present methodology is the reliance on current facts for future situations. It is not clear how even a fine-grained guide or checklist would resolve this problem.

Another method, which might be called heuristic, would specify and examine certain overall characteristics which concepts of a command and control system should have, so that when a study is made of the concepts of a future system the analysts will be certain to make sure these characteristics are incorporated. Participants in the Working Group on Command and Control at the 7th Military Operations Research Symposium put together a preliminary list of these (Weiner, 1962): "flexibility, expandability, security, survivability, integrity, capacity, variability in handling details, response rate, coherence, delegation, conservation of function, reliability and cost." Of course, the items in any such list not only would have to be elucidated further, but also one might desire to know something about the relative importance of individual items for different kinds of command and control systems.

Still another, perhaps more modest method might also be termed heuristic. One would specify "trouble-points" which must receive particular attention when concepts for new systems are being derived. Such trouble-points would be selected by examining current command and control systems and noting what troubles have occurred in them as a consequence of the concepts which had been adopted and on which system design had been based (not troubles which originated for other reasons). The fact that trouble occurred in an earlier system would imply, at some probability level, that the same trouble would occur in a future system if the same or similar concepts were adopted. One might profit from the experience of others. Of course, one would have to make a best estimate of the probability level. This would require a rather careful investigation and analysis of each type of trouble-point. This report has taken this approach to methodology, in part A which follows.

However, neither of the heuristic methods seems sufficient. The derivation of future system concepts or requirements is not something which can be adequately accomplished by a computer with programs of either algorithms or heuristics, although at some future date such programs might be of some assistance. If people are to have a major role in conceptualizing command and control systems, they can do it better if they are appropriately selected, trained and organized.

If one were to produce a superior methodology for conducting research, and if one interpreted the term "methodology" with sufficient breadth, one would not simply provide checklists or textbooks of how to do research to the researchers. One would be concerned about who the researchers were, how they had been or were to be schooled, and how the research organization was put together and managed. Since the derivation of system concepts or requirements can be regarded as a kind of research, it is suggested that the same aspects of methodology may be profitably applied. These are covered relatively briefly in part B.

Finally, there is the problem of prediction, to which allusion has already been made. All command and control systems are, in fact, unstable in some way. This has become clear from the survey of such systems which is documented earlier in this report. At installation none fully coincides with original concepts, nor does the system remain the same even during development, or during operation. Some have been cut back. In some, changes have been characterized by the increments of new modules, or simply by alterations in design within modules, or by both. In many or most cases change has been neither planned nor controlled (in the sense of feedback from experience and test) as systematically as it might have been. But changes have occurred in all systems. The history of command and control systems implies that changes are inevitable. If this is so, then it would seem that the concepts of new command and control systems simply cannot be derived initially with completeness or entire accuracy. In consequence, many observers have contended that such systems should be purposely "evolutionary." This means that the system grows incrementally and that new system concepts and requirements are derived during the life of the system, as a result of operational and test experience. It means further that the system should be conceived originally with such a progression in mind. This approach is documented more completely in Appendix IV. It is clear that the "evolutionary" concept generally has not been very thoroughly analyzed and that much more analysis is required before it is simply accepted or rejected.

A. TROUBLE-POINTS

The material which follows has been gleaned from a considerable number of publications and interviews. Some of the documentary sources dealt with particular systems, some were the published views of people with extensive experience concerning command and control systems. In order to keep the material unclassified, no references will be made to particular systems, unless an unclassified source can be cited. Consequently, the conclusions are presented in a very general way. They certainly should not be construed as being applicable to all existing command and control systems.

By no means are the five "trouble-points" treated here supposed to constitute an exhaustive inventory. They merely purport to illustrate what this kind of an approach can be, as well as pinpoint some particular areas. These are discussed under "Interfaces" (dealing with system boundaries), "The Front End" (input data), "Conversions" (interaction between noise and conversion of data), "Anti-System" (concept of the antagonist as part of the system), and "Exercising" (simulating the antagonist, the input data and the conversions). These five trouble-points are clearly interrelated.

1. Interfaces

Recently a personnel recruiting advertisement appeared in the Washington Post calling for "Interface Management Engineers." "Be one of the first," it urged. "However badly overworked the term 'interface' has become, this delicate engineering systems integration function is especially important to the Navy."

The advertisement, placed by the David Taylor Model Basin, went on: "To them, an interface is an inter- or intra-ship boundary through which flows information, command or physical action resulting in mutual dependency and responsiveness." It listed, "in terms of ships and submarines, three groupings of systems that must interface effectively at all times and under all operating conditions. 1. Weapons Systems -- all kinds of surface and subsurface launched missiles, ASW systems and conventional weapons. 2. Electronic Systems -- sensors (radar, sonar, infrared), communications, ECM, GCA, navigation, etc. 3. Support Systems -- electrical power, ventilation and air conditioning, water supply, hydraulic, compressor, air, electrical transfer and switching systems."

It may be permissible to amplify that text by adding "command and control systems" to the other three groupings and shore-based installations to "ships and submarines." One might also insert something to the effect that interface experts are needed throughout the system development cycle, and particularly when the system concepts and requirements are being derived. Perhaps one reason there are troubles at interfaces within and between command and control systems, and between these systems and other types of systems, is because interfaces are insufficiently scrutinized at the conceptual stage of development.

Interfaces are like the weather. Everyone talks about them (and writes reports which are disregarded, because no man's land belongs to no man), but no one does anything about them, or not enough. A classic military strategy has been to penetrate between two elements of the opposing side, i.e., at their interface. The weakness in the interface helps the enemy even when he does not intentionally exploit it, as at Pearl Harbor in 1941.

Of course, there are interfaces and interfaces. The advent of command and control systems possibly has increased their number, or at least added some new ones. One of the interfaces which has aroused most concern has been the interface(s) between one command and control system and one or more other command and control system(s), even within the same military department. Recently, according to Dr. Fubini, the Department of Defense has been "attempting to...take 'functional areas', such as command and control and review it as a consolidated package. This is in contrast to some of our previous procedures in which we reviewed specific programs such as the SAC command and control system (465L) without at the same time considering the impact on related systems and on the overall functional area comprising all command and control systems" (Data, 1965). However, the solution to the interface problem has not necessarily assumed the form of larger and larger systems. For example, as noted earlier in this report, the Army's CCIS-70 began as one large system with a number of sub-systems, and now has become several relatively independent systems.

"There are two main problems in this area of intersystem integration," Major General O'Neill of ESD has said. "The first is determining the boundaries of the system and, therefore, the point at which the functional interface with another system occurs.......The second problem is the absence of established standards which could ease the problem of compatibility at defined interfaces and eliminate much of the buffering, translation, and rehandling of functional information...." (Data, 1965).

One of the difficulties has been that "the defining boundaries of any particular system are assumed to be coterminal with a specific organization or geographic location," and that "the selection of the specific segment of a process to be defined as part of a system to be developed, improved, or automated is closely related to the limits of the authority of the developing organizations" so that "for jurisdictional and practical reasons the development of military command and control systems has been characterized by the development of specific systems for specific commands....In the case of military commands, there is often an element of competition with other commands: subordinate, lateral and superior; which almost inevitably means that the optimum system as defined by a specific command may be far from optimum in the total system" (McCarn, 1964).

Kroger (1964) has taken note of "the system pyramid concept", with NMCS at the apex, tactical systems at the base and various tiers of headquarters systems in between. However, the systems are not that neatly interrelated, he says, and the concept misleads people into thinking the interrelationships "can and should all be clearly defined before work is started toward building the system". But "it is virtually impossible to generate inter-relationship documents until the systems being examined have been defined -- and if it is insisted that the interrelationships be established before any substantial individual system work is started, the work will not get started. This is essentially the progress report on automated tactical information systems to date."

Interfaces between tactical air control or air defense systems have come under increasing scrutiny. They are complicated by the fact that there are roles and missions as well as technical compatibility problems, and by the coincidence of inter-organization interface with inter-system interface. Will a force at sea fail to notify, promptly and directly, a different, land-based air defense force that a missile-carrying submarine has been sighted? Will our own forces shoot down our own aircraft? These are the risks of this kind of interface trouble.

Where there are interfaces merely between organizations, and not between command and control systems as well, the advent of such systems has nevertheless brought new interface difficulties, as where a unified commander's staff and the staff of a component command share the same command and control system. Still another trouble-point lies in the interface between staffs of different organizations, one (or each) of which has a command and control system. "ADP techniques for....assisting interstaff coordination... have not been adequately developed and applied" and because of a certain parochialism created by the system "very little attention is paid to the flows of information and consultations between the staffs of the organization and the staffs of other organizations, in spite of the fact that the volume of such flows and the detail of the information greatly exceed the volume and detail provided by a staff to its commander" (McCarn, 1964).

In a technical sense trouble in the interface between command and control systems has taken two forms. One, it is not always clear how much access a system should have to the data base of a subordinate system; SDC has made an extensive study of this area and proposed a concept of "discretionary access" (Singleton, 1963). The second trouble occurs if computers in two systems have different characteristics or programming; "e.g., the language incompatibility between the Army and Navy data processing systems currently precludes a completely automated fire plan for joint operations; the incompatibility between the Navy Tactical Data System and SAGE precludes convenient target information exchange between the systems" (Kroger et al, 1961). Additional difficulties occur if different systems use different command languages.

"One JCS official lists 'increased compatibility between tactical command and control systems' as one of the major advances to be anticipated during the next year. Right now, the advanced Air Force system is under review by the JCS to clearly identify the interfaces between it and Army, Navy and air defense systems and to insure that there will be compatibility. 'We want these systems to be able to talk to each other,' is the way this Joint Staff man puts it. 'With joint operations becoming more common, we may find ourselves on the same beach with a Marine Tactical Data Unit and we want to be able to communicate,' is how an Air Force officer expresses the same thought" (Armed Forces Management, 1965).

Still another interface trouble has been found within a single command center. The Air Force's Winter Study Group which investigated command and control systems in 1959-60 said that "too little emphasis has been given to common means of effecting timely communications between various components of the command centers (intelligence, operations, planning, materiel" (Missiles and Rockets, 1960). Compartmentalization of these functions still creates concern.

Although all of these interface trouble-points are of extreme importance for the derivation of concepts or requirements for command and control systems, they are reasonably well known and so this review has not added anything. It is to another kind of interface trouble-point that the report wishes really to direct attention, because it is apparently so little understood that virtually no mention has been found in general discussions of interface problems. These are the interfaces between the functions described earlier in this report in "The Functional Structure of the Military Process."

In examining actual command and control systems, as was done in preparing the annotated catalog in this report, one finds that in their development such systems do not incorporate all the five broad functions of the military process in any major fashion. For example, a command and control system may itself do very little direct Sensing and instead depend on another system, or organization, or aggregate, to do its sensing for it. All of the systems possess a primary function Analysis, presumably because what they all (but one) have in common, what really differentiates them from what preceded them, and what gave rise to the concept "command and control system" was the introduction of automatic data processing. Many of the systems also possess the Communication function, presumably because data links are so closely involved with ADP.

No command and control system incorporates Action as a primary function, in the same sense that weapons constitute a primary Action function (at a command point). There appear to have been no instances where a weapons development was integrated as part of the development of the command and control system. The closest one comes is the Bomarc development as part of ADIS (before there were "command and control systems"). It is true that some systems under development include both weapons and extensive automatic data processing and communications. An example is Nike X. But they are not called command and control systems.

Very little Decision-making can be found in command and control systems. Some delegated decision-making occurs in a few air defense systems. But generally Decision-making is done by a commander, and commanders are not integral components of command and control systems as these have been defined in this report, that is, as something under development.

Nowhere can one find in any documentation about command and control systems any treatment of the commander as a system component analogous to the treatment given to components being developed for the system. To do so would require that his characteristics be specified, let us say in a requirements document; this just is not done, at the conceptual stage or later. His production would be undertaken, let us say by means of a training program; this is not done. He would go through a test phase; nor is this. Manuals would specify his procedures; they do not. It would be presumed he would not wear out until the system had gone operational and remained in operation for some time. But the turnover in commanders who are supported by -- but not part of -- command and control systems has been tremendous.

If one were to regard the commander as part of the command and control system, one would have to improve the methodology for deriving system concepts so the methodology would include ways of establishing the concept, the requirement, according to which one would fashion the commander. Never has it been asked whether, for some command and control system, the commander could be obtained off the shelf (austerely) or had to be developed. Commanders differ greatly. "I think that the system must be made flexible enough to meet the needs of a wide range of commanders," said Dr. Fubini (Armed Forces Management, 1965). "It must be able to satisfy both a Patton and a Montgomery, for instance. And I can't think of two people further apart in outlook." Commanders are not required to be standardized the way system components are standardized.

There are humans who are developed integral to a command and control system and thereby can be usefully identified as part of the system, but they are not the commander (or his staff). They are the people, particularly enlisted personnel but also some officer personnel, who operate the consoles, maintain the computers and communications and do the programming. The necessary characteristics of these people are specified in requirements documents. They are trained to perform certain tasks within the system, before it is placed in operation -- and after. Their procedures are written down in manuals. Performance of the system under their operation is tested. They remain on the job.

Of course, this exclusion of the commander -- and the Decision-making function -- from the system results from the usage of "system" in this report. Anyone may prefer a different usage, for example, to cover a large operating complex -- but not for the purposes of this study. This study is concerned with the development and particularly with the very first stage of development (conceptual), so "system" must be viewed as something being developed.

At present relatively few command and control systems integrally possess, in a major degree, the Sense function, almost none the Decision-making function and none the Action function.* The system boundaries stop short at these functions. What this means, and this is the critical point, is that interfaces between functions occur at the system boundaries, namely, at the interfaces between the system and other systems, aggregates or organizations. This may not be the way things should be, but it is the way things are. The implications are obvious, and serious. Interfaces present difficult problems anyway; these are perhaps quadrupled if the interface is double, that is, if two interfaces occur together.

* The HSR-SRI report also appears to exclude the Sense and Action functions, but incorporates Decision-making into command and control systems as these should be configured, in operation.

The problems are not ones just of compatibility. The real problem is one of optimum combination. If different organizations and different people are creating different functions, as they will if some functions lie within and some outside the command and control system boundaries, the probability that the optimum combination will be created is greatly reduced.

What can be done about this? The resolution is not made any easier by the misconceptions which so many people have about where the boundaries of command and control systems really lie. Possibly these misconceptions occur because after the system becomes operational, the name of the system may be applied colloquially to all of the associated functions together. SAGE is an example. Accordingly, if one looks only at operating systems, or thinks only about operating systems, one may be easily misled about system boundaries. System developers, including those who derive concepts or state requirements, should look harder at and think harder about the facts of the <u>development</u> of systems, actual and future. Otherwise the danger remains that, in the confusion about the location of system boundaries, interface trouble may get even less recognition because it is assumed that the interfaces lie within the system rather than at its boundaries.

To improve the methodology for establishing requirements for command and control systems, then, the following two steps are proposed:

(1) The relationship between functions and system boundaries must be specified clearly and after careful study of the best location of system

boundaries. It is indeed possible that future command and control systems should include more of the Sensing, Decision-making and possibly even Action functions than they have in the past. However, any study of system concepts should recognize just what this means and specify requirements for those functions. As illustrated in the discussion about the commander, this may not be easy to do.

(2) Whether the interfaces between functions are to occur at or within the system boundaries, they still represent trouble-points. In the studies and documents dealing with concepts or requirements, virtually as much emphasis should be given to the interfaces between functions as to the functions themselves; portions of any study, and parts of any document, could be specifically designated "interface". Specific responsibility could be assigned to "interface" coverage, as in the case of the "interface engineers" cited at the beginning of this section.

2. The Front End

The performance of those command and control systems whose primary purpose is to support the operational control of forces depends on whether the data they get is what the Analysis function requires. So the front end of the system would seem to be its most important portion.

But this is usually so neither in fact nor in recognition. It is not so in fact because the place, the equipment or the people where the data originates, the front end of the military process, is likely to be outside the boundary of the command and control system. As noted in the preceding section, the Sensing function is often elsewhere.

It is not so in recognition, because the front end competes for recognition with the middle and terminal parts of the military process. In the middle the data processing features of the Analysis function hold much more interest for system developers, and the Decision-making function seems far more significant to the Commander and his staff, if only because this is their big responsibility. Finally, the Action function is where the real prestige lies among operational personnel. In an air defense environment an interceptor pilot has more prestige by an order of magnitude than an ECCM operator of equivalent rank at one of the radar sites. Within the command and control system in this environment the intercept directors who interact with the pilots engender more respect than the air surveillance personnel. It makes no difference that the intercept directors and pilots can accomplish nothing unless the ECCM officer and surveillance personnel provide the proper data for Analysis which serves delegated Decision-Making (control) and Action. When the using organization influences the development of the system, it can happen that the front end takes a back seat.

For systems which depend heavily on radar data, a trouble-point may consist of the effect which noise can have on the quantity and quality of the data, as Israel (1965) has noted in discussing automatic track initiation in SAGE. Some aspects of this "noise" are mentioned in Appendix III. It can be nature-made as well as enemy-made (or self-made). Especially, perhaps, in the enemy-made case, because it may be uncertain just what to expect, the system designer may prefer to create his system first to operate in a relatively noise-free environment. His rationale states that initially one wants to see whether one can design, and make operate, the system at all, and then one can deal with the noise problem. This approach occurs first in establishing system requirements or concepts. The difficulty is that if the noise trouble-point is not handled at the start, the system may be so conceptualized and designed that the problem can never be adequately handled.

Fortunately, some realization has grown that this is the wrong way to create a system. For example, the Secretary of Defense has publicly stated that it would be foolish to build the Nike X system for defense against ICBMs unless and until it was possible to lick the problem of noise -- in this case the false signals generated by ICBM decoys. According to Aviation Week (1965), "Future of the Air Force's proposed Airborne Warning and Control (AWAC) aircraft program, a miniature flying SAGE direction center, is riding on technical feasibility tests to be conducted during the coming year...These flight tests and technical investigations are intended to determine whether an airborne track-while-scan surveillance radar can detect and track low-flying targets in the presence of ground reflection, i.e., ground clutter. Unless this basic problem is solved, the Pentagon holds that AWAC would be useless against what is now considered the most likely enemy tactic." In the AWAC case the noise is nature-made rather than the enemy-made noise which could afflict Nike X.

It is proposed that the methodology of deriving system concepts or requirements be improved by an insistence on making sure that the noise problem at the front end is solved or soluble along with the other problems facing a future or new command and control system. It should not be necessary for system concepts to be rejected at the highest levels because the noise trouble-point has been neglected.

Also one must guard against the over-optimism of technical experts in such fields as data processing. It may be erroneously assumed, or even insisted, that the noise problem can be entirely solved in the Analysis function, that is, through sophisticated data processing, so one does not have to worry about the sensor source. "For example, it has been feasible to consider the use of computers to make fine discriminations between electronically detected signals. Such use might not be desirable, though, from the standpoint of susceptibility to intentional jamming by an intelligent enemy. Yet, such negative considerations conflict with the current vogue of employing computers to the utmost in military operations" (Aircraft Armaments Incorporated, 1964). High speed data processing is not a panacea for handling sensor data. (An illustration of the dependence of automatic processing on the availability of sensor data comes from the mythology of industrial process control. It is said that automatic control has sometimes failed to forestall major disasters resulting from burned-out circuits, whereas humans could have prevented or did prevent them. When the insulation started burning the humans could smell it.)

However, such processing can be most helpful, when applied to the right situation. Sensor data, noisy or noise-free, may come from various sources -- radar, sonar, elint ferrets, photography, other devices and human observers. If data from more than one source contains the same class of information, and if the data from any single source is incomplete or suspect, then there should be some method of correlating the data from different sources to see whether thus one can obtain a more complete and reliable picture. A computer may be able to accomplish the correlation process much faster and more effectively than human operators -- though these may be needed in various intermediary roles. Correlation by computer of this nature could be introduced in air defense (anti-air warfare), in anti-submarine warfare and in other fields. The methodology for command and control system concepts could be improved by including and emphasizing the concepts of computer-aided correlation of sensor data.

In command systems, how much is really known about the data, the basic commodity with which a command system is concerned? Here is another trouble-point related to the "front end." Until the general subject of "obtaining data" is understood far better than it is now, it is not clear that it is possible to achieve an effective command system capability or to really know how to go about creating one. This trouble-point is discussed at greater length in Appendix II. The questions are, What Data?, Where to get the data?, and How to get the data? To improve the methodology for generating command and control system requirements, investigations can be undertaken to answer these three questions, and their conclusions introduced into the methodology.

3. Conversions

The stuff of command and control systems is information, and information flow is full of conversions.* It may be useful to consider "conversion" as an overall concept when we start to create requirements for command and control systems, because all conversions are trouble-points, to some degree. One reason they are trouble-points is that in any information conversion, there is risk that information may be lost or false information added.

There are all kinds of conversions, of course: conversions between the language one computer uses and another's; conversions between various forms of "natural language", including the specialized forms which are used by commanders and their staffs, and the languages computers use; conversions from compiler to machine languages; conversions between tape and card and typewriter or teletype; conversions from one data base to another; conversions to new display formats; conversions from unformatted reports to formatted, and vice versa; conversions consisting simply of manual transcription of voice messages, and vice versa, etc.

One interesting kind of conversion is the transformation of information available at a subordinate headquarters to the information which that headquarters should send to a higher echelon. Should it be converted at all, that is, should everything be provided? Should it be summarized or filtered, and if so, how? What should be supplied on demand, and what as a matter of course? These have become major questions where computers in command and control systems can be linked. For example,

* The HSR-SRI report also places emphasis on "conversions".

should the commander of a higher echelon, such as NORAD, get from SAGE the positions, courses, speeds and altitudes of hostile bombers in war-time? What can he do with this information? The Canadian COIN study (1961) advocated filtering out these details and showing simply the number of such aircraft at any time within a large area, such as a SAGE Sector.

Other than the COIN study, this kind of conversion question has rarely been investigated. Procedures are likely to be carried over from earlier times. Often, it is said, commanders want to know everything. Is it possible that instead they will know less, because the mass of data will overwhelm them? Is it possible that too much data can be misleading and help a wily adversary carry out feints? Perhaps there should be a good look at the "surplus curiosity" factor.

At some conversion trouble-points the question may arise as to whether humans or computers should perform the conversion. Here is where the interaction between conversion and noise may become important. Surveillance personnel in SAGE AEW&C aircraft who obtain data about detected and tracked aircraft on PPIs use polar coordinate identifying numerics. Since the SAGE computer operates with a rectangular coordinate scheme, the polar coordinates have to be converted to rectangular coordinates. Originally the operators in the AEW&C aircraft did this and transmitted the new coordinates to the Direction Center. A human factors study showed that there were long delays and many errors (there was "noise" in the operators) and recommended that the conversion be done by the computer at the DC, as subsequently happened.

But there are other situations where automatic processing may be less effective than human processing, such as noisy data where the human capability for pattern recognition can be exploited, as in photo-interpretation. However, radar engineers and computer programmers have been slow to acknowledge the potential of the human role in the conversion of radar data to digital data for computer processing (except for crude elimination of noise). An analysis of the complexities of the conversion of noisy radar data into digital data is presented at some length in Appendix III, together with comments about human intervention.

Although all conversions are trouble-points, it is desired in this report to draw attention especially to the class of conversions just mentioned, that in which sense data is converted into digital data and in which noise intrudes and degrades the conversion process. There is the case where radar or sonar data is converted automatically into digital form for data link transmission to a computer. And there is the case where a human being may be the direct sensing device, the converter and the transmitter as well. As analyzed in Appendix III, some interesting parallels seem to exist between the radar case and the human case.

This class of conversions has been emphasized in this report, with the illustrative examples in the appendix, because there seems to be relatively little awareness among system developers of their existence as trouble-points, in spite of their significance for the performance of many command and control systems. Further study of such conversions and the effects of noise could contribute to an improved methodology for creating system requirements, by indicating in general what the requirements should be at these trouble-points.

Where information flow originates with messages written by human observers or collaters, it is possible that substantial lags arise because the writers are insufficiently adept at composing messages. In the Dominican Republic crisis, for example, "most of the time lag in this flow" apparently occurred "in the initial writing of the message and its evaluation at the other end" (Armed Forces Management, 1965).

Do the "observers and collaters" get any special training as message composers or is it presumed, unwisely, that any literate person can perform this task adequately? In point of fact, conversion of sense data to words and of word data to other words is more complex than one may realize, especially with noisy data, as pointed out in Appendix III. In the Dominican Republic crisis it was alleged that government officials often received better information faster through newspaper reports than through official channels. The analysis of newspapers as information systems in Appendix I may suggest some concepts for improving the conversion process in the flow of military information.

4. The Anti-System

A new concept should be added to those which may be specified for consideration in establishing requirements for a future command and control system. This is the concept of "the anti-system."

The concept of "vulnerability" has, to be sure, usually been included among those which system developers must consider, beginning at the conceptual phase. But "vulnerability" offers connotations which are too narrow. It tends to restrict attention to the question of escaping nuclear damage or destruction. The concept of the anti-system is much wider. It includes everything the adversary may do to try to prevent one's command and control system from operating successfully. It is applicable to all kinds of command and control systems, but perhaps more to those with the operational control of forces as a major purpose, although there is applicability also to those which primarily collect information.

One must assume that a clever adversary knows about our command and control systems and has prepared means to foil them. But too frequently concepts for a new system are developed without sufficient regard for the enemy and what he might do, the anti-system. The classic case has been the co-location of SAGE Direction Centers with high pay-off targets, such as SAC bases. Defense against electronic warfare has been another area of relative neglect. In an unclassified document it is not possible to explore this area further, but the problem exists. It is a major trouble-point.

Further it seems possible that a virtual "ostrich syndrome" occurs when system developers start to think about what will happen after hostilities actually start. "The Winter Study Group found evidence that there has been too much emphasis on system features which are primarily for controlling forces prior to an attack, and too little on controlling forces after the initial attack" (Aviation Week, 1960).

There are many troubles to which neglect of the anti-system can lead in creating concepts. One may base one's concepts on the assumption that the enemy offensive force will behave like one's own offensive force, with similar tactics. One may assume he will be acting as he sets out to act, that is he will not make mistakes (which result in unexpected contingencies). One may assume he will regard as important in one's system what one regards as important oneself, namely the location where the commander and the automatic data processing equipment are situated; so one will not assume he may instead prefer to attack the sensors (which may be outside the system) or the communications, ground-ground or ground-air. One may focus so completely on the nuclear damage aspect of vulnerability that one fails to reduce other vulnerabilities. If the command and control system serves a peacetime mission as well as a wartime mission, it is likely that disproportionate effort will go into making it effective for the former, which is what the using organization lives with every day. In developing war games for evaluating the system concepts, one may withhold inputs which are too punitive. As Craig (1965) has noted, one may fail to explore the survival advantages of decentralized (dispersed) data processing, since at the same time one may assume, incorrectly, that centralized processing must be associated with centralized command. One may assume that the probability is very small that our weapons will not prevail, for example, that our side will lose air superiority or that the carrier will be sunk. (One does not assume this is impossible, one merely assigns a probability value low enough that it no longer seems necessary to devise really effective back-up capabilities, with the required facilities, personnel, training and information readiness.) Perhaps most important of all, one may fail to explore real but apparently remote contingencies, or the unexpected, the bizarre or break-through development. If one does not place the anti-system within one's own system boundaries, so to speak, one may fail to consider all the "interfaces with the adversary."

In military analysis, "the opposing will or intelligence must occupy a central role; this means it can't be supressed or treated by assumption," according to Quade (1962), who further points out that our habits of analysis may not be suited for giving the anti-system its due. "Conflict plays only a minor role in most peacetime analysis. I can imagine that in systems analysis as practiced by a telephone company, say, somebody has to worry about slugs in the coin boxes, but very little attention probably needs to be paid to the possibility that someone will deliberately jam their microwave relays."

The concept of the anti-system is simply a verbal device for organizing the attention of all who are engaged in deriving concepts for a new command and control system. It focuses on the adversary and requires that what he might do to the system be considered in establishing all system requirements. Its introduction would be a contribution to the methodology for generating those requirements -- not a very profound contribution, perhaps, but a useful one.

Particular techniques to implement the concept could include those suggested by Brooks (1960): "First, a hunt for measure, counter-measure dead ends; that is, we can design a hypothetical measure, counter-measure, counter-counter-measure sequence to see whether the enemy might develop a decisive counter at some stage not counterable by a reasonable extension of our own system's growth potential. Second, determination of the system's 'off-design' capabilities; that is, its versatility in the face of unexpected enemy technical or strategic developments."

5. Exercising

Command and control systems may be exercised for the purposes of training or evaluation, and sometimes both of these two purposes during the same exercise. System exercising is a little like motherhood -- universally regarded as a good thing. But those who love their mothers usually do so uncritically, and those who don't remember them on Mother's Day. Since system exercising tends to be either loved or neglected, it constitutes a trouble-point in the creation of concepts or requirements for command and control systems. It simply is not well understood, by either its proponents or those who could care less.

Much has been written about system exercising for particular systems, notably Air Force air defense system (SAGE, BUIC, 412L)(e.g., Rowell & Streich, 1964) but very little about the requirements for system exercising in general, to serve as guidance for a variety of command and control systems. In the general literature about command and control systems one finds a fair amount of material dealing with computer modeling and gaming (e.g., Edwards, 1965) but except for Israel (1965) in his discussion of air defense systems, there has been very little about operational exercising. This has been notably the case with respect to "command" systems. Kroger et all (1961) said no more than, "Automated command systems should be provided with an integral means for self-exercise, self-evaluation, and verification of design changes." Craig (1965) has noted that "the capability for conducting system exercises, which may be simulated to complement the field exercises, can be achieved with a frequency that can help disclose combinations of events and their statistics that could be extremely important operationally but might otherwise remain unnoticed." Even these comments are directed entirely toward evaluation and shun the training aspect (which is mentioned briefly, but only with respect to motivational incentives, in a study of command post information systems by Aircraft Armaments Incorporated (1964)). If bows were made to requirements for training in the reports of the Air Force's Winter Study Group and the Navy's Summer Study, these have not reached the open literature.

Although the Air Force has taken the lead in establishing system exercising in some of its command and control systems, no documentation describing guidance or requirements for this kind of training or evaluation has been introduced into the Air Force's "Personnel Subsystem" management scheme for system development. The Navy has just begun to create some capabilities for similar system exercising -- but only in its schools, not at the actual operating units, as in the Air Force case.

Among the troubles at this trouble-point have been (1) inadequate exploitation of the fact that system exercising can serve both training and evaluation; (2) infrequent demonstration that system exercising can actually improve the performance of the system; (3) failure to relate simulation exercising to "live" exercising and other training or testing media and methods; (4) insufficient analysis of the actual need for system exercising for either training or evaluation, for any particular command and control system or component thereof; and (5) ambiguity about the particular objectives of exercising for training or exercising for evaluation. Apparently the only comprehensive overview of system exercising in Air Force command and control systems was prepared for the Navy (Parsons, 1964).

Field exercises have been rather widely utilized by the Army to test doctrinal, weapons and organizational concepts, and recently U.S. Strike Command conducted field trials of competing tactical concepts (*Aviation Week*, 1964). However, although simulation or field exercises could be put to use to show whether a new command and control system was actually any more effective than the system it was designed to replace, this kind of competitive evaluation has never been undertaken.

Evaluation of system concepts is said to be an essential aspect of the so-called "evolutionary" approach in the development of such command systems as NMCS, 473L and 425L. Yet it is not clear to what extent any really systematic program of reasonably thorough and controlled test/evaluation has been undertaken for any of these or similar systems. It is conceded that sometimes system components, such as displays, are simply "played around with" and that performance evaluation may be "oriented toward flexible (perhaps, non-rigorous) evaluation techniques" (Steger, 1962).

It should not be expected that system exercising, especially simulation exercising, will be recognized and adopted because it is a good thing. Training is always regarded as a good thing but people hate to do it and it occupies a low rung on the prestige ladder. It is necessary to establish the requirements for simulation system exercising very early, when the rest of the system concepts are formulated. If this does not happen, (1) it may be assumed by those concerned with managing the developmental process that simulation system exercising is relatively unimportant, so it will get low priorities; (2) those equipments and computer programs necessary for implementing the simulation system exercising subsystem may not be ready when the system is ready for exercising. Some of these equipments, for example, must be "built into" the operational system. These include consoles, communications and computer programs for introducing the simulated inputs as well as for monitoring and recording/reducing data about the system's performance during the exercise. Other, non-built-in items may be long lead-time transducers, as well as facilities for formulating and producing the exercise inputs. Failure to include the built-in and non-built-in items among the very early requirements can result in delays in their availability when they are needed. Accordingly, the methodology for deriving system requirements can be improved by making sure that among these requirements are those for system exercising, as advised by Israel (1965).

There are four serendipitous effects of establishing a system exercising capability at the concept stage of system development. In the first place, since system exercising is directed at wartime conditions, to plan either simulation or live exercises one must examine the adversary and the actions he may take against one's own force, including those actions against one's own command and control system. So system exercising may strengthen the concept of the anti-system. In the second place, since simulation inputs are best introduced at the front end, attention is directed at the start of the information flow which the system will process. Third, one must cope with the interaction between conversion processes and noise. For example, if one wants to introduce the simulation inputs subsequent to the conversion process, in order to produce inputs as they would exist at that point one must predict what would have happened to them during the conversion. Because of the complex nature of noise and its interaction with conversion, this prediction may be difficult; and to generate simulation inputs reflecting a correct prediction may also be difficult. However, if the inputs do not represent what would have happened to noisy data during conversion, the system operators will not receive effective training, and evaluations of system performance will be most misleading. Accordingly, one may prefer to introduce the inputs at the very front end, before the conversion. The inputs, of course, must include simulations of noise, which may not be as easy to accomplish as simulation of signal. Because of this difficulty, and because of the preoccupation of data processing personnel with computers, introduction of inputs directly into the computer may receive strong support. It can be surprising how oblivious designers can get to the front end, especially if there is no requirement for continuous confrontation of the anti-system.

Finally, inclusion of system exercising among initial system concepts may have the serendipitous effect of forcing the specification of system objectives and performance criteria. These must be stated in terms which are concrete and rigorous enough that guidance will be provided to system developers and system testers. System concepts and requirements are supposed to meet fairly well-defined system objectives and performance criteria, or standards. If objectives and criteria are not appropriately available, there is a large hole in the methodology for deriving requirements. The planning of a system exercising capability may help improve the methodology by revealing or accentuating the gap, since part of the initial effort of conceptualizing a system exercising program for evaluation is the specification of system performance criteria on which to base a measurement technology. The opinion seems to be widely held that much should be done toward making such specifications earlier and better for command control systems. Although it constitutes the last of the trouble-points to be referenced in this report, the specification of system objective and performance criteria certainly is one of the most significant.

B. ENABLING CONDITIONS

As noted at the start of part III, algorithms or heuristics will not suffice to improve the methodology of deriving system requirements. If concepts for command and control systems are to be derived by humans, then one must also improve that part of methodology which, for convenience, is here called the enabling conditions. These consist of determining the appropriate kind of personnel to be included in the concept-derivation process, determining the kind of experience or schooling they should get for that particular purpose, and establishing the kind of organization which will make their efforts most successful. Concepts are produced by complex, skilled behavior called "conceiving" which is done better if better people are better trained to work better together.

1. Participation of the User

By no means would it be appropriate in this report to try to review all the necessary qualifications for joining the class of people who are entrusted with the responsibility of defining requirements or concepts for command and control systems. Rather, this discussion will focus on a single facet which has received in recent years very wide notice, namely, the notation that the using organization should participate intimately in the development of command and control systems.

The reason for concentrating on this facet is that despite a great many general statements very little has been established in the way of specifics. For example, what is meant by the "using organization"? In the Army the using organizations are supposed to be represented by a relatively new entity, U. S. Army Combat Development Command, headquartered at Fort Belvoir, Virginia. Yet in all kinds of organizations, military and civilian, operating units in the field have traditionally felt their needs could not be properly represented by any home-office group, even the ones in charge of them. At what stage of development should the using organization start to participate? At the concept stage? How intimate should the participation be, stage by stage? How much control should the using organization have over the direction in which development goes? Should its participation be merely advisory? Should it supply the initiative? Should it have a veto? Should its approval or concurrence be required step by step? Is the same kind and degree of participation best for all types of command and control systems?

What can the using organization provide that is otherwise lacking in the developmental process? In other words, why should it participate, other than because it simply might like to? Generally one or more, of several possible answers are made to this. (1) The using organization knows its needs better than anyone else. (2) The using organization knows best the environment, operational and organizational, into which the new command and control system must fit. (3) The using organization may have to adapt its structure, procedures and personnel requirements to the new system -- or make sure that the new system does not require this. (This rationale is seldom heard out loud. It is closely related to the next.) (4) The using organization is more likely to put the new system to real use if it shares in its development.

What has been asked perhaps less often is, what limits the participation which the user should have in development? Some of the answers are: (1) He is more concerned about present problems than with future ones. (2) He is likely to be too intrigued by sales pitches for new hardware and lacks the capability for screening these. (3) Along the same line, he may be more "deficiency-oriented" than he is function-oriented. He may prefer to fix an apparent malfunction rather than conduct a functional analysis which will show how improvement could be achieved on a much broader scale; in fact, he may not even understand what is involved in a functional analysis. (4) He is too busy with current operations to be able to devote enough time to planning and development. (5) His technical personnel do not exist in sufficient quantity or at high enough caliber to be able to understand complex new technology. If he makes the assumption that he does not need to understand, he makes unfortunate decisions and establishes unrealistic requirements. (6) Virtually no one within the using organization fully knows its operations, has thoroughly examined it, or understands how to convert requirements into a specification embodying a new concept. (7) The user is loath to change from previous techniques or procedures, even if new and novel ones are better, so he is unlikely to evolve these himself; he is not partial to innovation. (8) He does not have the capability of projecting into the future and understanding what must be undertaken now to satisfy future needs. (9) He is unlikely to be interested in applying a new technology whose principal effects are in fact likely to be serendipitous, that is, mostly beneficial not to the using organization but elsewhere. (10) There is insufficient continuity of command personnel within the using organization. What one commander wants, the next may not. (This, of course, is also a rationale for the so-called "evolutionary" approach.)

In one of the few attempts at probing the user participation problem, McCarn (1964) states: "In many systems now under development, the developers have been seduced by technical progress. The development of a system which extends the state of the art in military command and control has become a goal for itself. Some organizations have become convinced that, if their system will just work as advertised, they will gain the prestige of having an 'advanced' system even if it doesn't serve the command....An operating command cannot afford to guide research and development but must strive for day-to-day effectiveness. The command's desire for 'results' inevitably puts pressures on the systems developers which lead to compromise and patch work where a real advance might have been achieved." This observer adds: "The problem of defining functional requirements is the most difficult task associated with the design of military command and control systems. Almost inevitably most of the personnel operating current systems believe they are performing adequately. The definition of what can't be done which ought to be done is usually viewed as unwelcome criticism, and it is not surprising that good, functional requirements go undefined. The only requirements that really get well defined are those where a command wants to duplicate the efforts of another command or organization from which it has not received the responsive service it thinks it could provide itself. ....The control and coordination of innovation in a structure like the chain-of-command is a complex and difficult problem.

Some commands have an atmosphere which welcomes innovation and improvement, others are quite hositle to change."

Edwards (1965) comments: "No generally applicable statements exist of the requirements of military command headquarters for information systems support. Further no systematic, quantitative data are published relating to the functions of a headquarters command information system...What constitutes an improvement in a command information system? What is the quantitative measure of the improvement?"

The question remains, how should the using organization participate? Some kind of marriage or symbiosis seems essential. But just what? Too frequently the using organization and the research and development organization are unable to achieve compatible relationships. The former may feel that a research report is premature or immaterial, while the latter believes it was frustrated in collecting information on the operational scene. Various exhortations have been heard, for example; "The relations should be aimed at establishing mutual confidence as much as they should be aimed at establishing technical specifications. This often quoted and somewhat trite consideration has particular significance for command and control systems because both parties are working in the most difficult and critical areas of their respective professions" (Weiner & Taylor, 1962). McCarn (1964) suggests: "This conflict could be resolved by leaving advanced techniques development to the R&D community and also charging that community or some organization without operational responsibilities with the analysis and generalization of existing capabilities."

It seems to be generally agreed that designers and developers should try harder to find out what the user does, to learn his needs and help him specify what he thinks he wants. They should also instruct the using organization in system capabilities <u>and</u> in how to specify requirements. But uncertainty remains as to who should take the iniative? Who should write the functional descriptions? Who should then say what to do and how to do it?

Perhaps the problem of using organization participation has been better resolved for "command" systems, where the major innovations may be off-the-shelf data processors and new staff-supporting computer programs and data bases. In any case, the role of the using organization in the development of command systems has been established by a memorandum of the Secretary of Defense of October 26, 1963, which appears to give the Unified/Specified commanders primary responsibilities for such development.

Dr. Fubini has elaborated on this policy: "In a command and control situation, the commander is such an intrinsic part of the system that we have found no way of leaving him out during the development and have taken strong steps not only to bring him in but to keep him in and to put him in charge. Past methods of achieving this result by means of liaison officers have proven themselves unsatisfactory because the commander could not spare his best people for liaison with the development command. Therefore, he soon became detached from the system and the result could not help but be unsatisfactory. Now we have made the commander the central point for decisions on the system and its design. Instead of writing a set of requirements beforehand, the requirements are actually being written while the system is being developed. We are not sure whether this will be successful, but we think it will be" (Armed Forces Management, 1965).

492L is supposed to be the first application of this policy. Of course, the Air Force's Electronic Systems Division rather than Strike Command itself is actually designing the system, based on the requirements stated by the STRICOM commander. How does STRICOM generate requirements? "The great preponderance of user requirements emanate from the J-staffs to fulfill their informational needs. Most of these are valid capabilities and approved by the Command and Control Support Division. The approved requirements are then analyzed and developed into usable computer programs provided by the Development Branch. The few remaining questionable requirements are referred to the "Quad-C' for final decision..." (Armed Forces Management, 1965).

Major General O'Neill (1964) has stated the Air Force's position as follows: "Our experience demonstrates that it is understandably difficult for a major commander for whom a C&C system is being designed to provide us with the information on his operation that we must have unless we can have almost continuous access to his staff and frequent conversation with the commander himself throughout the acquisition process. By close association and participation in his exercises, we understand his problem better and we can, I believe, improve the feedback so that we can initiate promptly advanced developments which are essential for later system improvements. To strengthen our working relationships with the CINCs we intend to increase our design and management resources at the user's locale."

The Navy's approach has been explained by RAdm Lambert: "The Chief of Naval Operations has issued specific instructions concerning submission and processing of requests for command systems support from various Navy supported commands and agencies. The user is enjoined to submit his request only after considerable thought and planning. CNO also requires that each user will eventually conduct a study of his command structure so that ADP may be utilized more effectively. NAVCOSSACT is available to assist the user's staff in undertaking such studies. Active participation of the user's staff in the analysis task is also considered essential to ensure that the capability provided upon completion of the project truly reflects the needs, desires and operational experience of the command" (Data, 1965).

The foregoing commentary points up the effects which are now exerted on the specification of command and control system requirements and concepts by the organization of operational forces according to Unified and Specified Commands. Any Navy system to be generated to support directly such a command must take this structure into account. However, one is left with the question as to how the user should participate in the derivation of concepts and requirements for sensor-coupled and weapons-coupled command and control systems which are developed for service commands. These include air defense and tactical systems such as one which might be developed for anti-submarine warfare. They might also include some future system for a presently unheralded threat.

What seems to be needed is more in the way of specifics concerning the respective roles, responsibilities and procedures of developers and users.

If they must consummate a marriage, perhaps there should be a marriage manual. A guidance document of specifics might contribute significantly to improving the methodology of deriving command and control system concepts.

Along this line, Israel (1965) has suggested that "the representatives from the using command should include both planners and operators, with the balance gradually shifting to the latter as the project matures". In other words, the user's inputs should vary as the marriage proceeds on its course. He also notes the dangers of not consummating the union: "....the engineer tends to design a system which is difficult to operate or which only he can operate. (On the other hand, the operator tends either to redesign the existing system or to design a system which cannot be built.) The solution is close participation by the using command throughout the design phase. The participation must be from properly chosen personnel and their inputs must be controlled so that the design does not become merely a 'wish book' which cannot be met within the constraints of the allocated resources...."

The same writer offers some further caution: "Automated command and control has become extremely fashionable in recent years, achieving some appeal as a military status symbol" which leads to "precipitate action" that "the designer, the user, and the taxpayer may later regret".

However, making certain that the user personnel are "properly chosen" and avoiding the lures of status symbols may be just as difficult in this kind of marriage as in any other.

2. Learning the Task

To be skilled at the task of defining concepts or requirements for command and control systems, whoever attempts it, whether developer or user, must go through a learning process. He is not automatically anointed with the capability he should have simply by being designated to do the job.

Probably the best way to learn is by doing. So the best people to do the job of requirements writing would be those who have done it before, for prior command and control systems. But these are in short supply, especially within the military departments, including the Navy. Rather than resort to contractor support, it might be preferred to try to create synthetically the experience which otherwise is lacking.

Possibly some help may be derived from a performance aid, such as a checklist. Certainly these are useful for such tasks as electronic maintenance. But for complex intellectual endeavors such as deriving system concepts they would not suffice. It may be for this reason that curricula created to teach system designers sometimes incorporate courses in subjects not specific to the particular design task, such as mathematics and special techniques of operations research, such as queue theory and linear programming. These curricula may be put together by mathematicians or operations research specialists, who thereby reassure themselves that these techniques have some substantial applicability to system design. Perhaps it is hoped that if some component techniques have a scientific flavor, one is justified in believing that "information system science" is a science.

If "information system science" is indeed a science, then perhaps this science should be taught to those who are given the responsibility for designing information systems, including command and control systems. However, Davis (1964) believes it cannot be regarded as a science, at least at this point in time, nor as a profession. It would seem to be some combination of technology and art, which would require methods of teaching more closely related to generating synthetic experience than to instilling abstract knowledge.

How does one generate synthetic experience? One method is by learning about the experiences of others. In the case of command and control systems, this would require studying systems already in existence or in development or abandoned, not so much with respect to what they are or were but rather their developmental histories, the concepts with which their developments were started and what happened to them. How well have the concepts worked? Which stood the test of operational use? How did the system change? How good were predictions? What alternatives were faced? What concepts were <u>not</u> adopted? How were concepts derived?

This kind of learning, to be sure, would be directed not toward emulating what has been done in the past but toward profiting from the successes and failures of past experience. One can almost lay a claim to scientific method for this approach. A scientist who plans an experimental study is expected to investigate the literature to learn what others have done along the same line and to report how his own research differs from previous research. Even the acquisition of a scientific or engineering discipline itself can profit from investigating past endeavors. As Hall (1956) has remarked, "It would be better if the study of a section of the history of science and of the history of some engineering developments were regarded as essential in the preparation of any student of science or engineering, and if some study of the methods of application were also seriously made."

Unfortunately, very little exists in the readily available literature from which the student of the development of command and control systems could truly profit. Some material of a more or less general nature can be found in classified sources. However, it would be possible to assemble the kind of educational subject matter which would be required. In fact, the commentary in this report on "trouble-points" constitutes just such a compilation, on an illustrative and introductory scale. More comprehensive and thorough material could be gathered, although much of it would have to be classified or have a limited need-to-know. It is possible that the vanity of system developers could be adequately safeguarded by careful phrasing in presentation. It is suggested that such a compilation would provide considerable synthetic experience to those entrusted with deriving system concepts and thereby would improve the methodology for such tasks. A by-product of the use of such information might be the reduction in the amount of infallibility with which system designers sometimes endow themselves.

A second method would employ simulation. One would posit some presently unpredicted threat or presently unheralded technology that would indicate that a new command and control system might be needed. A certain amount of phantasy data would have to be created for the scenario. The individuals who were learning how to derive requirements for command and control systems would derive requirements for such a system to deal with the threat or technology. One such embedding hypothetical situation might be the emergence of a capability to control the level of the ocean selectively by geographical areas -- a situation which might appear to be within the Navy's jurisdiction. One could simulate that our side had the capability, that the adversary had it, or that both had it. It is a hypothetical situation which lends itself to some very interesting possibilities, as shown in its exploitation in science fiction (Fontenay, 1964). It could cover a wide range of requirements analysis.

Kahn and Mann (1957) have taken note of the pedagogical contribution of war-gaming, when done with actual players, in addition to the achievement of outcomes. Military leaders profit pedagogically from war games, business leaders learn from business management games. Why not let system developers learn how to conceive concepts by letting them play system development games? These could, of course, be either one-side or two-sided. In two-sided games, the adversary would be generating concepts for, among other operations, the anti-system.

3. Managing the Task

How the Navy should manage the process of deriving requirements for command and control systems is not the topic of this section. Those currently involved in its management are certainly familiar with such questions as management-by-coordination vs. centralized management, career growth of officer personnel in technical areas (advancement or kiss of death), the relative status of planners, and the recruitment and retention of competent in-house programmers. The topic of management has been introduced for two reasons. One is simply to give recognition that management of the concept derivation process is as important a methodological factor as anything else, if not more so. (Its importance in the total developmental process for command and control systems was indicated by the fact that some concentration of management functions was a major outcome of the Air Force's Winter Study Group, and also of the Navy's Summer Study, at the beginning of the present decade.)

The second reason is to put forth a management suggestion which ties in with the concept of the anti-system. It is believed that one of the difficulties in generating concepts about the adversary, in requirements studies for command and control systems, is that the same people who formulate the concepts for our system also make the predictions about what the enemy might try to do to it. This is about as satisfactory a method of representing the other side as playing a war game with oneself. It is unlikely that one will allow oneself to defeat oneself.

Instead, in any requirements study one or more of the participants could be given the responsibility of developing the concepts of the enemy forces, weapons, strategies, technologies, etc. This group's <u>sole</u> job would be to play the role of the enemy. Undivided attention to this task would remove the risk of wishful thinking and hopefully thus might raise the level of prediction. In the preceding section it was suggested that those learning how to derive concepts in a system development game might play the adversary. Here it is suggested that this kind of war gaming be extended to the concept derivation process in the development of actual command and control systems.

IV. CONTINUATION OF THE STUDY

As a third task in this study, the contractors were asked to make recommendations concerning its continuation.

It is proposed that the Office of Naval Research continue the study in-house by further collection of information about trouble-points in command and control systems originating from the concepts on which the systems were based. This information would be similar to the material in part III of this report. Analysis in depth similar to that in Appendix III should be undertaken for as many trouble-points as possible.

The material assembled need not be published in report form. Some of it may be classified, some rather sensitive from the point of view of those who originated the concepts or system requirements. However, the material should be made available to Navy personnel who will be engaged in developing the conceptual frameworks of future Navy command and control systems. The Office of Naval Research might also desire to make it available to other military departments and possibly even to contractors whose access was requested by the Office of the Secretary of Defense, through the Director of Defense Research and Engineering. If this were to occur, the Office of Naval Research would then be maintaining a central facility or repository of research in the development of command and control systems. It might also become a valuable support item for the Department of Defense Computer Institute already being operated by the Navy for the entire Department of Defense.

One way to look at such a continuation of the study would be to regard it as a modest, on-going Summer Study (the intensive examination of Navy command and control systems conducted in 1961) and Winter Study (the intensive examination of Air Force command and control systems in 1959-60) but embracing all command and control systems. These studies provided useful information for persons given the responsibility for formulating future systems, but their findings, some of which were not made widely available, have not been updated. However, the very fact that they were made suggests the value of the "trouble-point" approach, since to a considerable extent this was their approach, extending to be sure, beyond the concept or requirements derivation stage of system development.

With such a continuation, improvement in the methodology of deriving system requirements would be a living process. Contributions to that methodology from the other participants in the present study, and possible future contributions similar in nature, could also be important aids to system developers in an ONR Center of Command and Control System Research.

APPENDIX I

SOME IMPLICATIONS FROM NON-MILITARY ORGANIZATIONS FOR COMMAND AND CONTROL SYSTEM CONCEPTS

Command and control systems may be regarded as one of many classes of large and complex aggregates organized for some purpose. Some of these which are not command and control systems exist within the military world -- examples include a Naval ship, a Navy research agency or the Navy Department itself. Most of them are non-military and pervade our governmental, business, industrial, educational, religious, cultural, scientific, entertainment, etc., milieus.

The fact that all such organized, purposeful aggregates, including command and control systems, have some resemblance to each other, in that they are large, complex, organized and purposeful, should hardly seem surprising to anyone, nor should it lead to poetic transfers of the "command and control" label to all or any of the other classes. Without doing violence to nomenclature, however, it is possible to examine command and control systems to see whether anything learned from their creation might be applied constructively to other types of aggregates. This has been done on occasion, although the target seems to have been, almost exclusively, business management. It is also possible to examine the other types of aggregates to see whether anything about their operations might be applied constructively to concepts underlying the class called command and control systems.

This has been done seldom, if ever. The insight that it might prove fruitful came from the study's ONR Scientific Officer, and an exploratory venture in this direction follows. Rather than looking at what to many might seem the most obvious analog of command and control systems in the non-military world, namely, business or industrial management, this exploration deals with two classes of organization which have not commonly been likened to command and control systems but which grapple with two of the major responsibilities of such systems, in one case the acquisition and use of information, in the other the countering of an adversary.

1. A Daily Newspaper

Before there were computers, a large daily newspaper like the Washington Post or the New York Times could be regarded as the biggest information system or biggest information-processing system in existence, in terms of the amount of information processed per unit time. According to some criteria, such as variety of "meaning" and multiplicity of data sources and recipients, this characterization would still be true.

a. Reporting

How does news get reported, that is, how are the data gathered? One source is the reporter, who works for the newspaper itself or for a wire service, which may be a national agency, a specialized agency (e.g., science) or a local agency. The reporter may get his information first-hand (by direct observation and listening) or by interview or verbal report of participants or observers. He may write the report himself, either when he returns to his desk or before filing it by wire, telephone or mail. He may telephone the data to a rewrite man who actually writes the report. Data may come from "releases" made available to the reporter or sent to the newspaper. Editors or the reporter himself may select what should be reported on. A copy desk performs a quality assurance review of the finished report, to improve style, clarity and accuracy as well as create the accompanying headlines. The result is a remarkable amount of information generated at great speed, with a degree of accuracy which is not always ideal but which is also remarkable in view of the extent of data and speed of human processing.

A reporter does not report every bit of information he acquires. This would be impossible as well as futile; it could not be transmitted or printed and would not be read. So he filters. He operates with certain criteria concerned with newness of the data, significance of the data, and presumed reader interest. These criteria differ considerably among reporters, as among newspapers, partly because they cannot be clearly specified. Nevertheless, the filtering function goes on, and it is largely the reporter's job to do it, although a number of editors may also have a hand in it, with or without the reporter's agreement. Generally there is agreement because the reporter and his editors acquire the same criteria.

The reporter also formats the report to some extent, in that he follows a general rule to specify "who, when, where, how, why", and in that he first summarizes the report (the "lead"), then writes the report in increasing detail, and orders the component items in importance according to the criteria noted above. He tries to write in a way which will make the report clear and interesting, so it will be read. He must be concise and he must write fast -- fast enough to produce at least 2000 words per hour, in finished form.

The newspaper is published at fixed intervals, but the reports are not necessarily written or sent in at fixed intervals, for example, just before deadlines. The length of a report varies according to the amount and value of "news" in it, rather than on some standard basis. Reoccurring events are not regularly reported in the same fashion. A report is generated "by exception", that is, when something new and different occurs.

A reporter's skills are acquired generally from experience on the job, especially the skills of speed, clarity and conciseness of writing, of filtering in accordance with learned criteria, and of knowing how to seek out the news rather than let it come to him. (Sophistication about intricate substantive areas is not expected of the average reporter, although journalism schools attempt to provide some understanding. Such schools do not graduate reporters possessing the critical skills, although the graduates may know what they are and this knowledge may help their acquisition on the job.)

One characteristic certain types of command and control systems have in common with a daily newspaper--is the preparation at remote data collection points of large numbers of verbal messages which are transmitted to the central, computer-based headquarters. A frequent complaint is that there are intolerable time lags between the occurrence of the events or situations reported and the arrival of the report at the headquarters. One reason for the delay is the amount of time required to write the report. Another is the overloading of transmission channels because there are too many superfluous reports or details and the writing is not compact. Superfluities are equivalent to noise in the system.

Apparently a daily newspaper gets around these kinds of problems by substituting for fixed requirements a flexibility of requirements which gives considerable responsibility to the data gatherer/report writer and which filters out the noise at the source through the medium of trained operators. Reports are generated "by exception" and "on demand".

What is implied is that in creating the conceptual design of a command and control system, considerable attention should be given to the human data collectors and writers of reports, to their selection and training, and to the extent of responsibility and autonomy with which they should operate. Any risk of occasionally not getting important information because the agent at the source failed to report it should be balanced against the probability that large quantities of information will arrive too late to be useful.

Still another question is whether reports arriving at a command and control system center should be readable. Certainly the same requirements do not exist as those for attracting the interest and persistent perusal of a newspaper reader. Also, the contents of many military reports must, by the nature of their contents, be prosaic. Nevertheless, it is possible that top commanders may be more inclined to read important incoming reports if their language has what the Federal Departments call a low "fog index".

b. Correlation

In the operations of a daily metropolitan newspaper's surveillance subsystem, a particular news report may not emanate from just one reportorial source. Components of the story may be furnished by several reporters, by news agencies, by press releases, and by extracts from stored memory -- the clippings of earlier stories and reference documents in the "morgue". The total story, which may concern a military campaign, a hurricane, a large fire, a kidnapping or a diplomatic maneuver, is actually written by a rewrite man. He must track the thread of fast-breaking events through a welter of incoming reports, some conflicting with each other and some of only peripheral importance. In addition to organizing the big story, he must correlate reports against each other to determine which are the most recent and credible. An expert rewrite man can turn out a fantastic amount of well-correlated and filtered copy at great speed.

Without this kind of operation the pages of a newspaper would contain a number of separate reports covering the same ground, and the reader would be hard put to identify and classify the "signals", that is, the actual events or their most probable representations. This kind of rewrite operation is a data correlation function.

Some command and control systems have similar requirements for data correlation -- cross-comparisons of data from multiple sources to estimate the probability of signal as opposed to noise. Optimization may be accomplished best by means of a symbiosis between computer programs and human interpretation. Anti-submarine warfare is a case in point. However, the need for optimizing this kind of function may not be fully recognized when the system concepts are being derived. It is necessary, after all, first to create effective surveillance media, or one has nothing. But from at as early a stage in system design as possible one should also worry about their interfaces and establish the design concepts for data correlation.

2. A Labor Union

Unions and employers have many goals in common but others which compete. There is an ongoing cold conflict and sometimes a hot conflict which is variously known as employer trouble, or labor trouble, or a strike. There are limited conflicts and big-bang conflicts. Each side attemps to strengthen itself, tactically and strategically, and to weaken the other.

a. Backup Requirements

At lower leadership levels in labor unions the leaders are personnel who are also employees of the industrial organization in which their union component is situated, rather than organizers or executives working solely for the union. These people may be shop stewards, unit chairmen, shop paper editors, unit treasurers or similar volunteer officers. The vigor of the union component depends on their endeavors.

A conventional employer strategy for weakening the union is to enfeeble the local leadership. An employer has considerable power in this respect, because, within constraints imposed on some employers by government and by the union itself, the employer can hire and fire. One tactic for enfeebling the lower level leadership is to separate one or more of the leaders from the payroll. This tactic constitutes a familiar origin of strikes, wildcat or authorized. However, the union's preferred counter-tactic is preventive. The union tries to harden its position by negotiating into the collective bargaining contract guarantees for continued employment of its shop stewards as well as clarification of their permitted activities on company property and time to forestall rationales for dismissal.

The union's success at this tactic may generate such complacency that it fails to train additional members as local leadership backup. To its chagrin it may discover that the employer has many tactics to his bow of strategy of enfeebling the on-site leadership. One tactic is to infiltrate that leadership with employer agents. Vacancies result if they are discovered. Another tactic is through promotions or transfers to move some of the leaders into other jobs which they prefer but in which they can no longer be union leaders, because of either ineligibility or inaccessibility. This can be a wonderfully effective tactic if the union has not made provisions for backup.

One reason why the union management may fail to make such provision is that it has not suspected that this tactic might be employed. And one reason why it may not have so suspected is that the union cannot exercise the same tactic against its adversary, the employer. It cannot promote or transfer employer administrators or executives who are giving it trouble.

There's a lesson here for the design of command and control systems, of course -- in fact, a double lesson. In establishing the concepts for such a system, one should not limit one's expectations of enemy tactics to the tactics used by one's own forces (as France, for example, discovered in 1940 in spite of de Gaulle's earlier warnings about armored and mobile war). A command and control system for air defense of the North American continent should not assume that an attacking bomber force would use the tactics favored by the Strategic Air Command. A command and control system for anti-submarine warfare should not be conceptualized on the assumption that Soviet submarines will be deployed and maneuvered in the same way as United States submarines.

In the second place, because the unexpected is certain to occur, there will always be attrition which was also not expected. So in command and control systems there must always be backup. This must consist of more than just a designation. Backup must be prepared. People must be trained. Information must be available to the backup facility and its personnel to enable them to take over the function of the primary center when it goes out of business. Perhaps most important, procedures must be ready for the transfer of responsibility, and commanders and staffs must be trained through exercises for handling such transfer.

In designing a command and control system for anti-submarine warfare, for example, it must not be presumed that the carrier in the task force will never be sunk. On the chance that it might be, the system concepts should include those which assure that the tracking and pursuit of a detected hostile submarine can be assumed by another ship in the task force, or by another task force. Also, since the unexpected event and the resultant attrition are not always enemy-instigated, any computerized capability (such as NTDS) should be backed up by a manual capability. Again, this means more than mere designation. It means transfer procedures, data availability and training.

b. Feedback Requirements

Whenever two organizations are in hot conflict, such as a labor union and an employer, each requires an effective damage assessment program for ongoing cost/effectiveness, or cost/benefit, analyses. During a strike the employer wants to know how strongly the union members and leaders feel about its continuation. He may obtain some estimate from employee balloting. Also, to some extent the employer can gauge the damage being suffered on the part of the union by means of the number of defectors who cross the picket line and re-enter the plant. Also, the employer may have friendly elements within the union to provide intelligence. The union also wants to know how strongly the employer feel about continuation but similar sources of information are not reciprocally available. So it tries to sense the employer's determination by probes at a bargaining session, by deductions concerning the amount of damage inflicted and by assessing community reactions and pressures.

In any case, each antagonist tries to assess the damage being suffered by the other, as military antagonists also do. The task is neither trivial nor easy for a military agency to accomplish, especially where the adversary is a closed society, such as the Soviet Union, in contrast to the relative openness of the American system.

However, it must be done. Command and control systems which control weapons must have feedback loops designed into them to detect, report and assess the damage inflicted both on the enemy and by the enemy on one's own forces. Such systems must also include concepts for rapid redeployment of forces as a consequence of the feedback. How to achieve damage assessment in a contest with a "closed"adversary can be a real challenge to the system designer. He may obtain some insights by investigating how this is done in similar, non-military situations.

APPENDIX II

SOME MANIFESTATIONS OF COMMAND AND CONTROL AS A CONTEMPORARY CONCEPT

The command and control of military forces is an art that has been practiced for centuries. This is not to say, however, that the military has always had "Command and Control". "Command and Control" is a contemporary concept which was conceived with the advent of the digital computer and which offered, as its basic ingredient, the ability to process information. As such, "Command and Control" did not present itself as a means of commanding and controlling military forces, but rather as a means of performing certain related information processing functions.

Since its inception, however, the meaning of "Command and Control" has been expanded until it now assumes the proportions of a basic science which, at the minimum, encompasses all facets of military activities.

The danger in this approach lies in the naturally related belief that "Command and Control" is a super science offering a discrete and cohesive body of knowledge that can be applied in toto to the multitude of problems that have been grouped together under its auspicious cloak.

No argument is held with treating related activities as a body of things for there is an always present need to evaluate the attendant interactions and potential duplications of effort, thus avoiding the inefficiencies which derive from a compartmentalized approach. The "Command and Control" field, however, is becoming unduly large for there is a growing tendency to apply the term "Command and Control" to essentially everything new on the military scene. The term is much in vogue, and any process can be said to effect or support a command or control function.

It is this attitude that this paper addresses, for the tendency for "Command and Control" to assume an all pervasive, single-science form is causing a shift in viewpoint which is masking the differences in the separate kinds of capabilities necessary to a military system, thus clouding the analysis of future military requirements and, at the same time, leaving unsatisfied needs which are basic to serving "Command and Control's" original purpose.

When the digital computer was developed, it didn't take long for people to recognize the potential that the computer had to offer. Large amounts of data could be stored and rapidly retrieved in a selective way. These data could be correlated in essentially an unlimited number of ways and the results immediately made available to the person or equipment requiring such information. We had attained the ability to handle and process quantities of data that previously had not been possible by manual means. The significance of this to the military was enormous. Information could now be made available which could take into account any significant variable.

The Air Force "L" systems, (air defense; ballistic missile surveillance; weather forecasting; the command of air and unified forces, communications control, and electromagnetic reconnaissance) came into being. Other national and tactical command, control, and logistics management systems followed to avail themselves of this new way of handling and processing data. It is difficult to ascertain exactly when these kinds of capabilities assumed "Command and Control" status. Certainly by the time the Winter Study Group commenced its activities in late 1959 the term "Command and Control" was in wide-spread use.

One of the early problems faced by the Winter Study Group was the heterogeneous nature of those capabilities which had been grouped together under the common heading, "Command and Control." Since so many different kinds of capabilities are represented by the term, it is useful, and necessary before going further, to develop a way of looking at these differences. Before doing so, however, it is important to place "Command and Control" into context insofar as the role such systems play in overall military operations. Military operations are considered to comprise the following general functions:

- Obtain required information
- Decide
- Take Action

Within this framework, "Command and Control" systems are considered as having the mission indicated below:

Obtain Requisite Data, Analyze the Data, and Make Recommendations.	"Command and Control" System
Decide	Command Authority
Take Action	The Troops and their Weapons

A command and control system is considered to include both the equipment and the men which operate together to perform the indicated functions. One point is emphasized: while the command and control system doesn't "decide", it may, operating in accordance with previously decided on procedures, issue orders directly affecting the action elements. This is a relatively important consideration, for it is this aspect of command and control system operation which gives rise to the belief that command and control systems engage in decision making. A command and control system may implement a decision process; but it can do so only if it has been given authority by an appropriate command authority, and, more important, only if the procedures it is to follow have been carefully spelled out. These conditions must prevail before a "Command and Control" system can command or control anything. There is a potentially huge difference between what a command and control system does and the purpose it supports.

Any given command and control system may be considered to be engaged in two general types of activities, analysis and file keeping. Both of these activities carry with them the requirement that data be made available to provide the basis for analysis. Lest the term "analysis" be misunderstood, the kinds of analysis that may be performed include those which are directed toward the following functions:

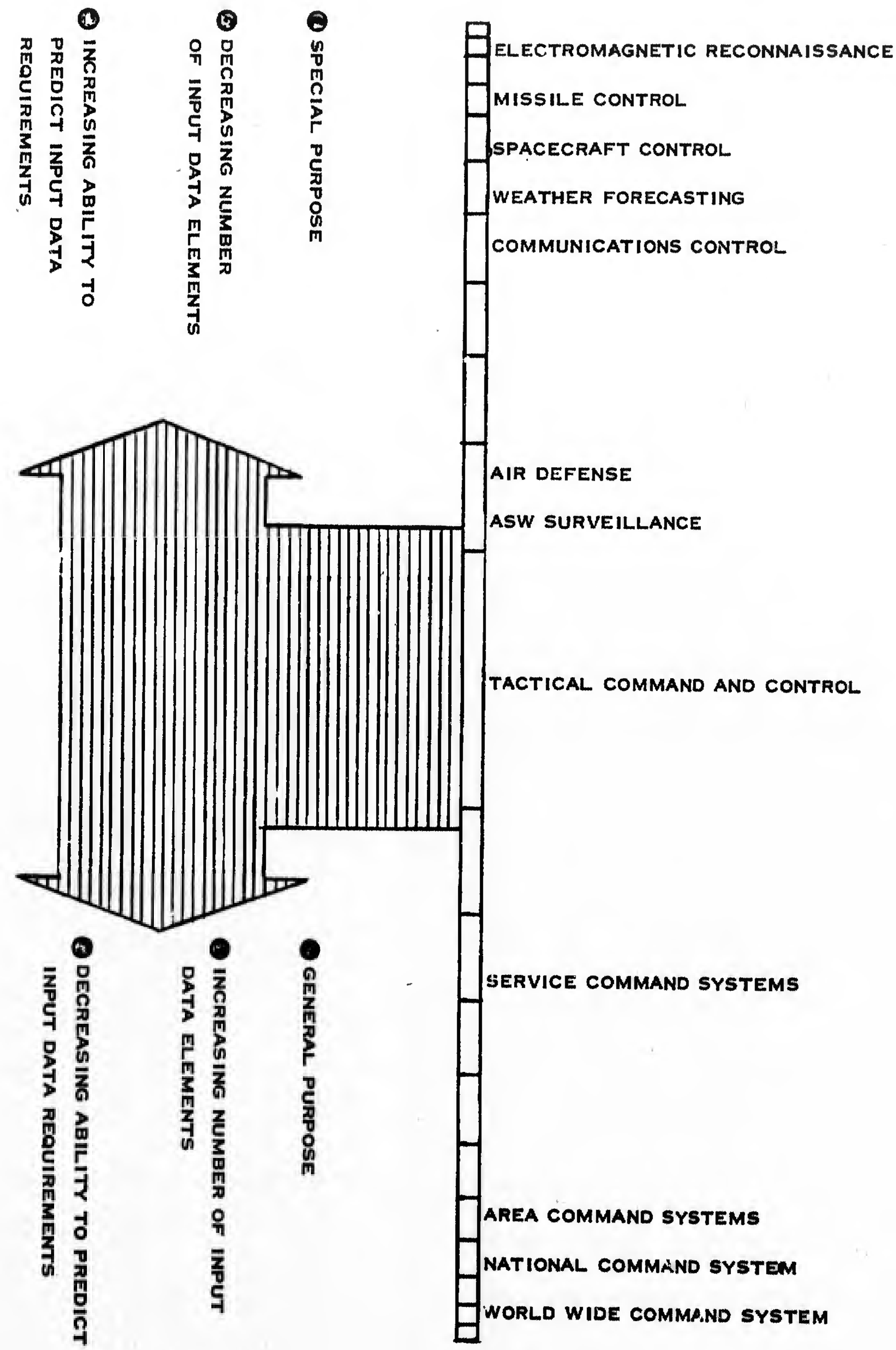
- Weapon Control
- Equipment Control
- Inventory Control
- Targeting
- Weather Forecasting
- Force Selection

Weapons Effects Determination	Intelligence Requirements Determination
Logistics Requirements Determination	Tactics Determination

If command and control systems are examined in the context which has been described above, two significant variants are exhibited. These variants, while not mutually independent, are useful for purposes of gross differentiation of the characteristics of command and control systems. They are:

1. The number of different input data elements required.
2. The degree to which the input requirements can be determined.

Using these variants as criteria, a spectrum of command and control capabilities can be fashioned. As indicated in the figure on the following page, capabilities falling to the left in the spectrum are, in general, "special purpose" capabilities which deal with a relatively small number of identifiable input data elements. Those capabilities falling to the right in the spectrum are, in general, "general purpose" capabilities which are required to deal with a large number of different input data elements whose separate significance cannot be predicted. As such, to the left in the spectrum would be those capabilities whose purpose is the control of a particular weapon or equipment, or the sensing of a particular aspect of the environment; to the right, capabilities such as the National Military Command System (NMCS); and near the center, those capabilities which included elements of both spectrum extremes. This spectrum is not intended to suggest a range of difficulty. Rather, it represents a range in terms of the <u>kind</u>



COMMAND AND CONTROL CAPABILITY SPECTRUM

of problem presented. Two words come to mind which, if their meanings are stretched somewhat, are useful in describing the basic difference in the kinds of problems represented by the spectrum extremes. These are "intricacy" and "complexity". Intricacy implies such interlacing of parts that, despite one's ability to separately identify the parts, interaction occurs in a way so entangled that it is almost impossible to follow the process. Complexity, on the other hand, suggests far more of the notion of uncertainty as to what the active elements are. Thus, to the left in the spectrum is the weapon control capability, which, relative to the command system, is concerned with a mere handful of parameters of input data but is plagued by the difficulty of correlating the implications of these data. To the right in the spectrum is the command system which has a seemingly less rigorous task but a greater uncertainty as to the significance of data which is potentially available to it. In the center of the spectrum, perhaps is the tactical command and control system which "enjoys" both kinds of problems, but not necessarily to a lesser degree.

The inferences to be drawn from this spectrum are:

1. Some command and control capabilities are special-purpose capabilities that have little in common except that data handling and processing, in some form, is involved.
2. Some command and control capabilities are general-purpose capabilities that share the problem of uncertainty of data needs.

3. Some command and control capabilities are, in part, general-purpose and, in part, special-purpose capabilities.

In reviewing the history of the special-purpose class of systems, little can be deduced of any real value in determining an "optimum" technical approach. Some of the tools may be the same, but the problem differs. In looking back on the history of command system development, however, a pattern seems to appear. It looks something like the following:

1. The need to provide the commander with more information coupled with the applicability of the digital computer to fulfilling this need was recognized and development was initiated.
2. It was learned that designing and building a given command system was a lot harder and more expensive than one might have expected.
3. A disappointing level of capability was achieved.
4. "Command system" assumed a meaning transcending the original purpose of the systems it had been applied to. The commander became an integral part of the process, and words such as "decision-making" came into general use.

Other factors were, of course, present. It seems, however, that we set out to do a better job of providing information to the commander, didn't do it very well, and found the attempt extremely expensive and time consuming. We have now somehow succeeded in redefining the problem so as to make the commander a part of the problem, and have reduced the emphasis on the essence of the original goal of a command system--providing information to the commander. This is not to suggest a limiting definition of "command system," but rather that this aspect of the command system problem is paramount, for regardless of how the reader may picture a command system, it presents a fairly dismal prospect without information.

Where have we been deficient in responding to this need? The means of accomplishing machine processing, both hardware and software, have improved markedly in the past few years. If this was once the problem, it probably isn't now. Communications? Not apparently, at least. Recent exercises and actual tension situations wherein communications facilities were stressed appear to speak well for our ability to communicate. Problems do exist in this area, but ability to communicate doesn't seem to be the overriding factor, at least not now. Displays? Output devices? Data Storage? None of these, taken singly or in combination represent overriding constraints. Our equipment technology needs improving but it's already good.

What then, is the problem? Perhaps it has to do with too large a share of the emphasis having been placed on the ways of communicating, processing and using the data and not nearly enough emphasis on the data itself. As compared to other accomplishments, how much is really known about the "data" the basic commodity with which a command system is concerned? One may be inclined to state that this problem has been addressed; that there has been a continual effort to determine what data the commander requires. This approach, however, is not likely to succeed. The commander cannot, in any depth, anticipate his information needs. Thus, of course, he cannot describe them. In any event, wasn't it the implied promise that any data of significance would be available for consideration?

It was suggested earlier that a command system present itself as a "general-purpose" capability. As such, it should have the ability to sense any aspect of its environment. The applicability of this command-system attribute seems to be reinforced by our inability to make the command system assume "special-purpose" properties by ascertaining the commander's complete and specific data needs. If then, the problem which presents itself is one of fashioning a means of developing a "general-purpose data sensor," would it not be desirable to develop a general-purpose way of looking at the data environment in its entirety? What kinds of data are there? Where are the best places to obtain these data? What are the best ways to obtain these data? What are the basic concepts which should guide the selection of "where" and "how" to obtain these data? Seemingly, finding answers to these questions presents problems; but until the general subject of "obtaining data" is understood far better than it is now, it is not clear that it is possible to achieve an effective command system capability or to really know how to go about creating one. To achieve the required degree of understanding would entail effort in the following three areas:

WHAT DATA? Accomplishing an orderly understanding of the kinds of data there are. This is not to suggest a process wherein each separate data element would be identified, but rather a process which would reveal, for example, that there are things to be known about major equipments, and that the classes of data one may obtain relative to major equipments may be "operational status," "performance characteristics," "configurations," etc.

WHERE TO GET THE DATA? Determining the best places to obtain these data, considering, where applicable, variations in summation levels. What would be important here would be the development of basic concepts which would guide the choice of "where" to go to get the data. Would a concept wherein data was obtained from the lowest level data summary point be workable? And would this concept, if appropriately tied to a data-on-demand concept of obtaining the data, remove in substantial part reporting burdens that currently exist while at the same time increase the effective knowledgeability of the command staff? These are the kinds of questions that this problem area poses.

HOW TO GET THE DATA. Determining "how" to obtain the data was touched on above. Efforts in this area should have the greatest impact on the particular way in which the future command system is configured. Is our current concept of a data base open to question? Should the primary role of the computer be one of determining "where" to go to get the data and only in isolated instances would this "where" be its own memory? Should data received from an external source always or sometimes or never be entered into the computer memory before being made available? These, and other similar questions, depend in large part for their answers on what has been learned in addressing the first two work areas: determining what kinds of data there are, and where the data should be obtained.

In summary, this paper has suggested that perhaps "Command and Control" has suffered by trying to be too much. It has tended to assume an almost panacea-like scientific quality when actually no science exists. Problems exist, mundane ones perhaps, but nevertheless important, and their identification and their solutions may depend on the assumption of a somewhat less grandiose notion of what "Command and Control" purports to accomplish.

APPENDIX III

EFFECTS OF INTERACTIONS BETWEEN NOISE AND DATA CONVERSIONS AT INTERFACES BETWEEN FUNCTIONS

Among the "trouble-points" to which particular attention must be given in creating concepts for command and control systems are the interfaces between the functions described in "The Functional Structure of the Military Process." A particular source of potential trouble lies in the interaction between the "noise" which intrudes and the conversions performed on the data. Perhaps one reason why one should worry about this particular trouble-point is that it is little understood and rarely emphasized, partly because it is situated at interfaces, partly because "noise" is an unpleasant topic for system designers. Accordingly, it is analyzed below in some detail.

One of the interfaces where this interaction can occur is that between sensing and analysis. Discussion of the effects of noise on information flow through this interface will be followed by a description of the conversion process which characterizes the interface. Then an attempt will be made to explain the interaction which occurs between the two. It would be useful similarly to examine the interface between decision-making and action but this will not be undertaken at this time.

In military operations two of the most-used sensing elements are radars and humans. The former yield radar signals, while the latter produce verbal messages. In each case the output (signals and messages) may fail to represent faithfully whatever it was desired to sense, and such failure may be attributed to a set of accompanying phenomena which can be characterized as "noise". Further, in each case the output may have to be transformed or converted so as to be suitable for analysis, i.e., processing by electronic or human data processors. Finally, as suggested above, there may be an interaction between the noise and the conversion operation such that the input to the processor becomes even less faithful to the external actuality.

A. The Radar Case

Let us look first at some length at the radar case, since it may generate some insights later about the human parallel. One can visualize an anti-air warfare or air defense situation where the radar is being employed to detect hostile bombers, although other uses of radar can be imagined -- for example, anti-ballistic missile defense or submarine detection. Radars are the principal sensors for many command and control systems. What must be realized, no matter how distasteful it may seem, is that wherever there's a radar there's noise, and it's worst in wartime.

1. Noise

One can talk of three kinds of noise: enemy-made (jamming, chaff, decoys, etc.); self-made (internal, mutual interference); and nature-made (weather, land or sea return, aurora borealis). A number of different effects can result. (1) Some number of signals are received which are virtually indistinguishable from the signal of the aircraft. (2) Some aspect of the aircraft signal is distorted or eliminated. For example, although its azimuth may be still ascertainable, the precision of that azimuth may be reduced, and even more important, its range may be "denied", that is, a series of noise inputs along the same azimuth may make it impossible to distinguish its distance from the radar; the time interval between transmission of the radar pulse and reception of its "echo" from the aircraft is no longer ascertainable because other inputs (noise) are arriving during and after that interval from the same direction. (3) Finally, a very large number of noise signals, with high power, may arrive at the radar. (These can even saturate the circuits in the radar receiver.)

Various electronic techniques are employed to try to counteract these noise effects. Some are directed toward emphasizing those subtle electronic characteristics which often do differentiate aircraft signals from noise, when the latter consists of certain varieties. Others simply reduce the amplification in the circuits, to diminish the strength of all inputs, hopefully eliminating the noise and not the aircraft signals. However, these techniques do not always work well. Also, enemy noisemakers are continually inventing new counter-counter-countermeasures. And given enough power, an enemy noisemaker can foil any technique.

2. Conversion

For processing in a computer-based system, radar signals must be converted to digital form for input into a digital computer via some kind of capacity-limited digital data link from the radar location to the computer location. The converting equipment, located at the radar, represents the interface between sensing and analysis (processing) elements. Its capacity inevitably also has certain limits. Its significance has seldom been fully appreciated.

The data which go from converter into link and then to computer consist of positional information about the signal, such as its azimuth and range (and from heightfinding radars, altitude). These are simply binary numbers.

The converter must determine what aggregate of radar returns constitutes an aircraft signal, by some kind of correlation process, unless this has already been accomplished by equipment in the radar receiver. The signal has some azimuthal width, so the converter must estimate the center, which then becomes the transmitted azimuth. There has to be some limit on the number of different azimuths which can be allocated, that is, the target center must be located inside one of a finite and specified number of directional subdivisions. The converter must also generate a digital representation of range (again, a binary number). For this purpose the coverage of the radar has to be divided into a finite and specified number of range subdivisions or "boxes".

The process of analog-to-digital conversion crudely outlined above for azimuth and range data is a familiar one to electronic engineers. No expertness is claimed concerning its details. However, there may be some value in rendering a layman's interpretation of that process.

One could say it is composed of four sub-processes, each of which is essential to the final outcome, so the four are, in a sense, inextricable from each other in actual machine operations. although they can be verbally distinguished. First, an aggregate of radar returns has to be isolated as constituting returns which belong together, i.e., from the same airborne object. Second, some central point in this aggregate must be established for designation purposes. Third, this designation point must be given a location within the total region of all possible location points. The domain must be subdivided into some kind of mosaic or matrix or grid of area components -- call them granules or lots or whatever you wish -- into one of which the designation point must be placed. The size of the granule or lot helps determine the precision of placement, of course; but the overall precision of position depends also on the accuracy and precision of prior processes. This process of subdivision and placement is called "quantization". Finally, each granule or lot is given a name, a quantitative name, that is, a pair of numbers from a system of coordinates. These numbers or digits are based on a binary system if they are destined to be transmitted to a computer designed to handle binary digits. For each coordinate the maximum, which establishes the granularity of quantization (how finely any designation point can be positioned), will be some power of 2. The translation or "coding" of the position of the designation point into binary digits, by giving it the digital name of the coordinate location of the granule in which it has been placed, constitutes the fourth and last of the sub-processes of analog to digital conversion. The data have now been digitized.

Without going into technical details, it must be pointed out that an important aspect of the combined quantization and coding sub-processes, and one which is inevitable in any analog to digital conversion equipment, is the imposition of some limit on the total number of signals which can go from radar to computer. This limitation on data flow through the sensing-analysis interface depends on the capacities of the computer, converter and data link between them.

The computer takes the digitized positional information and manipulates it in various ways. One outcome may be its representation on a display. If all the computer has received are binary numbers for range and azimuth, for each target, it may simply display a symbol, such as a dot, at the specified position -- for each target. In other words, every indicator of every radar target is the same -- a dot. (Later the computer may supplement or change the symbol, based on additional information which comes out of computer processing of the track.) The operator at the display "detects" an aircraft signal when he discriminates a track, that is, when two or more dots form a line. The computer may estimate course and speed from the positional information represented by adjoining or successive dots.

Human data processing can also occur prior to, or in the absence of, any computer data processing. At the radar the signals may be converted to a display on a CRT, in an analog presentation. In this transformation or conversion process, the direction or azimuth of the signal from the center of the scope represents the direction or azimuth of the aircraft when the rotating radar antenna illuminates it. The distance from the display center represents the time interval between pulse transmission and return of the "echo", that is, the range. The size and form of the "blip" -- the displayed aircraft signal -- may represent various parameters of the electronic signal and the individual returns which comprise it.

The transformation or conversion process is initiated by this visual presentation of the radar data and completed by what the human observer does with the data. The human determines what returns constitute an aggregate defining a target by correlating returns with each other; he does this by inspecting the patterning and contrast of the aggregate called the blip. The human selects the designation point within that pattern. The human quantizes the position, often aided by azimuth markers and range rings, by interpolating between reference lines. Finally, the human codes (names) the designation position; he is more than likely to use a decimal-based number system. As in the machine operations described earlier, these component processes are verbally distinguishable but seemingly inextricable from each other, especially the two processes of quantizing and coding or naming.

3. Noise-Conversion Interaction

What happens when noise is added to signal in the conversion process? Consider first conversion from analog to digital form for computer data processing. There are several different eventualities, all of them unfortunate.

(1) If an aggregate of noise cannot be differentiated by the converter (or radar receiver) from an aircraft signal, it will be transformed just like an aircraft signal would be transformed, and will then be represented by the computer as such through the same symbol.

(2) If noise is received by the radar along the same azimuth as that of the aircraft signal, the latter may then in effect, acquire a number of different ranges, with the result that the converter may designate a number of aggregates of noise along that azimuth as aircraft signals. The computer will then represent them all as aircraft, with no indication as to which is the real one.

(3) If a large quantity of noise arrives in the converter via the radar the conversion capacities of the converter and the transmission capacity of the data link may be overloaded. This overlaod may then result in a random exclusion or rejection of signals, those actually from aircraft as well as those produced by noise. The computer will not receive or display such "lost" aircraft signals.

Accordingly, what can happen is that the computer may receive, store and display some amount of noise as though it were aircraft, and it may not receive, store or display all aircraft signals. Let us remember that a computer-associated console operator can identify a dot as actually representing an aircraft only if a series of dots lines up to represent an aircraft's path. But if some or many of the dots are missing from the series, and if there are other dots all around, the operator may find it difficult or impossible to discriminate the path pattern. Accordingly, he may not know which is the aircraft, or he may not know there is an aircraft there at all. Nor may the computer find it easy to calculate accurately its course or speed, that is, to track. There are, of course, measures to take against such developments. One is to reduce, in one fashion or another, the total amount of input to the converter. This would prevent the overload which results in random loss of aircraft targets. However, there's always the chance that the methods of reducing that input will also cause a loss of targets in that input, so one has merely accomplished the same unfortunate result in an earlier stage. Further, if the input is reduced so there is little or no noise entering the converter, and the target is also lost, no data at all will reach the computer. Then the operator there does not even have noise-occasioned data to tell him there is a target somewhere in the vicinity. So human data processing which follows computer data processing involving noise inputs may not be able to resolve the problems which emanate from the automatic conversion process.

Human data processing prior to, or in the absence of, computer data processing can also be degraded by the interaction between noise and the conversion process. However, in the PPI-operator conversion there is a difference. The size, form and contrast of the aircraft signal's representation on the operator's scope, the blip, may significantly help the operator discriminate it from noise. He "reads through" noise to distinguish the aircraft blip. He does not necessarily require a sequence of aircraft signals to be able to make a detection; a single blip may suffice. Further, an operator may be able to estimate course and speed even when a highly degraded pattern of signals is mixed with noise.

What happens is that the human being's remarkable capability for pattern recognition is exploited. In the presence of extensive noise, this capability assumes greater significance in the trade-off against the human's relatively inadequate capacity to convert large numbers of signals, that is, his quantitative limitations.

Human discrimination to counteract the effects of the noise-conversion interaction can be improved through training. Even where noise does look very much like an aircraft signal, operators can learn to recognize subtle visual characteristics which differentiate them. Human engineering design of display features may also help. Personnel can be selected who are good at this sort of thing, and system performance may be improved if more than one person is assigned to the same task. Human discrimination can also be influenced by motivational factors, e.g., emphasizing the risk of classifying noise as target vs. emphasizing the risk of classifying target as noise, or emphasizing the benefit of detecting all targets (including some noise) vs. emphasizing the benefit of rejecting all noise (including some targets).

What this analysis of radar sensing has shown is that automatic conversion of radar signals to digital form for computer processing can result in a serious information problem when noise accompanies these signals. Information is lost or false information is added. Without noise the problem does not arise, or at least it does not become serious. When there is noise, but with a conversion process which exploits human pattern recognition before computer processing, the problem arises but may be easier to solve than it is with automatic conversion techniques Less information may be lost, and less false information may be introduced.

The lesson seems to be that in a noisy environment the method of conversion in the interface between sensing and processing can be critical. It deserves much more attention than it has received in the concepts for command and control systems. In reacting to the lure of automaticity and high data rates, those who have developed the concepts for such systems have neglected the problem of the interaction between noise and conversion. Human intervention has been introduced to rescue the computer, but long <u>after</u> the conversion process has been accomplished. It should be introduced instead into the conversion process itself. How to do this best in any particular system will depend on empirical analysis of various options. However, the requirement for such analysis must be stated at the outset, in the concept studies which precede the initiation of system design.

B. The Human Case

Direct sensing of the environment by a human being is accomplished, as we all know, mostly by the eyes and ears. What we do not always keep in mind, however, is that "noise" to some degree always intrudes here, too.

1. Noise

Noise is simply a convenient term for designating those influences which make what is sensed different from what it is desired to sense. Like noise in radar sensing, it may be enemy-made, self-made or nature-made. A number of different effects can result. (1) One discriminates something which is actually not there. (2) One fails to discriminate something which is actually there. (3) One's receiver is overwhelmed in some fashion by some kind of superabundance of input.

Various techniques are employed to counteract these noise effects. Through training, one's capability for discriminating signal characteristics from noise may be enhanced. One may employ behavioral techniques, such as focussing attention, to eliminate or reduce noise. One may place emphasis on the risk of registering false targets and thereby raise the threshold of registering noise -- and "stimulus" as well. It is not the purpose of this discussion to explore all techniques in detail, any more than to specify all the different kinds of noise and noise sources. But the analogy with radar sensing is clear.

Enemy noise-makers will assuredly attempt to introduce noise and reduce the effectiveness of all anti-noise techniques. Camouflaging will be improved and ambushes made more deceptive. Bodies of the fallen will be removed from the battlefield. Soldiers will dress like civilians who dress very much alike. Or they will make themselves look like trees or bushes. Troops will live underground. Adversaries will strike in different places at the same time, so one cannot tell where the major threat is really located. Verbal stimuli (statements) will be presented which do not reflect what the speaker is doing or planning, or which give false impressions, or they will be withheld when one might expect him to say something indicating his plans or intentions. Imitations of missile sites will be erected, and real ones will be emplaced within misleading surroundings. Banzai charges will be conducted to saturate the senses. There are many ways to generate hostile noise.

2. Conversion

The conversion process of particular interest is the conversion from sense data to some kind of report. The conversion may be effected by some mechanical devices such as a camera to produce an analog report. (Of course, mechanical devices such as binoculars could also be considered for dealing with noise.) Relatively unaided human conversions in military situations sometimes take an analog form, such as a sketch, although it may not be a very faithful one, or a map. (Perhaps some military reports would be more reliable if more military personnel could draw well.) But the principal type of conversion is one where the output is words, written or spoken.

To transform sense data into words, the "converter" in the human being must correlate individual or separate sense returns to form aggregates. He must establish some particular properties or characteristics of the aggregate for designation purposes and give them locations within the generalization domains of such properties or characteristics -- a classification procedure akin to quantizing. Finally, he must apply a name of some kind to the outcome of the foregoing process, that is, he must code it, drawing on his repertoire of names, a repertoire of finite size.

When the descriptive words which eventuate from this conversion process are numeric in form, one can properly call the process an analog to digital conversion. The numeric form may be decimal, of course, rather than binary. When the descriptive words are "alpha", that is, non-numeric, one must stretch the term "digitizing" somewhat to apply it to the process, but this can be a useful extension.

When the sense data have been "digitized", say into a written or spoken record, or even directly to a listener, the system process is not complete until the listener (in real time or otherwise) or reader decodes the digitized message, that is, "understands" and responds to it. His operation resembles that of the console operator who views a collection of computer-produced dots on a scope, following the radar conversion process outlined in the previous section, and who decodes, or tries to decode, the dots to detect a target.

The human conversion of sense data to words, described above, also resembles the radar conversion process. It seems to have the same component processes, which are difficult to disentangle from each other. Another parallel between the human case and the radar case is that in each the last part of the process appears to exert control over the way the preceding part is performed. The extent of the verbal repertoire (vocabulary) of the encoder, his capacity for naming, establishes the required dimensionality in the classification procedure, much as the channel capacity of a data link will establish the required dimensionality of quantization.

In each case, also, one can contrast the analog to digital conversion with the analog to analog conversion. In the radar case, the latter consisted of the PPI presentation, in the human drawing a picture. Compare the effect of the analog output with that of the digital output on the actual objective of the information, namely, the eventual recipient, who must decode. Without noise (an ideal state) the digital output may be more effective, since more items can be described. Saying or writing words takes less time than drawing a picture. But with noise the digital output may present more uncertainty about each item to the decoder. A picture can indeed be worth a thousand words.

3. Noise-Conversion Interaction

A number of different eventualities can be hypothesized when noise intrudes into the human conversion of sense data to words. For example:

(1) An aggregate of "false" stimuli is identified as the "true" aggregate which it was desired to sense. For example, a fake missile site is reported as a real one by an aerial observer, for example a pilot who may be relatively untrained for such observing. There are characteristics about the aggregate which might be recognized in a photograph, or which an artist might record, but which are difficult, especially for this observer, to put into words. In reporting that it was a "missile site", he may add that something looked "peculiar" about it, or he may give his report less than a 100 percent certainty rating, but these modifiers really fail to give much information to the decoder of the report, who responds as though it was indeed a missile site.

(2) Features of the "true" aggregate most easily exploited for recognizing it as such are denied to the observer -- hidden, or camouflaged -- so that an aggregate is indeed observed but it looks not like the one it was desired to find but like a large number of aggregates of no concern. For example, an actual missile site is disguised to resemble a barn. There are lots of barns in the area. The aerial observer, who is making notes or reporting by radio, knows

that missile sites can be and often are disguised as barns. He also happens to know that there is supposed to be a missile site among them. The real site does, as a matter of fact, have a characteristic which distinguishes it from other barns -- one side is slightly higher than the others. But this is a difficult cue for the pilot to discriminate precisely and put into words, since all the barns are somewhat irregular in shape, some more than others, and, besides, he grew up in the city. A barn is a barn. Should he report all the barns? If so, should he report them as barns or as apparent missile sites? In either case the receiver-decoder has a problem. Perhaps to the pilot one of the barns does look a little different from the others but he cannot quite verbalize what the difference is, and in any case he is too busy reporting several other barns he sees at about the same time. (He wishes he had a camera.) In fact there are so many barns to report that he omits reporting some. (His channel capacity is exceeded.) Did these include the missile site as well as real barns? Maybe he then decides there are so many barns he will purposely report only every other barn, or only barns with irregular contours above a certain threshold of irregularity. Suppose in the latter instance he now reports no barns, in fact nothing. Has his "intentional" action now excluded the missile site, as well as real barns? The decoder, of course, may draw the conclusion there is no missile site in that area.

Hopefully these examples illustrate what everyone knows, that when sense data are verbalized, details get lost. These details are often the cues for some kind of pattern recognition. They are particularly useful for distinguishing "targets" from noise. What this discussion, then, is supposed to indicate is that when noise interacts with human "digitizing" of sense data into words, the messages which result can be ambiguous, misleading, incomplete. Self-made (internal) noise in a human may hurt as much as enemy-made. The analysis does not pretend to be particularly sophisticated. But it should suggest that the entire procedure of verbalization of sense data by human observers should be thoroughly investigated, and carefully considered in establishing concepts for command and control systems, since the verbal messages utilized by such systems for the analysis function may consist to a considerable extent of such verbalizations. This is something to which very little thought apparently has been given. Yet the analysis function in such a system may be only as good as its input. One can hypothesize a number of techniques which investigation might show could improve human conversions which are degraded by noise, beyond substituting analog to analog techniques. One is selection, another is training, in each case directed at both discrimination skill and verbal repertoire. Procedural innovations might also help.

Perhaps the noise-conversion interaction problem has been neglected in relation to command and control systems because spectacular evidence from military sources has not been widely collected or disseminated. One can, however, readily go outside the military realm for such evidence -- to reports, for example, about flying saucers.

APPENDIX IV

THE CONCEPT OF "EVOLUTION" IN THE DEVELOPMENT OF COMMAND AND CONTROL SYSTEMS

During the last five or six years much has been said and written about the concept of "evolution" in the development of command and control systems. This paper first assembles a sample of this commentary, then makes some general observations, and finally examines the impact of the concept on the methodology of deriving command and control system requirements.

Commentary

Both the Air Force's Winter Study and the Navy's Summer Study favored an "evolutionary" approach for command systems. However, the reports of both are classified and cannot be quoted here. Aviation Week (1960) summarized the Winter Study finding as follows:

> Winter Study Group also emphasized the need for evolutionary introduction of command and control systems, to assure smoother transition from the old to the new.

The report on Computers in Command and Control of the Institute for Defense Analyses (Kroger et al, 1961) also explicitly advocated the concept of "evolution" for command systems. It said:

> The command should be given some computer capability early in the program. This will familiarize the command with computer capabilities and will aid in the evolutionary process. The funding and procurement practices followed should recognize

> that an evolutionary program has no "operational cutover date" when the system phases from development to use and no "complete operational date" beyond which it ceases to evolve. Since the system is evolutionary, at all stages it should have either unused capacity or quickly expandable capacity for growth.

The Kroger Committee report also commented:

> It is not possible to say what an optimal information system design is, in the sense of describing a firm structure. Nevertheless, it is clear that any organization that approaches optimality will be one in which flexibility and adaptive growth are paramount. This is so since the problems the systems must handle will change because the command is imbedded in a changing strategic context, has a role and a mission that may change, directs changing forces, is subject to modification of coordination requirements with lateral commands and man-machine functioning in different battle phases....The goal is to develop a time-phased plan which automates one function after another always keeping functionally integrated the over-all information system into which the parts fit. The information system analysis can usually be expected to imply that automation should proceed in steps to maximize its benefits. In this manner, automation and thus computer programming will be applied first to those areas where the ease of problem formulation has been weighed in comparison with the system benefits to be gained. The more difficult areas from a formulation standpoint may be tackled later when the command personnel have become more familiar with the capabilities, limitations, and difficulties of automation and can apply this knowledge to sharpening the definition of the problem.

The following, indicating the position of the Air Force, appeared first under the authorship of Major General O'Neill, Commander of the Electronic Systems Division of AFSC (Signal, 1964) and later under the name of Lt. General Ferguson, Deputy Chief of Staff for Research and Development, USAF (IEEE Transactions on Military Electronics, 1965):

> As we develop these systems, we are learning that they have characteristics quite different from weapons systems, which influence the way we are and will be doing business. Le me cite a few. We have found that it is impractical, if not downright unwise, to attempt to define, in a long-range way, the specific details of the requirement. This is because the

> the command and control structure -- the user's organization, his doctrine, and tactics vary in response to changes in national policy, changes in forces, and changes in the application of those forces. Hence, system requirements change. In addition, the user's desires for automated command and control support are modified as he learns to use the machines which have been provided to him. The dynamic nature of the requirements suggests that his needs are best satisfied by an evolutionary approach in which command and control capability is provided in a series of improvements which continually increase the total capability of the system. In this way, we are not committed to a large program at the outset, and the user is given a chance to operate the system and determine what each successive step -- or increase in capability -- should be. This is what is meant by the evolutionary approach. We believe it is a realistic and intelligent way to proceed.

The Navy's application of an evolutionary or incremental approach to specific systems was summarized by Capt. H. Stanwood Foote, quoted in Data (1965):

> The Naval Tactical Data System (NTDS) is currently limited to the exchange of tactical surveillance data in real-time in a localized operational area. This limitation is primarily due to an evolutionary implementation of this capability into fleet anti-air warfare operations. The next step is to introduce the system into smaller units. Thereafter, additional capabilities inherently possible will be considered for implementation....we consider the CDC 1604A OpConCenter installations to be of modular design...Future systems.... will most likely be of modular design. This permits expansion of a system coincident with an increase in a user's requirements or to facilitate simultaneous processing in an effort to approach real time response to queries or to provide off line processing...

The DDR&E viewpoint was succinctly stated by Dr. Fubini in an interview in Data (1965):

> Q. As a development manager, what is the key thing you look for in new command and control system proposals? A. An austere start. It seems to me that the knowledge available as to what is wanted and what is possible is limited and that there is no natural selection process. As a result, we have to watch very carefully the tendency for a lot of complex stuff to be built at the start and let the continuous interaction between need and capability show the way.

The cultural trend was sensed by Armed Forces Management (1965) as follows:

> Concomitant....is the emphasis on 'evolution' in command and control. The days of the big, elaborate C&C system have passed. "Rather than building an expensive system and then presenting it to the commander and having him tell us, 'well, that's fine, but I don't need it'," explains one service officer, "we'll find out what he thinks would help him. Maybe it will and maybe it won't, but by this process we'll eventually evolve a command and control system that he can use".

Relatively seldom has much been published which probes the "evolution" concept in any detailed manner. An exception was Marshall (1964), who drew a distinction between two types of "evolution", the "Detroit" and "Darwinian", of which the author considers the former more revolutionary and the latter more evolutionary:

> In the late 50's several ad hoc study groups, in reaction against the 'big system' or 'automate everything' approach, recommended that ADP support of a command should proceed in an evolutionary manner. As a result the term 'evolution' has become quite fashionable, in fact de rigeur in contract proposals. The term was so vaguely defined by the study groups that it has been applied to developmental approaches that would be quite revolutionary and disruptive to the recipient. Actually, both revolution and evolution designate extreme positions which no one actually advocates. The approaches which are recommended fall into two opposing factions both claiming to espouse the evolutionary approach. On the one hand we have advocates of the "Detroit" style of evolution, who believe the proper method is to develop an "initial operating capability" and then replace it at periodic intervals with improved models. The proposed inter-model period is usually from six months up to two years, following a two to three year initial development period. The "Darwinian" approach, on the other hand, is to start with a minimal set of hardware and utility programs, apply them to immediate well-defined tasks, add additional computer capability as needed, and expand the scope and complexity of the functions to be automated as these become well-defined. In this approach, there is no initial capability, per se, unless one considers the existing manual system as such. Changes to the system are made on an 'as needed' basis,

> with the time required to make the change depending only on its complexity and measured in terms of minutes, hours, and weeks, instead of years. Cogent arguments can be made for each of these approaches. Some of the more important ones for the "Detroit" approach are: 1. It is a far cheaper method if one can pre-specify the system requirements...2. It is easier under current regulations to obtain funds for development of a complete system....3. By restricting changes to large, widely spaced models, one subjects the staff to only occasional jolts rather than an almost continual succession of small changes....5. The problem of synchronizing changes which affect more than one system decreases with less frequent changes, and the difficulty of maintaining accurate documentation is reduced. 6. There is a large investment of both personnel and facilities in the complete system philosophy. 7. The more evolutionary approach is slower in that more people can be applied to the development process under the more revolutionary approach. The "Darwinian" advocates have few clear arguments on their side. There is, of course, the obvious fact that the command gets some improved capability at an early date....Another positive advantage to a more evolutionary approach is that it doesn't disrupt the command staff by presenting it with large changes to its operating procedures. This is also somewhat weak since it involves the debatable point of whether it is indeed better to present the user with frequent small changes rather than infrequent large changes. The one really telling argument in favor of a more evolutionary approach to development of command and resource management systems is that revolutionary approaches simply have not worked. A basic premise of the revolutionary approach, that the total information processing requirements can be specified before system development begins, has proven to be false....It is not that we don't want to reform the world overnight, we just don't know how.

(Over and over again, as above, one hears the same refrain, that the less evolutionary approach (Detroit), generally called non-evolutionary, has been tried and has failed. However, the evidence is never cited, nor the embedding circumstances. One gets the impression that a number of command and control systems were started with this approach and that they have been fiascoes. In fact, of course, it would be difficult to support such a thesis. For example, whatever its other shortcomings, one can claim that SAGE has evolved reasonably well with a Detroit-like approach. This approach was actually never fully implemented in the one or two other Air Force systems usually mentioned when the critic is pressed for proof. Nor in the degree to which it was implemented in the most popular example was the implementation as good as it could have been and today probably would be.)

Marshall also set forth how Darwinian evolution could be facilitated:

> A review of new and existing features and techniques in the light of this analysis of the nature of evolution should show how each of these contribute to the characteristics which support evolution. The features which are of interest are those which make a system: 1) general purpose to cover a range of problems; 2) open-ended so that new capabilities can be added easily; 3) integrated so that file accesses can be batched and program operations can be interdependent; 4) disciplined so that changes are properly coordinated and documented; and 5) standardized to facilitate inter-system data exchange. The features which might provide these characteristics include: 1) a data management system; 2) programming tools; 3) on-line consoles; 4) user-oriented languages; 5) a scheduling and priority package -- (time-sharing); and 6) internal documentation and training aids.

Marshall concluded:

> ....what do we mean by evolution? Simply that, given a system with the above features and characteristics, over a period of time increases will occur in the amount and variety of data carried in the system, the variety of operations which can be performed on the data, the number of individuals who have access to the system, and in the amount of interaction among the users. The range of ways to express a problem or to format an answer will change correspondingly. These kinds of changes can be made easier by providing an appropriate set of features in the initial system.

Bryant & Todd (1965) have also explored the "evolution" concept in more depth than is customary. They distinguish between the "job-shop" and "turn-key" approaches:

> The fundamental problem in development appears to stem from incomplete or inadequate system designs. By "design" is meant the specification of type, quantity, function, and relationship of major system components such as personnel, equipment, and information, and of minor system components such as procedures, programs and files of information....Incomplete system designs appear to stem from an inability to obtain, understand, or accurately state requirements. While many reasons can be offered to explain such inability, it is suggested that the most basic explanations can be couched in terms of time and rigidity. Time implies changes in requirements and variance between actual requirements and requirements extrapolated from present to future time....During the interval between statement of requirements and initiation of system operation, current operations continue to evolve as problems and information change. Consequently, the difference between projected requirements and actual requirements at operation time is often large and the design, therefore, inadequate, or at least, incomplete....Deviations of the actual requirements from the planned or projected are caused by advances in technology, weapons system development, national policy, military posture, and staff organization and mission....Rigidity in design appears to result partly from the nature of automatic data processing systems which require very detailed and specific computer programs, operating procedures, and data base definition -- some specific to particular hardware -- and partly from commonly accepted tradeoffs between economy in time and cost of development, flexibility, and speed of machine operation....The point is that such collections of programs or systems are not adaptive, or can be adapted only with the expenditure of effort and time which may approach or equal the original investment....These problems have, no doubt, contributed to the diverse approaches to development that have been attempted, ranging from the "job shop" at one extreme, to the "turn-key" system at the other.

Respective advantages and disadvantages of "job-shop" and "turn-key" have been presented by Bryant & Todd as follows:

> One result of the conditions referred to is the continuing requirement for systems capabilities at too short notice to allow an optimum technical approach to be used. This has resulted in many independent, special-purpose programs being written to perform the jobs required,

> each program design being tailored to that job as representing the speediest method of fulfilling the requirement. These jobs are then run on a job shop basis. In a command or intelligence environment this approach does prove to be responsive to individual staff elements for specific and isolated projects....However, the job shop approach does not demand standardization of data base structure or adherence to the conventions of a master control system, which prevents easy exchange of information between various data files. It has inherent limitations which preclude its use in satisfying requirements for on-line operation. The development process is essentially decentralized, and therefore technical control is difficult.... there is considerable likelihood that duplication of effort will occur as a result of several groups requiring and producing at least similar information retrieval, file maintenance, and report generation programs.... At the opposite end of the spectrum is the "turn-key" approach. With this approach, all requirements are collected and analyzed before design and development are initiated. The "total" system is designed, including staff operations, reporting systems, displays, programs, and facility and equipment interfaces. The program components will include a monitor and will usually be modularized by machine functions such as input processor, file maintenance routines, display generator, etc., rather than by job or specific operational capability. The turnover process occurs all at once, requiring parallel operations of the old and new systems during checkout and training....This approach requires considerable lead time for development....Technical coordination and control are difficult because of "tight" specifications, the requirement for coordinating and integrating voluminous design materials, and the extensive and detailed interfaces within the system. Production errors can be extremely costly because their effect can 'ripple' far into areas of development other than the one in which the error was made. Making design changes, either during development or after initiation of operations, is equally difficult for the same reason....The problem facing the designer of a command or intelligence information system, therefore, is that of combining the best features of the two approaches....The approach which permits a step-by-step increase in the operational capabilities of the system has been termed the evolutionary or incremental approach. The design of the evolutionary system will tend more toward one of the previously described extremes or the other, depending on the functions of the staff which it is to support.

Bryant & Todd further have outlined some of the techniques which they believe are required to effect a good compromise between "job-shop" and "turn-key". Finally, they have placed emphasis on a "general purpose" master control program:

> Dependent to a large degree upon the concept of operations and the selected equipment configuration is the basic system program known variously as the master control program, executive routine, system monitor, or operating system....its design must be frozen early in the implementation cycle. The design of this program is critical to the growth potential of the system in terms of both hardware and software. Efforts must be made to keep it as 'general purpose' as possible.

Israel (1965) has likewise explored "evolution" in some depth:

> The current emphasis on evolution, however, may confuse what are perhaps two separate ideas. The first is the concept of a time-phased implementation, or what might be termed a planned evolution toward a predetermined design. The second relates to provisions for the unplanned modifications necessitated as a result of operating experience or changes in requirements or the technology.
>
> In this light, the evolutionary approach has some dangers which should not go unrecognized. In particular, a time-phased implementation should not be used as an excuse for avoiding the total system design problem. If only the first increment is planned, then there is a strong possibility that inadequate attention will be given to the design requirements imposed by subsequent steps. Specifically, the universal lack of funds and the influence of ever-present economy drives cause strong pressures in this direction and may force a decision to buy only the equipment or capability required for the first steps and not allow time for sufficient analysis and design of the total, long-range system. Restrictions on building size, power, or air-conditioning can be as serious as limited computer capability. Subsequent steps are then very difficult and costly to implement, possibly requiring grossly different equipments and costly retrofits to existing equipments.

He further urges that design should include "a reasonable degree of excess capacity and flexibility in all subsystems and elements to permit long-term unplanned evolution", that the ultimate design should be established before step-wise implementation is undertaken, and that "the designer should consider with caution....the claims for the applicability and availability of 'off-the-shelf' equipments."

2. Considerations

Without doubt the term evolution has been used in connection with command and control systems in essential disregard of its meaning in biology. Those who favor evolution for these systems do so in a Lamarckian or Lysenkoite sense, rather than a Darwinian, even or especially when they modify the term with "Darwinian." They imply that the system will change in some rationally progressive fashion, presumably having learned from past experience, that is, inheriting previous learning, rather than by mutation and a process of natural selection.

(It could be claimed, of course, that sometimes the development of one system follows that of a previously-developed system in a Darwinian manner, to the extent that the developers do not possess the learning acquired by their predecessors. Reinventing the wheel is Darwinian.)

However, this perversion of scientific terminology should not be surprising. The entire realm is one in which catchy concepts engage in battle. In addition to "Detroit" vs. "Darwinian", we have seen "job-shop" vs. "turn-key". The non-incremental approach has also been called "shotgun automation" and "efficiently automated inefficiency". The incremental approach has been labelled "design by Topsy", the "Erector Set" technique, "metamorphic" and "design by whim". Recently its defenders have come up with "planned evolution", certainly a phrase which would make Darwin revolve in his tomb. What it seems to mean is that the end product is conceptualized at the start of a series of developmental iterations, which are planned and occur more or less according to schedule because a strong and stable management keeps this strategy from degenerating into haphazard change.

Another general concept is "adaptation". This differs from "evolution" in the emphasis placed on first creating "general purpose" capabilities for the data processing system and then "adapting" these to new needs, taking advantage of recent technological innovations which provide considerable flexibility and control to the user.

Another interesting thing about discussions concerning evolution in command and control systems is the apparent disinterest in parallel problems in the wider world. Large-scale, long-term planning has always presented delemmas. Political idealogists have fought over the same ground for decades, if not centuries, with Karl Marx, for example, on one side, and numerous "liberals" on the other. Parallels between approaches to developing of command and control systems and methods of designing utopias have been delineated recently by Boguslaw (1965), who has distinguished among four approaches: "formalist", "heuristic", "operating unit", and "ad hoc". The techniques for changing the ways of large societal aggregates, or trying to, have long been the subject of sociological and anthropological study.

Closer to home, the development of weapons systems has also been the area of choice between total planning/prediction and a more gradualistic method. Klein & Meckling (1958) contrast "Mr. Optimizer", who makes estimates of all applicable variables in formulating his long-range plan and establishes a specific goal, and "Mr. Skeptic", who "does not attempt to reproduce the operational environment ten years hence in the minutest detail...In brief, Mr. Skeptic's strategy reflects a deliberate effort to keep his program flexible in the early stages of development, so that he can take advantage of what he has learned....Thus as development proceeds he progressively narrows the range of alternatives on the basis of information acquired, and eventually arrives at the construction of a specific system."

"In looking into the experience of 24 Air Force and Navy aircraft developed since World War II", Klein and Meckling write, "we find that there were only three programs in which the final engine coincided with the one initially planned. Nine of these aircraft development projects had associated with them, at one time or another, three or more engines -- several projects had as many as five. Most of these changes occurred because better engines became available, while in other cases a different engine choice was dictated by changes in the airframe design."

So the problem of how well one can plan ahead is not a novel one. At times one is forced to plan completely and proceed on the basis of the plan, because there is no time for an extended development; the risk is too great to wait. The ICBM program typified this situation and led to the concept of "concurrency", which probably originally influenced Air Force policy somewhat also with respect to command and control systems.

In developing such systems the Navy has followed a much more gradualistic approach, with which, so to speak, policy within the Defense command and control community has caught up. (One observer has suggested that the Navy went through its cycle of "massive" exploitation of new technology (hull design, propulsion, navigation) in ship construction in the years 1865-1917.) Currently, 473L and 492L are often hailed as the innovators of the evolutionary approach in command and control system development, as though the OpConCens and NTDS did not exist. Perhaps even stranger is an implication that there has been no "evolution" in the Air Force's earlier command and control system developments of a more massive nature. The fact is, of course, that SAGE, as the prime example, has gone through many computer program models. Also, "evolution" in SAGE has taken the form of iterations on paper, in the formulation of "operational design", and included an early experimental system and much experimental testing of components.

But the "evolution" of a sensor-coupled system for control operations can be a very different thing from that of a command system. There may be a current danger in the indiscriminate verbalization of "evolution" of the type presently favored for command systems as applicable to command and control systems in general. The restriction of the term to command systems found in reports of some years ago appears to be less carefully practiced today. This can be one of the dangers of the new vogue.

One can wish, for example, that one heard more frequently the kind of distinction made by Benington (1964), who acutely commented:

> For the tactical systems, we can have several different types of models in the field, each model with its own modernness. If we develop an advanced air-defense system after a relatively long lead time, we can train operators and command personnel for that particular system. But

> we needn't replace the older systems in the field until these systems become economically or operationally obsolete in comparison with the more modern system. On the other hand, with the strategic system we have a single, continuing system. We can add or subtract from it, enhance or degrade its functions, modernize one or more of its parts, but we must always solve the problems of cutover and integrity when any change is made.

There are other dangers which an "evolution" approach can bring with it. Obviously it shifts the burden of development to the user. Will the user really bring it about? After the first happy flush of possession, will he keep on making changes, incrementing? Or will there be too much of that inertia which inevitably exists in the absence of the "institutionalization of innovation" that March and Simon (1958) believed to be essential? Will the user acquire the technically-trained people who will be the innovators, and if he does, will the traditional difficulties of the relationship between operational and development types simply shift to a new locus, within the operational command -- where the development types are at a competitive disadvantage? Will the user revise his organizational structure to nourish this new kind of activity? Will he undertake the required retraining of personnel and particularly the familiarization of senior officers, and also develop their enthusiasm for the follow-up on which "evolution" depends? Will the process of continuous changes required by "evolution" be frustrated by the new and hardening procedures for managing a system life cycle? Will the temptation to create the easy things first (1) dangerously postpone dealing with the difficult, and (2) make the commander dissatisfied with the sufficiency of the system? What should be the rate of change? These are some of the questions which must be posed about "evolution".

3. Impact on Derivation of Requirements

"Evolution" or not, there will still be a need to generate concepts and requirements for command and control systems. In an incrementally-developed system, they will be generated serially, but they still will have to be produced. One difference is that they will be produced by the user. Aspects of the user's qualifications for the task have been discussed in part III of this report.

It may be inferred that incremental development will facilitate the production of concepts because one builds on operational experience. What does this mean? What kinds of increments and innovations can really profit from such experience and what cannot? This question demands some analysis.

One answer says it is unlikely that operational experience as such will yield better predictions about future events -- threats, technologies, strategies. Further, the user may have less access to the required information which improves such predictions than do development agencies. In this connection, if the external factors are those which give the user his most significant new needs, it can hardly be said that the user knows his own needs best. He may know some current ones, but not necessarily those of the future.

On the other hand, if one can shorten the time required to make changes in and additions to the system, then one does not have to plan so far ahead. So essentially the value of the incremental approach depends on how much it reduces the time needed for implementing the requirements. The possible advantages of this approach lies in the time-reduction features of its technology, rather than in providing better guidance through operational experience.

What remains to be seen is not only the extent to which lead time is reduced, in the systems now being created incrementally, but also the degree to which this saving produces overall gains in the tradeoff with possible losses which may be incurred because of the new location of the developmental effort. In any case, with respect to impact on the methodology of generating concepts or requirements, the principal effect of incremental development could be the facilitation of prediction because requirements writers need no longer plan so far ahead.

Where there indeed are internal factors (i.e., within the organization or operations of the user) which are discovered or eventuate and which require changes in, or additions to, the command and control system, then the derivation of requirements or concepts can be based on the user's experience. There is no longer a prediction problem, but the matter of lead-time still can be important, since (1) rapid change or supplementation may be needed, or (2) such change or supplementation must be effected before the requirements change still further.

For internal factors to be discovered there should be techniques systematically employed to provide the information on which new requirements will be based. One technique is system exercising with simulation or live inputs. Another is a program of ongoing research in system operations. Since the generation of requirements in an incremental or "evolution" type of system development becomes the responsibility of the user, it is essential that the user incorporate these techniques, especially system exercising, wholeheartedly into his management procedures. It seems improbable that requirements can be adequately derived if the process of their derivation rests simply on the daily observations or cogitations of members of the user staff.

The relative importance of external and internal factors presumably will vary over time within a system, and will also vary between systems. The impact of "evolution" on the manner in which requirements are or should be derived will co-vary with this relationship between external and internal factors. A considerable amount of further analysis is needed to describe these two kinds of factors and show how they are differentially related to varying types of command and control systems.

APPENDIX V

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Security Classification

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY *(Corporate author)* System Development Corporation	2a. REPORT SECURITY CLASSIFICATION Unclassified	
	2b. GROUP	
3. REPORT TITLE Concepts for Command and Control Systems		
4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)* Final Report (May 10 - Dec. 31, 1965)		
5. AUTHOR(S) *(Last name, first name, initial)* Parsons, Henry M. Perry, William E.		
6. REPORT DATE 23 December 1965	7a. TOTAL NO. OF PAGES 199	7b. NO. OF REFS 61
8a. CONTRACT OR GRANT NO. Nonr 4923(00) b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TM-WD-227/000/00 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*	
10. AVAILABILITY/LIMITATION NOTICES Qualified requesters may obtain copies of this report from DDC.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Naval Research Washington 25, D. C.	

13. ABSTRACT "Command and control system" is "defined" by: (1) outlining a tentative model of the embedding "military process" consisting of five "functions" (sense, analyze, decide, act, communicate) at command points, with emphasis on the interfaces between these functions; (2) describing eighteen military command and control systems in operation or under development; (3) noting how analysts have categorized this kind of system; and (4) indicating resemblances between this kind of system and two non-military organizations. It is thereupon suggested that the methodology for improving the derivation of concepts for command and control systems can be improved by profiting from past experience concerning five inter-related "trouble-points" originating in the concepts for such systems: interfaces at function and system boundaries, data input at the front end, interaction of noise and data conversions, consideration of the "anti-system", and system exercising. Two of these "trouble-points" are examined in some detail to show how such analyses might contribute further to an improved methodology. Optimization of "enabling conditions" could also result in such improvement. These include participation of the user, learning the task of conceptual design, managing that task, and letting the system evolve. It is recommended that the Navy continue this study in-house by assembling further information about trouble-points so that designers can learn from problems encountered in the past and their resolutions or continuing challenges.

DD FORM 1 JAN 64 1473 0101-807-6800

Unclassified

Security Classification

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Command and Control						
Military Systems						
Operational Requirements						
Conceptual Design						
Improved Methodology						
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