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1. The objective of the research project is to develop an analysis and evaluation methodology for addressing questions regarding the performance and effectiveness of operational command and control elements in manned systems. The final technical report for this effort is a document entitled "An Analysis and Evaluation Methodology for Command and Control: Final Technical Report". In addition, four other reports in support of the technical report are being issued. The titles of these supplemental reports are

a. "Ergonomic Models of Human Performance: Source Materials for the Analyst"

b. "A Computer Model for Command and Control Analysis"

c. "A Handbook of Systems Descriptions Methods"

d. "Human Factors Research and the Development of a Manned Systems Applications Science: The Systems Sampling Problem and a Solution"

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AN ANALYSIS AND EVALUATION METHODOLOGY FOR COMMAND AND CONTROL: FINAL TECHNICAL REPORT (U)

November 1975

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AN ANALYSIS AND EVALUATION METHODOLOGY FOR COMMAND AND CONTROL

FINAL TECHNICAL REPORT (U)

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96 p.

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Prepared for:

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The program concerned problems in assessing the status, potentials, and weaknesses of operational manned systems and of dealing analytically with that variance in system behavior attributable to its human members. As the core problem is the behavior of the responsible system element, Command and Control (C&C), the specific question addressed was, "How can the effectiveness and performance of operational C&C be better measured, analyzed, and evaluated?"

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These problems were resolved through the development of methods and a methodological framework for dealing with C&C as an integral part of systems. The framework consists of analysis process stages conceived to take place prior to quantitative data analysis. The foundational concepts of the methodology include definitions of C&C, taxonomization, the Systems Taxonomy Model, systems description discussions, ideas for the use of operator models, and analytic decision-making concepts. The analytic tools include an orientation towards the kind of question being asked, system description methods, measures and measurement, a C&C Analysis Model, data integration concepts, C&C evaluation considerations, and guidelines for the application of decision and utility concepts.

TABLE OF CONTENTS

FOREWORD

This report is the final and central report to be issued under Contract N00014-74-C-0324, "Future Data Analysis Methods." The Scientific Officers for this program have been Dr. Toke Jayachandran, CDR William A. Arata, and CDR Robert A. McCaffery of the Naval Analysis Programs division (Code 431) of the Office of Naval Research. The Principal Investigator has been Dorothy L. Finley of Manned Systems Sciences, Inc.

I. INTRODUCTION

PROGRAM PURPOSE AND GOALS

This program has been oriented towards the general problems of assessing the status, potentials, and problems of operational manned systems and of dealing analytically with that variance in system behavior attributable to its human members. As the core problem is the behavior of the responsible system element, Command and Control, the specific question of concern is, "How can the performance and effectiveness of operational Command and Control (C&C) be better measured, analyzed, and evaluated?"

The purpose of the program has been to resolve these problems through the development of methods and a methodological framework for dealing with C&C as an integral part of systems. (This is in deliberate contrast to the seemingly prevailing view that C&C is a separate system, solely unto itself.) The goal of the program is to develop an applied methodology for C&C analysis and evaluation. Such a methodology is one consisting of concepts and methods organized within an analysis process context which will provide guidance to the analyst in the matters of:

a. What kinds of information will application of a concept or method provide?

b. How can the method be tailored so as to more efficiently provide the needed information?

c. How does each method fit within the overall analytic process spanning the interval between initial presentation of the question and obtaining the final answer?

d. Given the value of the information to be gained and the resources available to the analyst, what methods can best be combined into a total C&C analysis and evaluation program?

PROGRAM APPROACH AND METHOD

Program goals have been approached from the viewpoint that the analyst's task is essentially a problem-solving one involving question-answer processes; and that our job was to facilitate these processes. As a result, methodology contents consist of foundational concepts which will aid in better formulating the questions and of methods which will aid in obtaining better answers.

The study methods have included study of all past and current schools of thought felt to be of potential value and indepth onsite studies of operational Navy systems. The studied systems have been complex and "rich" ones, primarily ones found on carrier vessels and the ASW weapon system crews. The principal crews studied onboard the carriers have been those in the Carrier Air Traffic Control Centers (CATCCs) and the reader is referred to Finley, et al (Ref. 7) for the details of these studies. The advantages of these methods have been that, on the one hand, we have rather fully used the resource of current scientific knowledge; while, on the other hand, this use has been tempered and additional inputs have been made based on what is viable and valid for application to questions regarding the real world of operational Navy systems.

UNIQUE ASPECTS OF THE PROGRAM

In attempting to realize goals and purposes such as the foregoing, it has been necessary to look at some frequently ignored problems and to take some unusual approaches. It might be of interest to the reader to review some of the more unique aspects of this program.

PROBLEMS Although many problems received a great deal of attention in this program, note can be made of three which are special; special in that they are central, critical, and often ignored or "skipped over lightly". These include: (1) How to conceive of C&C such that it can be explicitly dealt with as an integral part of and the responsible element in any system that is not totally automated; (2) How to conceptualize the system and its human members such that operational system performance and effectiveness variance can be better organized and accounted for; and (3) How to realize and contend with the costs of analyses in terms of resources available and information gained. The first two of the foregoing really add up to one basic concern: How can the C&C element and human members of a system be related analytically to - and therefore be held accountable for - the variances in the performance and effectiveness of operational systems. The third item is concerned with the relative reasonableness, efficiency, and efficacy with which alternative analysis and evaluation packages can be performed.

APPROACHES Unique aspects of the approach taken include the following:

a. Applications Oriented - the above are real-world problems encountered when dealing with real operational systems. The areas between basic and applied research, and between theory and field operations, are the relatively unexplored ones of applications research and applied methodologies. It is these areas which were felt to provide the question-answer relationships needed in this program in order to make general scientific knowledges applicable to specific operational problems.

b. Analysis Process Rooted - to develop an assortment of concepts and methods for a purpose is one thing. To organize them so as to make them really applicable to a variety of problems, i.e., to develop an applied methodology, is something else again and requires that they be developed and arranged according to some organizing principle. The organizing principle in this study has been the analysis process flow. Which, of course, presented an immediate problem in that this process has not previously been greatly discussed or used in this manner. (Most analysis methods books, for example, have been organized according to either theory or problem categories.) It was therefore necessary that time and effort be devoted just to the definition of this process (see Chapter II).

c. Applied Measurement - there is a great deal of general measurement theory, but little in the way of applied theory or method. Each measure, with its associated measurement procedures, provides data containing some particular piece of information - and no other. It is the analyst's task to select those measures and/or that already available measurement data which will provide him with that specific information he especially needs. Although the mathematical scaling and other properties of measure are indeed important, of far greater importance, from an applied question-answer standpoint, is the definition, or meaning, provided by data on that measure. Concepts and methods presented in the sections that follow will be presented from the viewpoint that understood meaning is the goal of analysis and that valid and sufficient measurement - whether qualitative (e.g., verbal) or quantitative - is the means to that end.

d. Decision and Utility Notions - it should be clear by now that the goal of this report is not to enable analysis for analysis' sake. Rather, it is to enable analyses regarding C&[illegible] which provide relevant, valuable, and cost-effective meaning - i.e., information which answers the questions asked within the value and resource bounds set for the analyses. While several sections address problems associated with effective management of analysis p[illegible]rams, Chapters IV and VI are the most directly concerned with these issues.

A REVIEW OF PROGRAM OUTPUTS

Program outputs include an initial study progress report, this report, which is the central and final report, and several supporting documents. So as to provide the reader with a program overview and references, the initial report and supporting documents are further described here.

INITIAL REPORT A detailed report of the first year's study methods, progress, and findings is provided by the following:

Finley, D.L., Muckler, F.A., Gainer, C.A., and Roe, W.T. Development of an analysis and evaluation methodology for Command and Control: First technical report. Contract N00014-73-C-0095, Naval Analysis Programs, Office of Naval Research, Arlington, VA, March 1974 (AD 778 028).

First year results included definition of the methodological framework, the identification and initiation of development effort on needed concepts and methods, and the provision of recommendations for improvement of observed fleet systems and operational policies.

SUPPORTING DOCUMENTS In order to make the overall methodological framework more evident and so as to better emphasize the conceptual network and contents contained therein in this, the central and integrating report, some materials have been presented in separate reports. These are materials which are essential parts of the methodology, but, nonetheless, are sufficiently developed at this time so as to be able to stand alone as individual reports as well.

The reports, in order of production, are:

Roe, W.T. and Finley, D.L. Ergonomic models of human performance: Source materials for the analyst. Contract N00014-74-C-0324, Naval Analysis Programs, Office of Naval Research, Arlington, VA, September 1975 (AD).

Obermayer, R.W. A computer model for Command and Control analyses. Contract N00014-74-C-0324, Naval Analysis Programs, Office of Naval Research, Arlington, VA, November 1975 (AD).

Gainer, C.A. A handbook of systems description methods. Contract N00014-74-C-0324, Naval Analysis Programs, Office of Naval Research, Arlington, VA, December 1975 (AD).

Finley, D.L. and Muckler, F.A. Human factors research and the development of a manned systems applications science: The systems sampling problem and a solution. Contract N00014-74-C-0324, Naval Analysis Programs, Office of Naval Research, Arlington, VA, December 1975 (AD).

These documents contain source materials, methods, guidelines and procedures, and theory background and development details.

A CLOSING NOTE A completely developed methodology for dealing analytically with questions of the performance and effectiveness of C&C would comprise a much heftier central volume than this and require several more supporting documents. Which is simply to say that much work remains to be done on this topic and we hope that others will continue where we have left off.

II. DEFINITION OF THE ANALYSIS PROCESS

THE ANALYST

The principal user of the C&C analysis and evaluation methodology is considered to be an analyst possessing certain characteristics. These include:

a. Being tasked with deriving information, principally through measurement and analytic procedures, regarding C&C performance and effectiveness in operating systems. The desired information is that which is evaluative, diagnostic, or predictive in nature and which is useful in resolving management, planning, and resource allocation problems.

b. Having these resources available to him:

   (1) The normally available record data, which, in this report, will be referred to as "available data". These include not only that data obtainable from computerized data banks, but also that which is contained in files and on tapes of much lesser degrees of standardization and organization.

   (2) The ability to query systems personnel so as to obtain additional qualitative and quantitative data.

   (3) Some data retrieval and computational capabilities.

   (4) Some ability to modify normal data collection procedures so as to better satisfy current or future data needs.

c. Being required to constrain the use of the above resources within reasonable utility and feasibility bounds.

The user of this methodology is also assumed to be a person faced with a question which requires that several decisions be made in the process of obtaining a final answer. The methodology is, as can be seen from a review of the Table of Contents, structured to aid several of these decisions. An underlying set of decisions the analyst is considered to make relates to the matter of what constitutes the sequence of attribute, performance, and effectiveness relationships in the system. That is, deciding what are the parameters of and relationships between (1) the system elements and components at any one level of definition, (2) the levels of system definition, and (3) the systems under study, other systems, and the system environments.

THE PROCESS

A basic analytic process concept was developed during the first year of program effort to serve as the organizing principle for methodology development efforts. The graphic representation that was used at that time is repeated in Figure 1. It is meant, by its layout, to convey the thoughts that (1) analysis should be a sequential, albeit iterative, process and (2) the steps taken at any one point of the process are largely determined and limited by the results of preceding analyses.

Since then the concept of an analysis process has further evolved such that a graphic overview would now appear as in Figure 2. A more detailed listing of analysis stages is the following:

a. Stating the question.

b. Taxonomization of the universe of things to be dealt with.

c. Initial and general identification of measures.

d. System identification through the accumulation, analysis, development, and preparation of system descriptive information and the "available data".

e. Initial specification of the models and operations and their association with members of the measures set.

f. Final specification of the desired members of the measures set.

g. Final evaluation of the available data and definition of the measures represented therein.

h. Final evaluation and selection of the measures and measurement data samples to be actually used.

i. Final formulations of the system models and model operations.

j. Final selection of analytic approaches and performance of the deterministic and stochastic analyses.

As noted at the bottom of Figure 2, the chapters of this report support the identified analysis stages and have been organized accordingly.

This is the opportune point at which to introduce the reader to two aspects of the analysis process which will underly the presentation of some of the materials in later chapters. These two aspects are presented in Table 1 and Figure 3. In Table 1, the possible topical components that might be contained in a

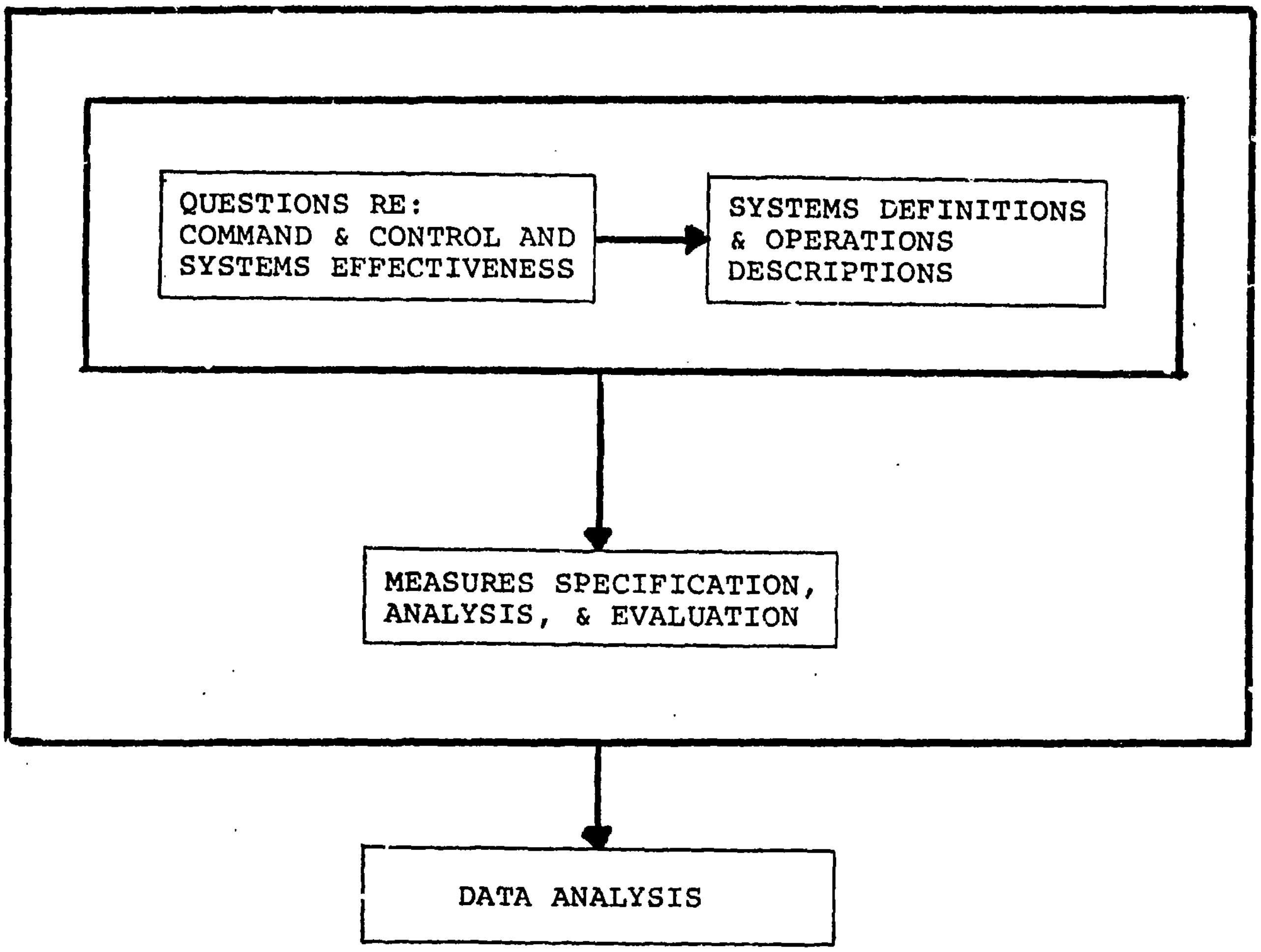

Figure 1. The Basic Analytic Process Concept Developed During the First Year of Program Effort (taken from Finley, et al, Ref. 7).

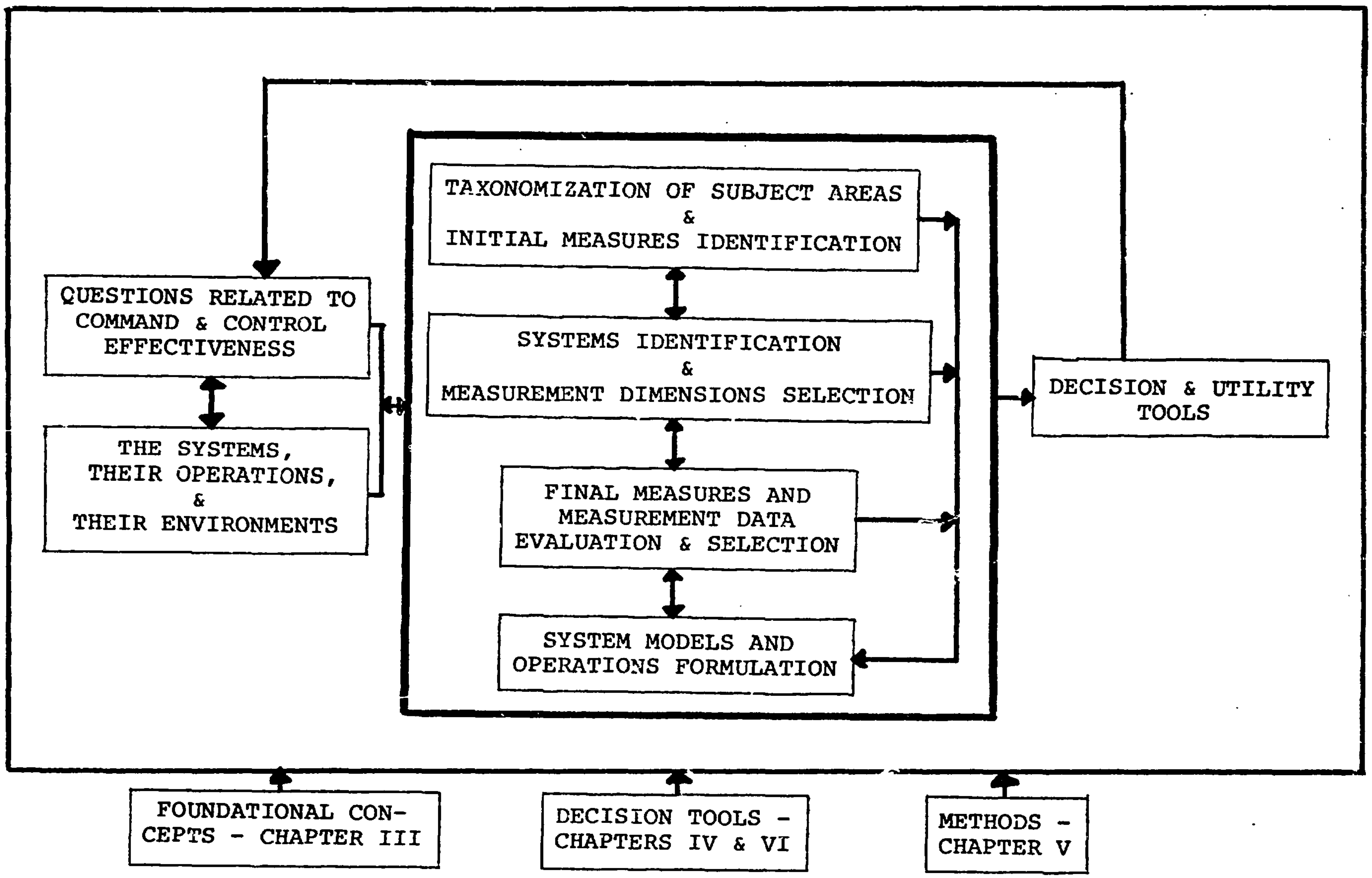

Figure 2. The Basic Analytic Process Concept as it Evolved During the Second Year of the Program.

TABLE 1. RELATIONSHIPS BETWEEN QUESTION TOPIC COMPONENTS AND THE ANALYSIS STAGES OF SYSTEM DESCRIPTION, MEASURES DEFINITION, AND SYSTEM MODELS FORMULATION (page 1 of 2)

	ANALYSIS STAGES		
POSSIBLE QUESTION TOPIC COMPONENTS	SYSTEMS DESCRIPTION	MEASURES DEFINITION	FORMULATION OF SYSTEM MODELS CONTENT & OPERATION
WHO OR WHAT?	System/Subsystem Identities & Relationships System components Man: Individuals, teams, other units Machine: Operator & system hardware, software, status displays	Identify the populations of objectives to be sampled for measurement	Decide what and how entities might be represented (e.g., as GPSS "facilities")
IN WHAT MISSION ENVIRONMENT?	Environments Internal environments, impacting environment, other systems	Identify the populations of conditions to be sampled for measurement	Define system model operations
ACCORDING TO WHAT PLAN?	Mission Scenario Alternative scenarios, segments, contingencies		
⋮	⋮	⋮	⋮

TABLE 1. -continued- (page 2 of 2

DOING WHAT?/WHY?	System purpose Functions & Objectives	Define Measures	Define System Model Parameters
VIA?	System Activities Decisions, actions, communications, movements		
UNDER WHAT ENVIRONMENTAL CONDITIONS?	System & Component Operating Environments		
USING WHAT RESOURCES?	Resource Qualities and Capabilities Required Man: Output levels, reliabilities Machine: Output levels, reliabilities		
WITH RESPECT TO WHAT CRITERIA?	Operating Performance & Effectiveness Criteria Operating Costs & Efficiencies Criteria		
WITHIN WHAT TIME FRAME?	Scenario Time Base Point-in-time, number of missions/mission cycles repeated over time	Define points of measurement, i.e., data samples definition	System model operation representation

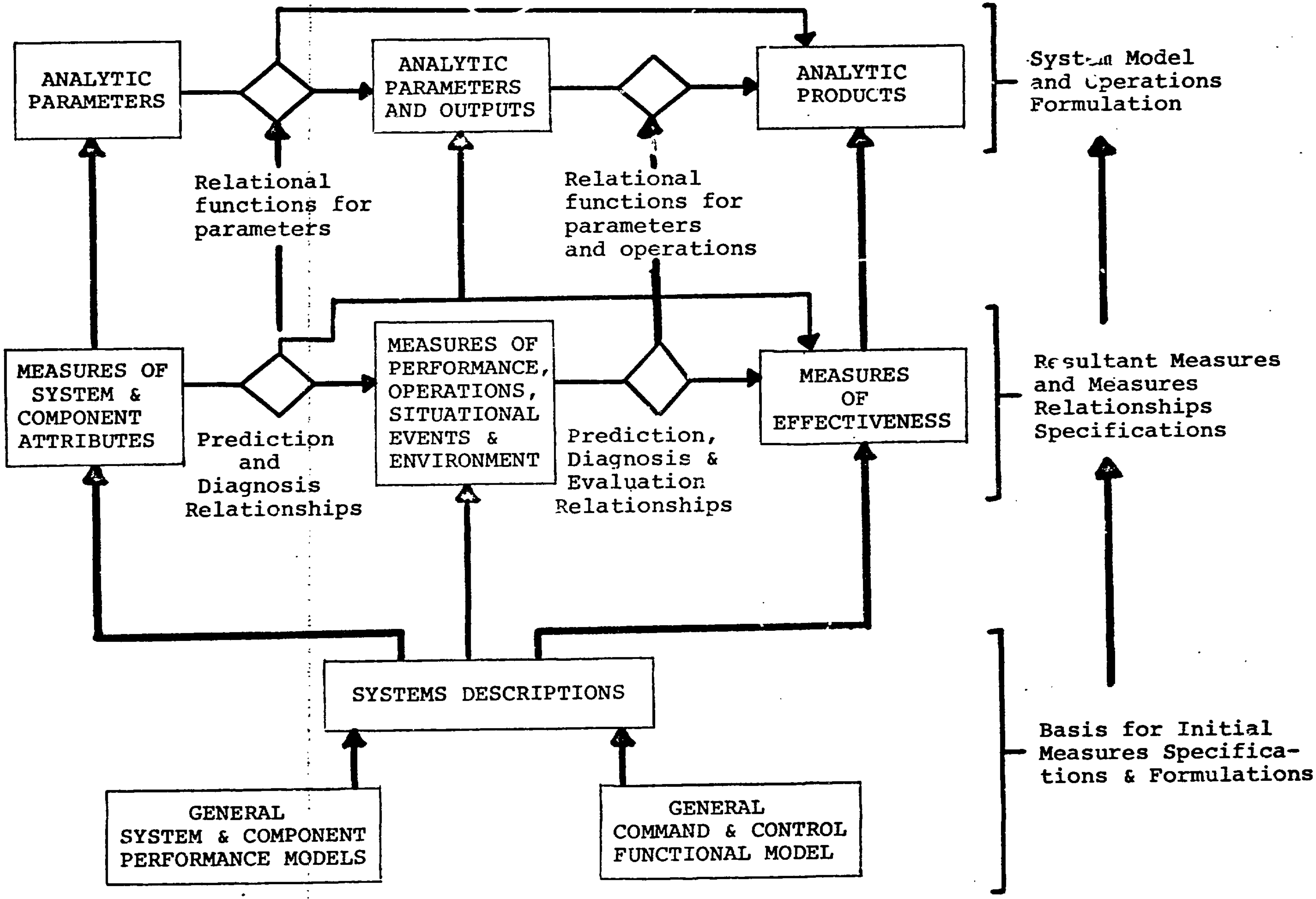

Figure 3. The Evolution of a System Model Contents and Operations Formulation.

question under study are listed and related to three major analysis stages. The relationship is in terms of impact on the analysis steps to be taken. In Figure 3, effects of analysis process stages on the evolution and formulation of a system model and its operations are depicted.

Finally, as a closing note of interest, the analysis process stages were used to specify the sequence of steps taken in two activities of concern to us here: (1) the design and execution of an empirical study in order to obtain information and (2) the design and execution of an analytical study using "available data" for the same purpose. The result of this exercise is presented in Table 2 and it is interesting to note how similar the processes in these two activities can be made to appear.

TABLE 2. A COMPARISON OF EMPIRICAL EXPERIMENTS AND DATA BASE ANALYSIS PROGRAMS (Page 1 of 2)

	PROGRAMS	
	DATA BASE ANALYSIS	EMPIRICAL EXPERIMENTS
PURPOSES	The general purposes are to collect specially defined data which can be used to test hypotheses, derive parameter value estimates, and derive function definitions - all as needed to answer a question	Same
CONSTRAINTS	Limitations on the amount of information potentially contained in "available data" bases	Limitations in the environments, etc., available for study purposes and the amount and nature of situation manipulation and onsite measurement possible
	Data retrieval capabilities and resources	Resources for and adequacy of manipulations made and measurements taken
	Resources available for analysis	Resources available for analysis
PROCESS:		
Step a.	Statement of question	Statement of question
Step b.	Populations identification and definition	Same as step b for data programs
Step c.	Populations sample specification	Same
Step d.	Scenarios/conditions specification	Same
Step e.	Specification of measures and data samples	Same
Step f.	Analysis and evaluation "available" data resources	Analysis and evaluation of situations, etc., available for experiment conduct
	⋮	⋮

TABLE 2. -continued- (Page 2 of 2)

Step g.	Specification of assumptions and hypotheses	Same
Step h.	Reiterate Steps b - e	Same
Step i.	Specification and integration of analytic programs	Specification of experimental design and procedures
Step j.	Specification of procedures for evaluation of analysis results	Specification of data reduction and analysis procedures
Step k.	Retrieve data	Run experiment
Step l.	Reiterate Step j as necessary	Same
Step m.	Analyze data	Same
CONCEPTS USED IN THE PERFORMANCE OF THE ABOVE PROCESS	Performance of above Steps a through h is guided by general models - the investigator's views of systems, components, elements, and environments with regard to their structure, functioning, behavior, and interactions - whether or not these models are explicitly recognized and acknowledged by the investigator. The results of Step i is the formalization of specific cases drawn from these general models.	Same

III. ANALYSIS FOUNDATIONS: SYSTEM CONCEPTS AND MODELS

COMMAND AND CONTROL: DEFINITIONS, DISCUSSIONS, AND MODELS

DEFINITIONS Because there are many conflicting concepts of C&C, it is useful to state here what definition has been assumed for this report: Command and control is the management component of any system.

Some clarification and expansion of this definition may be useful:

1. C&C is a subsystem. For some purpose, it may be useful to consider C&C as an isolated entity. For example, when problems have been identified in the C&C element, those problems may be examined solely within the element itself. But, the use of the phrase "command and control system" is a conventional convenience. What is ultimately of interest is what the C&C component does in relation to all other components of the total system.

2. C&C functions are exercised throughout the system, not solely at the "top" of the system. For example, directives issued from the C&C component are always subject to some interpretation and application in other parts of the system. In the act of applying these directives, variations - intended or not intended - are always introduced. In every real system, unofficial command directives and actions may be generated depending upon the extent and degree of system control. Flexibility appears to be essential for any system, and flexibility implies that other elements of the system have some options in at least limited execution of C&C functions.

In the vital area of information flow through real systems, no system can transmit exactly the information output of the C&C component. The communication message may be the same to all components, but the interpretation of the message will always vary. Further, information supplied to the C&C component has always been suspect to some degree, and rightly so. Data inputs to the C&C component must be filtered, or C&C would be overwhelmed with quantity of data. But the act of filtering inevitably distorts the data being transmitted; the C&C component must test the data flow process to insure that the filtering does not change meaning.

3. C&C as a subsystem of military systems is equivalent to civilian management systems. Outside of the element of personal risk, there are no significant functional differences between military and civilian management. Differences are of degree and not of kind.

Military systems are often characterized as examples of strong centralization. Yet, in fact, many military systems stress at least temporary decentralization in the sense of encouraging individual and unit initiative. Many civilian systems have greater degrees of centralization than military systems.

With respect of physical stressors, military systems represent, of course, an extreme point on the continuum of management systems. But, looking at psychological and social stresses, civilian management systems in some cases create sustained stress conditions continuously for periods of years.

4. C&C is not a physical location. The command post is not the C&C component; rather, it is a tool used, or not used, by the C&C component. Producers of command installations frequently appear to confuse structure with function.

5. C&C is not solely an individual, but consists of all individuals within the total system that generate and/or execute C&C functions. It is convenient to identify C&C with the commander, but in fact C&C functions are distributed through many individuals in the system.

COMMAND AND CONTROL FUNCTIONS It is necessary to expand the term "management component" into the C&C functions performed by the command component. The initial technical report (Ref. 7) listed six major functions which may be considered a minimum set of functions that define the management component. These are considered to be necessary although they are probably not sufficient. In summary:

1. The C&C component establishes general and specific goals and standards. No other component can perform this function. Parenthetically, this does not necessarily imply a unilateral action by the C&C component. The goals and standards may be generated jointly by such methods as management by objectives. However, this concerns the methods by which the goals and standards are derived and not the performance of the function per se.

2. The C&C component establishes procedures and techniques by which the system will achieve goals. On the positive side, this assists the total system in suggesting ways of achieving goals. Here, the desirable degree of flexibility is an important issue. There is no substantial objective evidence that any degree of specificity is better than any other. As a heuristic in practice, it is probable the extremes - total or no specification - are to be avoided. It may be that the optimal level of specificity on procedures and techniques is dictated by the mission tasks.

3. The C&C component defines the constraints under which the system will operate. This function is the important one of establishing what the system cannot do. Most C&C and management systems have been reluctant to perform this function on the grounds that it may restrict the system in performance. Yet, many system problems that occur constantly could be avoided if specific constraints were stated explicitly. This is particularly true of the utilization of the personnel component.

4. The C&C component is responsible for the level of system performance achieved. Command is responsible, and command is accountable, since command has been given the authority.

5. The C&C component defines the nature of the interaction between management and the rest of the system. This function includes both organizational structure and style - at least to the degree that such processes can be meaningfully organized by formal action. It may be that some freedom is essential in dynamic organizations for these parameters to develop spontaneously. C&C can then codify or modify the interactions as necessary.

6. The C&C component establishes data acquisition, data processing and information needs for all levels of the system. The violation of this function has led, we believe, to the current state of ineffective and extremely costly communication within systems. Further, as will be discussed later (Chapter VI), the C&C component should be governed by a minimization axiom with respect to intra-system communication. Far too much irrelevant data are being exchanged within modern day systems. This seems particularly true if the system has abundant ADP capability.

A MODEL FOR COMMAND AND CONTROL The previous technical report proposed a generalized model for C&C as shown in Figure 4. This has seemed particularly useful in maintaining the operational distinctions between command flow vs. control flow vs. data/information transmission within the total system structure.

Assuming that such models are useful (if, indeed, not essential) to better understanding, it becomes critical to be able to classify system structure and process. Models cannot be built without classification, and, hence, it has become necessary to explore taxonomization problems; this is done in the next two sections. Taxonomization is basically concerned with rational description. If we cannot describe a system, it is doubtful that we can understand the system.

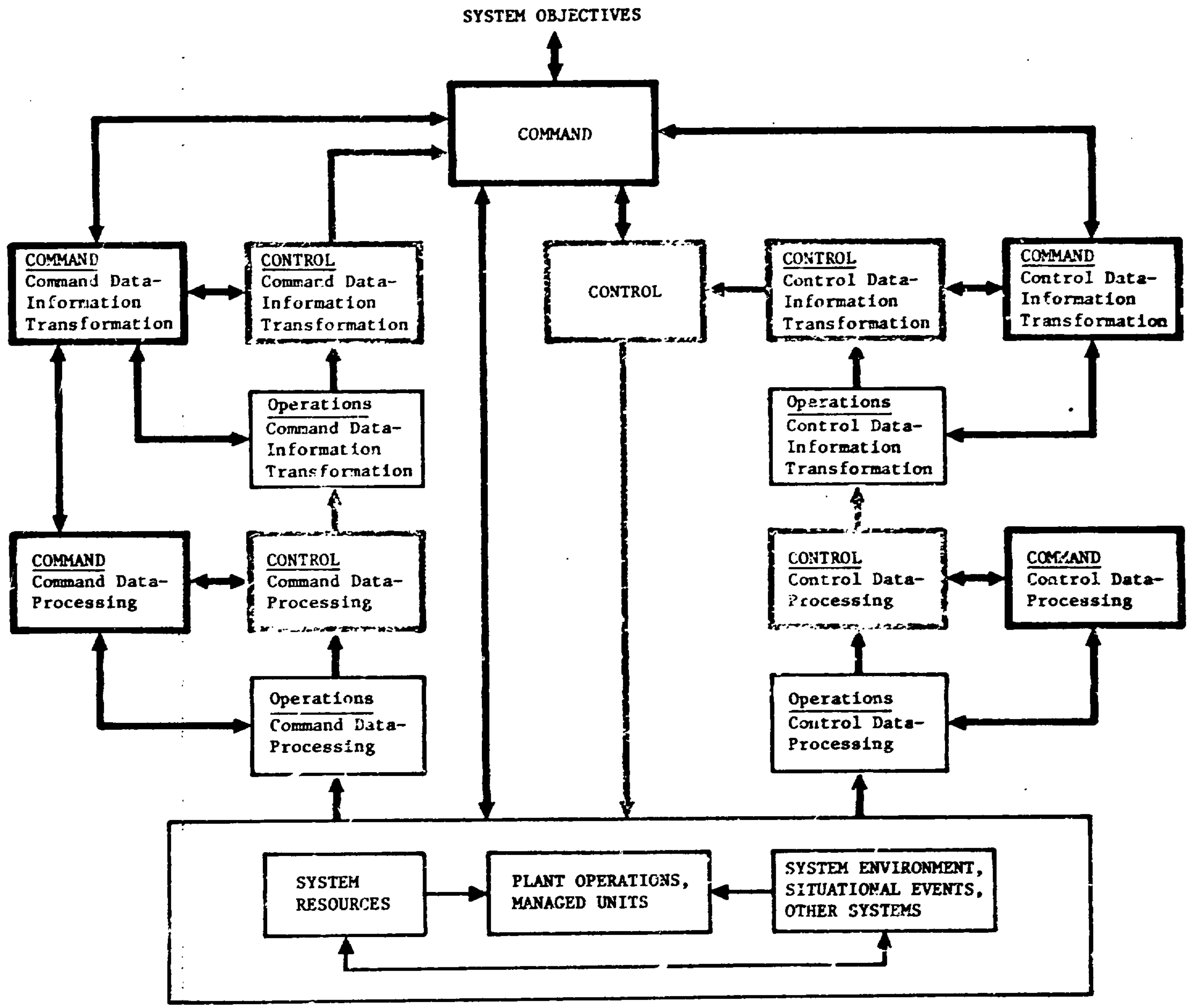

Figure 4. A Possible C&C System Functional Model for Analysis and Evaluation Purposes (taken from Finley et al, Ref. 7).

TAXONOMIZATION CONCEPTS

Taxonomy, or the science of classification, is concerned with the grouping and ordering of things so as to achieve meaning and manipulational capability; as such it is a most fundamental instrument in the development of a science. In the basic sciences, well-known examples of taxonomies include the phyla of zoology and botany and the periodic table of chemistry. In the applied science of human factors, we have descriptive and analytic task taxonomies.

In this business of grouping and ordering collections of things, there are two aspects to be concerned with; one is the criteria, or rules of assignment and distinction, used to separate members of a collection into their respective groups. That is, the criteria that put a taxonomy into operation. This aspect has been the traditional and principal concern of the science of classification (cf, ref. 19). The other aspect is that of taxonomization, or the process of developing the taxonomy to begin with. This initial process stage has never been examined in any detail; probably because it is a creative act, an act requiring talent, and as such has been assumed to be unexaminable.

Perhaps "...rushing in where angels fear to tread", we are not only going to look into the matters of Taxonomy* and taxonomization in this section, we are also going to propose an aid to the process, when attempting to accomplish certain ends, in the next section. For the reader interested in further discussions than is provided in these two sections, reference is made to Finley and Muckler (ref. 6).

TAXONOMIZATION: WHAT IS IT? Taxonomization is the process of first collecting things of interest together and then finding some identification and organization of these things which will lead to further understanding and/or will make these things manageable in some way. It is usually the case that, with the understanding gained from the first effort at taxonomizing at a relatively gross level, more detailed and complexly structured taxonomies are subsequently developed. While the levels most often form a hierarchical structure, this is not necessarily the case (e.g., string taxonomies and taxonomies of overlapping classes located by ordinates in a multidimensional space).

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*Taxonomy, when capitalized, will refer to the science. When uncapitalized, it will refer to a classification system.

Examples of the results of taxonomization efforts include the kingdom, phyla, genera, and species taxonomies for living organisms. On the one hand, these represent attempts to establish a "natural" or evolutionary order for the organisms; on the other hand, the resulting taxonomies also assist the organization and focusing of studies on organism behaviors. Another example is the indexing of books in a library; this enables the librarian to both evaluate the inventory overall and retrieve individual books as needed. Yet another example is the development and application of a task taxonomy to a collection of job behaviors. Here the purpose might be to develop an information base that can be studied and manipulated as needed to design a system training program and the training equipment.

In all of the foregoing examples, it can be noted that the development and application of the taxonomy was actually a way of giving additional and useful meaning to collections of things. For the scientist, it is usually a matter of working with a particular and preselected set of things and attempting to find that classification system which provides some "natural" order based on properties which are either evolutionary in nature or might reflect some scientific principle. For the practitioner, it is often an even more basic process in that the first questions to be addressed often concern the matter of, "Just which sets of things are even the right ones to look at?" (For example, given a system development program and limited resources, which of the operators, operations, and equipments should be studied in detail so as to optimize which of the system development and operations criteria?)

Another distinction with regard to the practitioner is that he is taxonomizing things so as to make evident those properties relevant to solving an applied problem - rather than seeking any "natural" order of things. Example problems might be ones of designing tasks so as to optimize either system control, system safety, or worker satisfaction. It can be seen that each of these problems concern rather different, even though overlapping, subsets of all the properties that could be associated with a collection of tasks. The practitioner must develop and apply that taxonomy which will emphasize those task properties relevant to the problem and organize these properties and/or the tasks themselves in a way which leads to problem solution. And one thing that must be remembered, but too often is not - that task taxonomy which yields information useful for addressing one of the foregoing task design problems is not likely to yield much, if any, information for solving any of the other problems.

In summary, taxonomization is the process of developing a taxonomy, or classification system, which will group and order things so as to give them greater meaning and to make them more manageable. For the scientist the purpose is to gain knowledge about the things studied per se, while for the practitioner the purpose is to gain knowledge relevant to the solution of an applied problem.

WHERE IS TAXONOMIZATION USED? Taxonomization is used throughout the analytic process, wherever it is necessary to organize and identify things in order to proceed. Some of these points of usage are discussed briefly here so as to provide examples: (1) Populations identification, (2) Systems description, (3) Measurement scales and data sampling, and (4) Models formulation.

POPULATIONS IDENTIFICATION OR, DEVELOPMENT OF A POPULATIONS TAXONOMY Given a question, the first matter that requires resolution is, "Just which populations of objects and conditions do we need to be concerned with?" As indicated in Figure 2, Tables 1 and 2, and on page 6, this is a prerequisite to identifying what models and samples of the real world are to be studied and what measures are to be taken. The performance of this first task requires that the analyst or practitioner review the operational world and, in effect, group and organize the components thereof in terms of the question. The result of this effort is usually both a gradual restatement of the question and an organization, or taxonomization, of the world until the one can be mapped into the other. The effort will be successful, i.e., the question will be answerable, to the extent that populations of objects (e.g., systems, operators, behaviors) and conditions (e.g., scenarios) can be identified which are directly relevant to the question and, also, are valid and meaningful samples of the real world for extrapolation purposes.

SYSTEMS DESCRIPTION The foregoing, populations identification, is the first and an iteratively performed step of systems description, where the purpose is to formally define a set of taxonomies and apply them to the populations that have been selected for study. The act of describing the system and system environments of concern is one of applying the descriptive and analytic taxonomies that have first been formulated "in the head". The process of preparing for these description activities is one of taxonomization; the results of the preparation process are the system and task taxonomies used for system description purposes.

MEASUREMENT SCALES AND DATA SAMPLING The process of defining the measures to be used in a study involves several steps which are either based on the results of taxonomization or else require taxonomization to accomplish them. The initial efforts at defining measures involves an examination of the populations determined to be relevant to the problem (or available for study at least) and a determination of what measures, if any*, ought to

*No measures may be taken if, for example, it is decided to use sampling procedures such that the population can be assumed to be "representative" and no information about the effects of population differences is desired.

be taken on each of these populations. As the determination of what constitutes the study relevant populations is a taxonomization procedure, the initial efforts at defining measures is based on the results of taxonomization.

Two later steps are the determinations of (1) How should the measurement scales be bounded and divided?*, and (2) How should the resulting scale segments be sampled? The first determination is a matter of scale definition in terms of study purpose vs. measurement capabilities and, like populations definition, is a taxonomization question. The second determination results in a data sample taxonomy of sorts where the categories are defined in terms of quantity relationships (i.e., the sample N taken at each of the "factor levels") and randon vs. fixed sampling definitions, all of which serve to determine statistical procedures and the conclusions that can be drawn from analysis results (cf, ref. 23).

MODELS FORMULATION As noted in Figures 2 and 3, and Table 1, system model contents and operations formulation is the final "putting together" of all the pieces, measures and descriptions, resulting from the previous steps in the analysis process. As such, the goodness with which it can be accomplished is very dependent on the completeness, validity, and relevancy of preceding steps. And the goodness of accomplishment in turn fully determines the extent to which useful information can be gained in subsequent analyses where the formulated models and data inputs are exercised.

HOW DOES ONE DO IT? In the beginning we noted that there were two aspects to this business of grouping and ordering collections of things: (1) the rules of assignment and distinction for taxonomies and (2) the process of taxonomization. The first aspect, as then noted, has been the main province of Taxonomy. A good overview of what Taxonomy can presently provide to the analyst is given by Sokal (ref. 19). A summary is as follows:

a. Mathematical tools r deriving a posteriori taxonomies. Examples of well-know.. techniques include factor analysis and cluster analysis methods.

b. In effect, a data bank, or library, is available for reference purposes. This library contains all the already developed taxonomies.

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*E.g., should phenomena in the temperature range of 40^o to 100^o or 60^o to 80^o be investigated? And should the "factor levels" studied within these bounds represent divisions of, for example, 10^o (e.g., 60^o, 70^o, and 80^o) or 5^o or 1^o?

c. Principles for the structuring of taxonomies. These range from mutually exclusive classes without order to hierarchically ordered mutually exclusive classes to overlapping classes located by ordinates in a multi-dimensional space.

d. Principles for classification procedure, i.e., rules for operating a classification system. Examples include monothetic vs. polythetic classification.

The second aspect, taxonomization, is perhaps best described as an ability which can be improved upon through recognition of its existence and evaluations of the taxonomies resulting from its operation. We don't know how one actually goes about "doing it", but any practitioner knows how useful the right taxonomy for the job is; and how worthless, if not dangerous, the wrong taxonomy is. And scientists clearly know that progress in an area is first evident in and is dependent on the development of a usable taxonomy.

SYSTEMS TAXONOMY MODEL

Practitioners and analysts involved in working on systems problems often complain that few research findings appear to have any relevance or utility for their system problems. The fact is, at least with manned systems, despite the amount of so called systems work that has been done, very little exists in the way of system level understanding and knowledge (cf, refs. 12 and 13). Actually, a principal reason for this condition is a rather obvious one - few studies ever include in their measure sets parameters of input, state characteristics, or output performance and effectiveness at both the component and that system levels of description. For example, as noted by Meister with regard to studies of "man-machine" systems, researchers often study parameters related to the man (e.g., training, attitudes, operator performance), occasionally study parameters of the machine (e.g., display size), but very seldom study parameters of the system (e.g., layout and coordination of the system components, system level performance) (ref. 13). And a review of systems analysis reports quickly leads to the conclusion that the same tendencies, in reverse order, are true for these kinds of studies (cf, ref. 21). As the practitioner and the analyst need information on all of these in combination: the components, the overall system, and the component-system relationships, studies which omit the system or one of the major components (e.g., the man or the machine) - i.e., investigate only part of the problem - do not provide the necessary information.

As discussed in some detail in Finley and Muckler (ref. 6), a most basic reason for the foregoing problem appears to be the failure on the part of researchers, and on the part of practitioners and analysts too, to realize the explicit existence of both systems and their components as separate and distinct entities; entities which constitute separate populations of N>0, populations that can be sampled and measured so that conclusions related to systems and to system-component relationships can be drawn.

As previously noted in Tables 1 and 2, one of the first steps in the design of a data base analysis program or an empirical experiment is to identify the populations of objects and conditions to be worked with. And as noted in above discussions this identification of populations is a taxonomization kind of step, resulting in a problem oriented populations taxonomy, and is an essential prerequisite to developing a comprehensive set of measures for data collection and analysis purposes. As an example of what is meant by "identification of populations", consider a hypothetical system reliability problem: the mean time between failure (MTBF) rates for an aircraft weapon system are generally higher than they should be and higher at some air bases than at others. For a problem of this sort, the populations taxonomy might include the following:

Flightline maintenance systems
Shop maintenance systems
Maintenance equipments
Technician crews
Individual technicians
Technician and crew tasks

Supply systems

Weapon systems
Weapon system subsystems
Weapon system aircrews
Individual operators
Operator and crew tasks
Weapon system hard and software components

Command and control elements
Supervisors
Work environments

Forms used for debriefing, etc.

Missions
Mission environments

On each of the above populations, the investigator would have to make a decision as to whether to measure parameters describing the population, or to control these parameters in samples drawn from the population to a constant value (e.g., work only with equally and highly-skilled technicians), or to sample from the population in such a way that the sample can be assumed to be a representative one across the parameters of concern. One thing should be clearly noted in the above taxonomy of populations: systems, subsystems, components, behaviors, and system environments are all included. And it is only by such an explicit cognizance of systems, etc., each as a separate population, that measures will be taken on each of them, sampling procedures individually considered, and then relationships drawn between the measures - by either the researcher, the systems practitioner, or the analyst.

Having said, however, that the populations taxonomy developed for investigating a systems problem needs to be system oriented and to include the system as a population, as well as the system components, does not make it an easily accomplished matter. One can only assume that if it were easy, it would be done much more frequently than it is. The above list is the result of considerable experience with that kind of problem plus a foundational concept to be offered in this section: the Systems Taxonomy Model.

The purpose of this model is to provide a basis and tool for developing conceptualizations of:

a. Systems as entities which form populations,

b. Populations taxonomies which include the populations of both systems and system components, and

c. System taxonomies which are organizations of populations class and differential characteristics meaningful for the purposes of research design and planning.

The discussions presented in this report regarding the model, in the following paragraphs, provide a brief introduction to model background concepts and to the model itself. For a detailed discussion of the viewpoints and concepts which form the foundations for the model (populations definition concepts, human factors research, Taxonomy, and situational taxonomies), of the model itself, and of how to actually use the model for forming a systems taxonomy (i.e., dimensionalizing the system entity for purposes of identifying system and component populations, and population characteristics), the reader is referred to Ref. 6.

DEL BACKGROUND CONCEPTS The Systems Taxonomy Model was developed around three concepts: (1) Measurement level definitions, (2) Levels of system description, and (3) Types of question.

MEASUREMENT LEVEL DEFINITIONS When taxonomies are considered in the abstract, all they are essentially is a set of measures and measure relationships. And, an interesting fact about measures - and, therefore, about taxonomies - is that there are the measurement levels of nominal, ordinal, interval, and ratio; and that these levels can be grouped into two categories: nominal which includes only the nominal level of measurement, and relative, which includes the ordinal, interval, and ratio levels.

Nominal measurement systems and nominal taxonomies are essentially the same thing: a set of categories, into which objects can be placed, but which bear no necessary relationship to each other. An Apples and Oranges taxonomy is a good example in that things are either apples or they are oranges and no underlying relationship or common dimension is assumed.

Relative measurement and classification systems, on the other hand, consist of a different kind of category, or measure. These categories are dimensions which are used to give objects a relative value; these values are then the basis for ordering the objects with respect to each other. Take, for example, the interval taxonomy, or set of measures, provided by a five point rating scale of "goodness". Objects or conditions, once assigned a number from this scale, can be grouped into one of five categories and will then have an order relationship to all other objects to which a number has also been assigned. A relative classification system, or taxonomy, consists of some set of such taxa, or measurement dimensions.

The thing of interest here is that the nominal systems give us a management capability over things in terms of their unique aspects, while relative systems give us a management capability over things in terms of their relationships to each other. Whether one capability or the other or both is desirable depends upon one's purpose. Both of these capabilities can be used to define entity characteristics and to distinguish between populations; the difference is what kinds of characteristics one wishes to deal with - nominal, relative, or both.

LEVELS OF SYSTEM DESCRIPTION Systems can be described in a number of ways but one which is both reasonably common and very suitable here is the one of: (1) System objectives, (2) System functional purposes, and (3) The various system activities, characteristics, and requirements. Of interest here is that a listing of systems by objectives tends to form a very large (perhaps infinite) nominal classification system - e.g., navigation, transportation, health care, etc. - where unique information is given about each system but not much is said about how the systems are similar to or dissimilar from each other. On the other hand, a listing of systems by characteristics tends to form a relative classification system - e.g., size, level of automation, environmental conditions, etc. - where considerable is said about how the systems compare to each other, but their uniqueness is not made obvious.

TYPES OF QUESTION Questions are not only asked about different topics and with different objectives in mind (e.g., to predict vs. to diagnose), but also for different purposes. Two basic purposes of interest here are those of fundamental research vs. those of applied research. The answers sought by fundamental researchers are the more general ones, ones applicable to systems in general with some knowledge of the impact of major system differences. The answers sought by the applied researcher are ones specific to a particular system and problem at hand. From the standpoints of the practitioner and the analyst who wishes to extrapolate, the most useful documentation is that which is an optimum mix of both the general and the specific, both the fundamental and the applied. Which kind of answers one achieves is most basically determined by the kinds of taxonomy one starts out with; i.e., what one identifies as the populations and population characteristics about which the study is to be concerned.

THE SYSTEMS TAXONOMY MODEL Given the possibility of an infinite number of possible system problems, it is entirely reasonable to conceive that an infinite number of different populations taxonomies and populations characteristics taxonomies also exist for the solution of these problems. This is simply because the most useful taxonomy of any sort is one that is very specifically tailored to the information needs of the particular problem. Be that as it may, however, it is still possible that a general form, or model, exists within which all of these taxonomies would fit. If the general model could be known then it seems reasonable to expect that this knowledge would facilitate the development of problem-specific populations taxonomies - and, consequently, any other activities which are closely dependent on taxonomy development, such as specification of the relationships between measures, i.e., the MOE hierarchy.

In Figure 5 the beginnings of such a model are presented. As listed in the second column of Figure 5, the Systems Taxonomy Model consists of three major levels, distinguished as follows:

a. System objectives - the reasons for a particular systems existence;

b. System functional purposes - that which it must achieve to some level of adequacy; and

c. System characteristics: Structural, Operator/Equipment, Operating, and Support Requirements - how the system is to or does operate.

The definitions of these three model levels include a relationship to the nominal vs. relative levels of measurement. This relationship is given through the association of column two with column one in Figure 5. Examples of the kinds of taxonomic categories or dimensions that might be associated with each of the model levels are given in column three.

The model is to be used to form systems populations, systems characteristics taxonomies, and systems subpopulations. Detailed directions on its use are given in Ref. 6. Suffice it to say here that the user would select the highest level (Level One is the highest level, Level Three the lowest) needed to obtain information on his particular problem and that the resulting taxonomies would then be based on that top level plus each of the lower levels. The extent to which the lower levels are used will depend on whether the question under investigation is simply a status question or is instead a predictive or diagnostic question. As an example, suppose that the analyst wished to gain predictive and diagnostic information regarding the achievement of specific system objectives; in this case, the analyst would wish to start at Level One of the model and include all of the lower levels. In the interest of performing studies which will gradually form a systems and system-component relationships information base useful to analysts and practitioners in solving applied systems

	MEASUREMENT LEVELS	SYSTEM TAXONOMIC LEVELS	EXAMPLES OF POSSIBLE TAXONOMIC CATEGORIES AND DIMENSIONS
LEVEL ONE	Nominal System Measures	. SYSTEM OBJECTIVES	. Production . Supply . Navigation . Air Traffic Control . Health & Welfare . Transportation . Maintenance . Weapons . Surveillance . Etc.
LEVEL TWO	Nominal ⇑ - - - ⇓ Relative	. SYSTEM FUNCTIONAL PURPOSE	<u>Nominal</u> . Indirect command/control/guidance operations . Relatively direct control/navigation operations . Maintenance operations . Data or materials processing - - - - - - - - - - <u>Relative</u> . Command . Control . Information . Data
⋮	⋮	⋮	⋮

Figure 5. A General Systems Taxonomy Model. (page 1 of 2)

LEVEL THREE	Relative System Measures (Ordinal, Interval and Ratio	. STRUCTURAL CHARACTERISTICS	. Organization and layout . Size . Level of automation . Implementation capabilities
		. OPERATOR/EQUIPMENT CHARACTERISTICS	. Human skills, equipment conditions . Human abilities & IQs, equipment capabilities . Values . Needs
		. OPERATING CHARACTERISTICS	. Inputs to operator . Operator processing . Operator outputs . Units being dealt with by system . Environment . Feedback
		. SUPPORT REQUIREMENTS CHARACTERISTICS	. Materials (including people) . Maintenance (including people)

Figure 5. A General Systems Taxonomy Model. (page 2 of 2)

problems, it is recommended that the researcher always start at Levels One or Two and be sure to include all of the lower levels (cf, Ref. 6).

SYSTEMS DESCRIPTION: APPROACHES, COSTS, AND PAYOFFS

The purpose of system description, or identification, is spelled out in Figure 2 and Table 1. It is to provide the systematic knowledge and understanding of system constitution and operation needed for effective action in subsequent analysis stages. The importance and use of information provided by systems description is discussed in detail throughout this report (cf, e.g., pp. 21, 55-57, 67-68). To be provided here is a general discussion of the approaches, costs, and payoffs associated with the system description effort.

APPROACHES Three issues will be considered here: defining the question, collecting the data, and performing the analyses.

DEFINING THE QUESTION Given the question, the first step, as discussed earlier (p. 21) is to identify the populations that will need to be dealt with. An aid to this step is provided in Table 1 where the items requiring description are broken out according to the possible components of a question. The next step is to develop a set of descriptive and analytic system and task taxonomies which, when applied, will bring out the information needed to address the question and organize it in a useful manner. The application of these taxonomies results in the data base of descriptive materials needed for measures definition and for system model and operations formulation.

COLLECTING THE DATA As discussed in Finley, et al (Ref. 7) there are three essential sources of information regarding an operational system: observation of the system, the system operators*, and system documentation. If these were to be rank ordered according to the utility and amount of information to be gained from them, the system operator would be judged to be one of the best sources while system documentation would be judged to be the least useful. Which is not to say that one would wish to depend on only a single source. If at all possible, all three sources should be used in an integrated manner. This will afford the maximum data from each (one can, for example, gain much more from system observation if one already has the working knowledge that can be gained from documentation) and a basis for judging the validity and completeness of data gained from each source (each operator, for example, has some perceptions of his system unique unto himself).

It was noted in the first report (Ref. 7) that the common practice of performing system description analyses based on just system documentation, without inputs from both system observation

*As will be spelled out in the next section, concerning operator models, the term operator should be understood here to include members of both the "plant" and the C&C element.

and operators, often produced incomplete and erroneous description materials. Based on our own program work with a Navy system, the Carrier Air Traffic Control Centers (CATCCs), and subsequent efforts to produce descriptions of it, that original contention has been substantiated and underscored: the production of valid and useful information regarding complex and dynamic manned systems <u>requires</u> observation of the system and interaction with its operators - as well as the use of system documentation.

<u>PERFORMING THE ANALYSES</u> As will be discussed further in the paragraphs below, descriptive analyses, the application of system/task description and analytic methods, is a costly and time-consuming process. One must do it if one is to make informed decisions in subsequent analysis stages - but one must proceed carefully or the whole budget for analysis will be shot and the desired information will still not have been acquired.

As will be noted in a later section (pp. 50-51), there are several general methods and an infinite variety of problem-tailored modifications of these. Based on what one wants to find out (Table 1 again) one selects a subset of these methods, tailors them to the question and the system under investigation, and applies them sequentially to the system until the necessary and sufficient information base has been developed. The results stemming from application of the first method provide some inputs for application of the second method, etc. It is suggested that the most cost- and information-effective way to proceed is carefully and iteratively. As one gains more knowledge about the system and, as a consequence, about the question being asked of the analyst, it is often the case that a reapplication of a method, with some modifications or to a different part of the system, will provide additional and better information. What is being suggested here is that once the initial selection of description methods has been made and the detailed taxonomies constituting them have been initially developed, that relatively inexpensive trial applications of the methods be made. The results of these trial applications, and data on the cost of performing them, then need to be reviewed by the description analysts and the subsequent users of the materials being produced to see if the desired information is being created and whether the costs will be commensurate with the budget. Changes can then be made in the methods and taxonomies being applied to the system so that cost and information criteria will indeed be met. If the manned system is complex, the question an important one, and the analysis budget limited, it is generally best to iterate through such an application-test and evaluate-modify-reapply cycle more than once.

COSTS AND PAYOFFS One fact is that descriptive analyses are expensive and time-consuming to perform. Even more expensive, however, and perhaps dangerous as well, is the performance of subsequent analyses without a valid and sufficient set of measures, models, and scenarios. The result is no information, useless information, or worse, wrong information. Given this, the analyst must make a decision as to how much of his budget should be dedicated to system identification. No final answers (e.g., 30% of the budget) can be given, but considerations important to that decision can be identified: (1) The costs of performing the description analyses vs. the cost of inadequate or wrong answers to the questions, and (2) The resources available for collecting the data and performing the analyses vs. the value of valid and sufficient answers. An iterative analysis procedure, as described above, will permit the analyst to optimize across these considerations.

HUMAN OPERATOR MODELS: THEIR USE IN C&C ANALYSES

There has been a great deal of exasperation expressed by analysts who, in the middle of a systems analysis or development program, are searching for ready-made human operator models which they can just "plug in" to the system model - or which, by a quick and easy exercise, will provide them with the answers to their immediate problem. The complaint is that none of the existing, ready-made models seem to fit the problem. That is, they don't include input and output terms which are relatable to terms included in the system model and/or they don't concern the functions, tasks, or aspects of performance which seem to be the critical ones. And, to the extent that the analyst has carefully gone through a system description process, so that he truly understands the unique characteristics of that system in terms of this problem, this is ever more likely to be true. This situation is not really very surprising, however, to anyone who realizes two things: (1) that while general answers to general questions provide very helpful guidance, it is still nonetheless true that specific questions require specific answers, and that these answers must usually be obtained by means specifically tailored to that problem; and (2) the complexity and variety of human components and of the operations they can and do perform in systems. It should also go without saying, however, that a knowledge of existing models is very helpful and, indeed, necessary if one is not to keep rediscovering the wheel unnecessarily. First of all, there is always the possibility that there is indeed a ready-made model in existence which can be used with little modification or further development. But even if an altogether new model must be developed, a knowledge and understanding of existing models is an invaluable resource of ideas and provides the basis of understanding needed to start the effort.

Given the foregoing, there seemed to be two ways in which this program might assist the analyst in dealing with human operator models. One way, of course, was to develop ideas concerning how to actually use these models in C&C analyses. The other way, an outgrowth of the foregoing statements, was to develop aids for the analyst in selecting and/or developing a human operator model for his program. We will discuss the latter problem first.

THE SELECTION AND DEVELOPMENT OF OPERATOR MODELS As befits the complexity of humans and the variety of systems, there are an enormous number and variety of human operator models. This collection of models would be a tremendous resource of knowledge and ideas to the analyst if they were organized in some fashion so as to be reviewable in terms of analyst information needs and if there were some guidelines available on how to narrow and direct one's field of search. Some trial efforts were made in this program with respect to both of these needs.

With respect to guidelines for narrowing one's field of search, efforts were first made to organize stages of analysis (see Chapter II) and to relate these to question topic components. Next the realm of operator models and model terms were organized in terms of question subject matter. This latter organization of models was then mapped into classical subject areas found to represent the literature. One of the classical subject areas was then selected for a trial effort in developing a models resource document which the analyst could use for review and reference purposes. These efforts are each discussed further in the following paragraphs.

ORGANIZATION OF MODELING ACTIVITIES WITH RESPECT TO QUESTION TOPIC COMPONENTS As discussed in Chapter II, the analysis process was broken into several stages of analysis. Three major stages - systems description, measures definition, and the formulation of system model content and operation - were then related to question topic components. These relationships are presented in Table 1, page 9.

ORGANIZATION OF MODELS AND THEIR TERMS WITH RESPECT TO QUESTION SUBJECT MATTER A desirable breakout of operator models is one which reflects the different classes of question subject matters an analyst might be concerned with and then implies different classes of dependent and independent variables for dealing with each of these question classes. Such a breakout was arrived at during the first year of program effort (Ref. 7, p. 32) and, at this point, it still seems to be the most useful one for analyst purposes. This breakout consists of three classes: (1) Operating/Mission models, (2) Extended Mission models, and (3) Maintenance/Support models. These classes reflect questions about: (1) mission operations and design per se where time, when considered, is used as an operations time line, (2) extended and repeated missions where time can also become an affect or stress factor, and (3) personnel maintenance and support systems, where time, when considered, can take on a personal, as opposed to a mission, lifetime definition. The relationships between these three classes and types of dependent and independent variables are presented in Table 3.

A MAPPING OF THE LITERATURE AND THE DEVELOPMENT OF RESOURCE DOCUMENTS Along with the development of ideas contained in Table 3, the literatures dealing with human operator performance were reviewed to determine how they might best be categorized at a general level so as to make them accessible to and reviewable by the analyst. The thought here was to develop categories representing the overall and traditional makeup of the literature, to map these categories into the three classes of models, and then to develop resource documents for each of the categories which could be used by analysts as references for review purposes. The categories identified as representing the general literature were: ergonomics, engineering psychology, industrial psychology, motivation theory, personality theory, and clinical psychology. These categories were mapped into the three classes of models

TABLE 3. FACTORS AND OUTPUTS ASSOCIATED WITH SYSTEM/OPERATOR PERFORMANCE MODEL CLASSES

	SYSTEM/OPERATOR PERFORMANCE MODEL TERMS	
SYSTEM/OPERATOR PERFORMANCE MODEL CLASSES	FACTORS TO WHICH PERFORMANCE, SITUATION, AND ATTRIBUTE MEASURES CAN BE ASSIGNED	OUTPUTS TO WHICH PERFORMANCE, COST, AND EFFECTIVENESS MEASURES CAN BE ASSIGNED
OPERATION/MISSION MODELS	Inputs to System/Operator Perception Processing Decision-making Skills Abilities Demands on System/Operator Mission Conditions & Events	Decisions Made and Actions Performed
EXTENDED MISSION MODELS	Changes over time with respect to: Procedures Skills, Knowledge Levels Adherence to Procedures Attention to Details Fatigue Motivation Hostility Morale	Continuity, Level Changes, and Variations over Time in the Decisions Made and Actions Performed
MAINTENANCE/SUPPORT MODELS	Career Life Style Standard of living Age Family Benefits Schedules Pay Training programs Messing Berthing Recreational facilities	Continuity and Level Changes over Time in the Decisions Made and Actions Performed

and ranked according to judged relative contribution as follows:

OPERATING/MISSION MODELS	EXTENDED MISSION MODELS	MAINTENANCE/ SUPPORT MODELS
Ergonomics	Motivation theory	Industrial psych.
Engineering psych.	Industrial psych.	Motivation theory
Motivation theory	Personality theory	Personality theory
Industrial psych.	Clinical psychology	
Personality theory	Ergonomics	

One of the better developed and more contained of these areas, ergonomics, was then selected for the development of a trial resource document and the result is cited as Reference 16. The materials in this document are organized in a way which, it is hoped, will do three things: (1) serve to introduce the ergonomics view of man to the analyst who is without background in the behavioral and biological sciences, (2) make the spectrum of ergonomics models apparent to and reviewable by the sophisticated analyst, and (3) by the very expliciteness and detail of the materials make it apparent that ergonomics depicts only a few limited aspects of the human operator and that even these can be very complex. We are rather pleased with the extent to which materials were pulled together and organized from this subject area so as to meet the needs of the analyst who is attempting to integrate the ergonomics aspects of "plant" operations into an overall system analysis program. We suggest that similar efforts made in the other subject areas might also produce useful results.

THE USE OF OPERATOR MODELS IN C&C ANALYSES In an earlier section of this chapter, the functions and purposes of C&C were spelled out. A distinction was made between operators, as well as commanding officers, operating in the C&C vs. the "plant" modes. It was then pointed out that it is the responsibility of the C&C element to manage and modify the plant and its environment to the extent possible so as to reach system objectives within resource constraints. The impact of this on evaluation of the C&C element is that evaluation of C&C performance is in terms of the plant and the plant's environment; while evaluation of C&C effectiveness is in terms of system achievement and resource utilization. Now, when we say that "evaluation of performance is in terms of the plant", what we are really saying is that many of the variations that can be made in the terms and operation of a human operator performance model* are, in effect,

*and models of the other system components as well. The focus of this discussion is on operator models, but variations, for example, in hardware reliability, are also reflections of C&C performance and need to also be considered in any comprehensive evaluation of C&C.

representations of C&C performance, strategy and tactics. That is, that if we vary models in particular ways we are representing alternative C&C approaches, i.e., C&C performance. If we then exercise these different versions of an operator model, the resulting changes in system achievement, if any and in view of the resources expended, are then measures of the effectiveness of the C&C element's strategy, tactics, and performance.

HOW TO USE OPERATOR MODELS IN C&C ANALYSES The use of operator models for C&C analyses must be based on a thorough understanding of (1) C&C, (2) the particular system being worked with, (3) the relationships between C&C and operator processes, and (4) the ways in which operator models can be varied to reflect C&C performance and effectiveness. The foundations for understanding items (1) and (2) are covered elsewhere in this chapter, while the methods for understanding these items are presented in Chapter V. Items (3) and (4) constitute the subjects for this section.

C&C AND PLANT OPERATOR RELATIONSHIPS To assist the understanding of relationships existing between the C&C element and the operator, performing as a member of the system plant, a C&C/Human Operator Relationships model is presented in Figure 6. The model consists of a C&C block, a human operator block, and two kinds of relationships between them: a C&C flow and an information and data flow. There are two things to be noted about this model. One is that the C&C and operator blocks should each be understood to represent modes of operation rather than necessarily representing separate or individual people. Any one person, or teams of people, may at times operate in either or both modes. The important consideration is that the performance of an operator in the plant mode is intimately affected by the performance of that same operator and/or others in the C&C mode. The main concern here is an understanding of those things which can be directly vs. indirectly modified by the C&C element and of what kinds of things the C&C information system can get data on.

Second, the human operator model contained within the operator block is a more general and comprehensive one than most and should encompass most existing operator models. It should be noted that the model not only includes motives and levels of aspiration blocks, it also includes, as intermediaries, the levels of performance possible vs. desired. And, most important, that the levels of performance desired are defined by inputs from the C&C block and weighted by such things as system responsibility and importance. Further, it should be noted that while the model includes levels of aspiration, it also includes such things as actual vs. possible environments, and abilities and skills, as inputs to the determination of that level - and that the level of performance achieved is a subsequent output, with the ultimate consequence of everything being the setting of attitude (greater endeavor vs. hostility, etc.) which then acts in a feedback loop of the model. The development of the overall

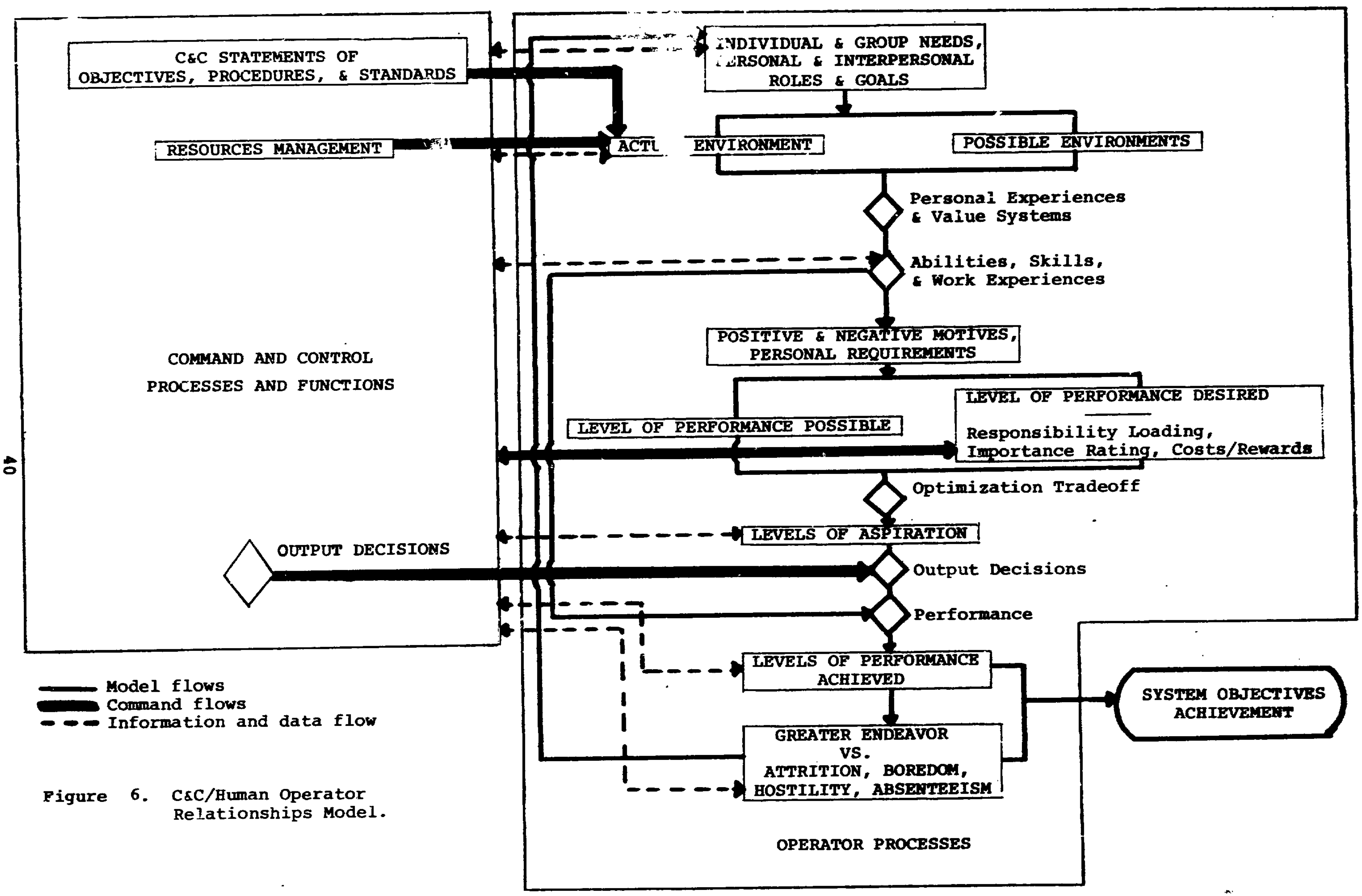

Figure 6. C&C/Human Operator Relationships Model.

relationships model and the operator model was based on the definitions of systems, C&C, and system plants; our observations of the relationships actually in effect in operational systems (principally the Carrier Air Traffic Control Centers, or CATCCs); and a general model of the operator developed by Ullrich and rooted mainly in motivation and subjective utility theory (Ref. 20).

VARYING OPERATOR MODELS When it is said that the C&C element is responsible for enactment of system roles and for achievement of system goals, it follows that the C&C element is responsible for managing the states and activities of the plant and its environment such that these things can be accomplished - both in the short and the long run and within resource constraints. From this it follows that anything which can be varied in a human operator model - and could be expected to vary as a function of C&C action alternatives - can then be used by the analyst to reflect actual or possible C&C strategies and tactics. Each model presents its own special case of possibilities, but, so as to provide a better idea of what these might be, some of these will be listed and then what could be done with a selected sample of four models will be discussed. The list is as follows:

(1) Performance standards
Criteria for performance
Prioritization or "essentiality" ratings assigned to tasks

(2) The range values of performance variable distributions
The shapes of performance variables distributions
Parameter values

Each of the above in the first group can be modified or maintained by the direct order of the C&C element. Each in the second group can be expected to change or remain the same as a consequence of certain command actions. For example, the command element could change the training or staffing quality and quantity requirements and this would, in turn, tend to modify the skill, fatigue, and motivation levels of personnel and, consequently, the ranges and distribution of their performance levels.

A MONTE CARLO MODEL OF TRACKING BEHAVIOR A remarkable study was reported on in 1963 by Adams and Webber (Ref. 1). The focus of the authors in the report was on the validity and utility of a Monte Carlo model they had developed of operator tracking behavior. From our standpoint, however, the model itself is of least interest. What is of considerable interest is the manner in which they went about constructing and evaluating their model because, in this, they provide (1) a basis for evaluating C&C and (2) a test of one way of using "available" data. With regard to C&C evaluation, the authors constructed a model of tracking behavior where an ultimate effectiveness measure is seen to be a function of a set of performance measures derived from operator time and error scores. These, in turn, are a function of conditions. For conditions the authors chose N = number of trials (which could be labeled an operator characteristic, in this case task skill level), R and I = regular vs. irregular signal inputs to the operator (a system condition or mission situation kind of variable), and x and x,y = one or two dimensional tracking (a system design or status kind of variable). These kinds of conditions could each be a C&C responsibility in a particular system. If any of them are indeed a C&C responsibility in the system under evaluation then the C&C level of performance is a function of the valuation of the condition terms, modified by the relative extent of their impact on system measures of effectiveness (MOEs) and cost. Of further interest is that the authors constructed a model of behavior which could vary as a function of any other kind of condition which could also be reasonably expected to modify tracking behavior. The foregoing conditions were simply the ones selected for the first evaluation of the model.

A final note of interest with respect to C&C evaluation is that because the ultimate model term is a system measure, Time-on-Target (TOT) in this case, variations in this value which result from changes in conditions caused by C&C management action are, in fact, measures of C&C effectiveness.

Adams and Webber also provided a test of the possibility of using available data (see Chapter II for a discussion of what constitutes "available" data) by running a series of experiments to collect performance and TOT data under variations of the aforenamed conditions. These data were then used to establish alternative model term values and functions for each of the different conditions, to exercise the model so as to gain model-generated performance data, and to evaluate the formulation of the model they had developed. The two concepts they established by their data analyses were the possibilities of different performance variables distribution shapes as a function of such factors as skill level (fatigue and hostility would seem to be other possibilities) and of different distribution range values as a function of different condition values. We suggest that the analyst can similarly use, to some greater or lesser extent depending on data quality, appropriateness of the measures, etc., data available to him for the purpose of formulating and exercising hypothetical models, evaluating their formulations, and, as a consequence, evaluating C&C.

1, 2 OPERATOR SIMULATION MODEL Siegel and Wolf (Ref. 18) have developed what is essentially a procedures simulation model for 1 or 2 operators. Task performance is described by time and error values and procedural performance is determined by mission timeline, task sequence requirements, and an "essentiality" factor. Task time and error distributions are an input to the model and can therefore be varied for C&C evaluation purposes if so desired by the analyst. Similarly, task procedure sequences, which could result from either C&C action or inaction, can be modified and the results evaluated. Of special interest is the authors' concept which specifies whether or not successful performance of a subtask is essential to successful completion of the task. Nonessential subtasks can be ignored in the simulation during "highly urgent" conditions. This concept is somewhat similar to that of "prioritization", where the command element establishes priorities for the tasks, functions, criteria, etc., within the system which can then be used in making day-by-day control decisions. By changing the essentiality ratings in a model like Siegel and Wolf's, we are then reflecting alternative command strategies and tactics. And thus an exercise of the model using different essentiality ratings provides a means of evaluating the effects of different C&C performances.

QUASI-LINEAR DESCRIBING FUNCTION MODELS These models (cf, Refs. 14 and 17) represent the human operator as a continuous describing function plus a remnant in control systems operation. The operator variables used to determine describing function values include gain, reaction time, signal anticipation, and averaging variables. Each of these variables can be expected to vary as a function of training, fatigue, equipment status, operator ability, and planning - all of which can be considered to reflect C&C performance. Therefore, to the extent that C&C could possibly modify the distributions of any of these variables, then the changes in gain, reaction time, etc., can be taken to reflect C&C performance. And the effects of these changes on the model output terms then can be taken as a measure of C&C effectiveness.

C&C ANALYSIS MODEL The C&C Analysis Model was first developed and tested as a GPSS language model of CATCC which simulates air traffic, command, control, and information flows. The discussion here will be a general one and the reader should refer to pp. 60-68 and to Ref. 15 for more details regarding the model.

The quality and manner of operation of the foregoing flows are understood to represent the results of alternative system arrangements, procedures, operator and equipment quality, command mission decisions, situational events, etc. The simulation of the flows, so as to accomplish the recovery of a flight of aircraft, determines the system MOE values that can result from each of the alternative flow conditions. The C&C Analysis Model can simulate alternative operational scenarios, procedures, and conditions to that level of detail where the simulation can still be expressed in terms of flow effects. Some flow effects can be understood to be directly the result of C&C action (e.g., the aircraft separation criterion selected for that recovery), while others can be understood as being determined by C&C (e.g., poor control due to training or fatigue problems; or missed information due to poor radar maintenance, operator hostility, team management, or C&C information system design problems). These effects can therefore be varied to reflect C&C performance and the results analyzed to evaluate C&C effectiveness.

IV. ANALYSIS FOUNDATIONS: DECISION CONCEPTS AND METHODS

FOUR HYPOTHESES

In the analysis and evaluation of C&C one problem is not a lack of raw data. Developments over the past decade in data acquisition have made available enormous quantities of data. This statement is not meant to imply that all data acquisition problems have been solved. Nor is there the implication intended that all relevant data are readily accessible. But, in every case, if sheer quantities of data are desired they can be found in abundance.

But, more data are not necessarily better. Based on experience, four hypotheses of C&C data analysis may be proposed:

H_1: Most C&C elements demand too much data.

H_2: Most of the data obtained is not relevant to system control and planning.

H_3: The more the system is perceived to be in trouble, the more data will be demanded.

H_4: The more data demanded, the more time will be spent in gathering data and less time in performing functions.

Some comment on each of these hypotheses may be in order.

DATA DEMANDS (H_1): Ready availability of data has lead to what we have called "an orgy of data acquisition" (Ref. 7, p. 18). There is a persistent belief that quantity of data will somehow solve problems. Given that assumption, it follows that more data will solve more problems.

In fact, one could argue, based on recent experience, that more data may lead to solving less problems. There is a point at which the analyst and decision maker can receive more data than it is possible for them to assimulate and process. The channel capacity of the human is overwhelmed. Beyond that point, additional data lead not to problem solving but to confusion. A basic limit, therefore, on data acquisition is the amount of data an analyst can receive and process in a reasonable amount of time. It is to be suspected that the human limit is far less than the capability of present data acquisition systems.

RELEVANT DATA (H_2): Most available data are irrelevant. They serve no apparent purpose. Classic in this regard is the standard application blank for employment. The majority of the information supplied by the candidate is never used because there is no conceivable use for the data. The data are not relevant to the decision involved: selection and placement of the prospective employee. Indeed, data relevant to that decision are often not present.

For C&C element control and planning, most decisions depend upon the prediction of events to come. Control and planning require anticipation of future system states and the future actions necessary to change them. In short, what must be estimated are things to come.

Historical data are useful to the extent that the system is relatively stable. The more the system changes the less valid predictions based on these data will be. In using historical data, the analyst must also estimate stability for prediction purposes. This is not an easy analytic task; there are no formal rules to assist the analyst.

DATA AND SYSTEM PROBLEMS (H_3): When a system is perceived to be in trouble, there are a number of possibilities. The system may, indeed, be in trouble or the system may not be in trouble. Problems, if they exist, may not be those of the analyst's perception. It is interesting how often system "problems" are perceived based on vague (and sometimes erroneous) notions of the analyst and the decision maker.

Whatever the case, given the perception of a problem, it is almost automatic that the analyst and the decision maker will demand more data from the system. Ostensibly, this is a reasonable step; one wants more data upon which to base corrective action.

But, in practice, data acquisition may confuse rather than clarify system problems. The problem is: data about what? The analyst and the decision maker should interrogate selectively. The first step is to ascertain what the problems are (e.g., the status question; see pp. 48-50). Only then should detailed diagnostic data probing take place.

A particular difficulty for systems in trouble is "filtered" data. Data sources may, knowingly or unknowingly, shape data inputs. These "data" may either hide or unnecessarily accentuate system problems. This tendency places a requirement on the analyst to obtain validity estimates of data received.

DATA TIME DEMANDS (H_4): Very few analysts and decision makers appear to realize the demands that data acquisition can make on a system. Every system is resource-limited, and it is imperative to exercise careful control over resource allocation for data acquisition.

The more time system personnel spend in data generation for evaluation purposes the less time they can spend in performing system functions. C&C (and management) elements appear to be particularly plagued by this problem. Many middle-level managers, for example, appear to spend most of their time reporting rather than directing and performing system functions. If this is a deliberate allocation decision, then it is acceptable. If not, one must accept the consequent degradation of system performance.

MEASUREMENT UTILITY

UTILITY CONSTRAINTS A fundamental constraint that C&C analysis and decision makers must accept is cost-effectiveness in data collection. Every data point must be evaluated by a number of questions before the data are collected: What question will the data answer?, Are the data already available if an ADP data store exists?, Can the data be collected?, What resources must be spent in collecting the data?, If acquired, will the data be worth knowing?, and How much will it cost to collect the data?.

Data collection is not a free variable in the system. Data cannot be acquired without resource expenditure. Thus, the analyst and the decision maker must be bound by utility constraints in data processing. Information collection is essential to the survival of systems and the operation of their C&C elements. But excessive data processing can damage the system if cost-effectiveness constraints are not placed upon system performance measurement.

MEASUREMENT UTILITY CONCEPT Following the work of Cronbach and Gleser (Ref. 2), the notion of measurement utility can be made mathematically explicit. The following equation identifies the parameters that should be considered with respect to measurement:

$$U = N \sum_{y} p_y \sum_{t} p_{t/y} \sum_{c} p_{c/yt}\, e_c - N \sum_{y} p_y C_y$$

Where:

- U = utility of the measurements being taken
- N = number of observations
- y = information category
- p = probability
- t = treatment
- c = outcome
- e_c = value of outcome
- C_y = cost of collecting the measurements

Of basic concern here are the payoff functions associated with measurement collection. In short, in any given case, what measurements are worth collecting?

This approach stresses a number of critical aspects to measurement utility:

First, what measures (y) are necessary and sufficient to describe the process being measured? A great deal of experience has shown that an "obvious" measure often does not, in fact, provide useful information.

Second, what sets of rules are assumed as constraints on number sets (e.g., the strategy matrix $p_{t/y}$ in the equation)? These rules are often used to sort data for future, more detailed, evaluation. They are particularly important if adaptive measurement systems are used.

Third, what is the reliability of measurement? Reliable (i.e., consistent) measurement does not guarantee useful information. However, unreliable data will lead to no information whatsoever. This is a necessary, but not sufficient, constraint.

Fourth, what is the validity of measurement ($p_{c/yt}$)? Do the data measure what they say they measure? A surprising result here is that useful information can be obtained with less than completely valid data. Indeed, in some cases, a degree of validity may be sacrificed depending on desired level of precision and the cost of the required information. However, some minimum level of validity must be obtained; what that level is depends upon the specific context.

Fifth, what is the value (e_c) of collecting the information? Is it worth knowing? It may be possible that the majority of the measurements yields data that are not of sufficient value to be known.

Sixth, what is the cost of collecting the data (C_y)? This cost must consider not only the direct cost of the resources spent for data acquisition, but also the system "cost" in resource allocation. What functions are not being done when data collection occurs?

All of these six questions must be asked and answered if the utility - the cost-effectiveness - of measurement is to be justified. The C&C analyst will be well-served in using these questions to guide his data collection process. He will not only obtain better data, but he will be able to justify the utility of the data he has collected.

V. ANALYSIS TOOLS: CONCEPTS, METHODS, AND GUIDELINES FOR THE ANALYSIS PROCESS

WHAT IS THE QUESTION?

THE QUESTIONS OF THE ANALYST Fundamental to the analysis process is the asking of relevant questions about the system and the components of the system. The strategy by which the analyst asks his questions will have enormous impact on data acquisition, processing, and interpretation. What the analyst is trying to do is to turn data into information, not random information, but information directly relevant to systems and subsystem questions.

Unless the analyst is extremely careful about this process he probably will incur two undesirable results: (1) he will not get meaningful answers to the questions he is asking and (2) he will make unreasonable data demands on the system and system components. Great care, therefore, must be exercised by the analyst in his search for information.

THE FUZZY QUESTION Most frequently, the analyst will probably initiate his information search with a fuzzy question. That is, the question will probably be vague to some extent. It is assumed that he may not know exactly what he is trying to find out. Even when the analyst thinks he has a specific and well-defined question, the question may not be the one he should be asking.

Because of questions that are fuzzy or irrelevant to the analyst's search for information, the analyst should be prepared for a process of search on the data base. At least two steps are involved: (1) he must be refining his question based on data obtained and (2) he must be checking the question for relevance. He must ask himself: "Is my question clear?" and "Am I getting an answer I can use?" At best, his success may be relative, but that is usually sufficient.

A common mistake in the design of management information systems has been to assume that all possible questions can be defined a priori, and then fixed into the system. If this were reasonable, then there is no doubt that design would be simplified. However, in practice, what has resulted is a set of simple and usually irrelevant questions which the data system can answer quickly but which are not useful. Unfortunately (but understandably), under the pressure of design time limits, the question set is usually defined too quickly, and emphasis is placed on questions that are easily structured and accommodated to a data base design. They are usually not the questions the analyst needs to know in operations.

The information system designer, therefore, must allow for the fuzzy questions which the analyst will be asking. The designer should consider providing search aids for the analyst. On the other hand, the analyst must exercise discipline in his search or the data demands on the system may become excessive (see Chapter IV).

THREE FUNDAMENTAL QUESTIONS In the initial technical report (Ref. 7), a taxonomy of three basic kinds of questions was proposed: (1) system status, (2) system prediction, and (3) system diagnosis.

1. The system status questions are of the general form: "How goes it?" Most usually, they are measures of effectiveness (MOE) about the total system and not about system components. The existing MOE technology appears to confuse this point, and often substitutes component MOEs as if they express total system performance. They do not. Optimal subsystem performance often means sub-optimal total system performance. Indeed, for optimal system performance, it is often necessary to sub-optimize the components. For example, maximum pay benefits for personnel may well be an optimization function for the manpower component but it is hardly optimal (or even feasible) for the total system.

2. System prediction questions search for the future: "What is going to happen?" Most of the critical questions for the C&C component will be of this class. To make meaningful control actions, the C&C component must anticipate system events. Therefore, it must make estimates of what might happen both with and without alternative management actions.

All prediction is difficult and none more so than with manned systems. In general, the farther out in time the less valid the prediction will be. The analyst surely may (and often must) ask prediction questions in the five and ten year time spans. But he must be extremely careful in using the predictions. Further, he is wise not to ask precise and detailed prediction questions about time-distant events.

3. System diagnostic questions are obviously concerned with the question: "What is going wrong?" To ask this class of questions assumes prior status and/or prediction answers. These questions begin with the estimate that something is, or will be, inadequate. The analyst's task is, then, to search for the causes of deficiency. In this case, the search probably must extend into the precise details of component performance.

But, the analyst must be alert to the possibility that the system is not, in fact, deficient. Status and prediction system estimates are often global sometimes imprecise, and open to misinterpretation. The latter is particularly true when desired system performance standards are not made explicit.

For example, one may implicitly assume that the system is 100% reliable. For human systems, this appears to be an unattainable goal, desirable as a goal but with the understanding that something less will be achieved in practice. What the analyst must define is the acceptable, practical, level of system reliability that is adequate for system performance. Without that value, actual reliability data obtained from status questions cannot be properly evaluated.

Worse, the analyst may trigger detailed diagnostic questions when it is unnecessary. The analyst must realize that diagnostic questions make great data demands on the system, and he should only ask for these data when he is strongly assured that he needs the data.

FORMING THE QUESTIONS Although this methodology suggests much flexibility for the analyst in asking system and subsystem questions, it is essential that some question structure be established. The analyst must be given some assistance in methods of question search and of tools for asking those questions which can be structured in the design of the management information system.

There are many ways the question structure and process can be configured. Experience from previous systems may be useful. Expert opinion, when properly collected, will be fruitful. More careful analysis of the potential questions, and the methods by which answers can be obtained, is always indicated. For the C&C component, analysis of potential management questions is rarely performed.

In C&C, for example, the decision maker often does not know exactly what he should ask. When he wishes to know the status of the system, he may not be sure how to ask for a status answer in terms which are most meaningful and timely to him. If something is wrong (the diagnostic question), he may not know the best way to find out what is wrong. Or, in either case, he may ask some specific set of questions which will not, in the end, give him meaningful answers.

Some structure, therefore, is essential to speed and increase the efficiency of the question search process. How exact that structure can be is a function of many variables. One critical variable is the degree to which the system process is understood. It is for this reason that so much emphasis has been given in this report to taxonomization and description. We must be able to describe the system if we are to understand it. And the degree to which we are able to describe the system will determine how easily (or not) we are able to structure the questions we want to ask about the system (see Table 1 for a question-analysis stage relationship structure).

SYSTEM DESCRIPTION METHODS

Program efforts on system description methods were for the purposes of exploring ways to describe systems for C&C analyses and to investigate the costs and payoffs associated with these. Creative efforts resulted in an integration of existing methods into a new Operation/Mission Requirements Analysis Method, seen to be the first and major method in any sequential set of methods that might be applied to a system. This method was developed and evaluated through work with a Navy system, CATCC, and is reported on in References 7 and 8.

Other methods were also tested and evaluated in this program in support of the C&C Analysis Model development effort (pp. 60-68). The goal was to determine a set of methods which would satisfy the information needs for system model and operations formulation, where the test vehicle was the development of two computer models of CATCC. Methods found to satisfy CATCC model programming needs, up to a point, were the aforementioned Operating/Mission Requirements Analysis, Operational Sequence Diagrams (OSDs), and supplemental descriptions of the information contained in data transmissions and of decision processes during a sample of scenarios containing contingency events which modified information and aircraft flows (e.g., radar breakdown, bolter/waveoff aircraft). An additional program output resulting from these efforts was a handbook. The handbook describes the above methods and provides details on the work that was done with them on CATCC. The reader is referred to Gainer, Reference 8, for information on this document.

It will be noted that the phrase "up to a point" was used above. As discussed on pp. 67-68, the computer simulation language used by the C&C Analysis Model is capable of richly simulating operator behavior. To use this language to its full capability required, however, more information than was provided by the above methods or could be provided by any other traditional description method. As noted on pp. 67-68, it would appear very worthwhile to develop a new description method which would provide the programmer with the additional information needed to fully use computer simulation languages. If such is not developed then either we (1) cannot fully analyze the effects of the plant operator or of the C&C element on overall system effectiveness and performance, or (2) the programmer makes modeling decisions based on inadequate information. Based on our efforts with CATCC and CATCC program development, it appears that a description method could be built around the General Purpose System Simulator (GPSS) language and that such a method plus the Operating/Mission Requirements Analysis Method would provide sufficient information of themselves; that is, that the additional OSD and supplemental description methods would not be needed.

MEASURES AND MEASUREMENT

As stated at the outset in Chapter I: "...understood meaning is the goal of analysis and...valid and sufficient measurement - whether qualitative (e.g., verbal) or quantitative - is the means to that end." (page 3). Each piece of data collected represents a very specific piece of information; the information content is known only to the extent that the measure represented by that data has been fully and validly defined.

Given the foregoing, it seemed to be most important that a general methodology for the analyst, like this one, be oriented towards the problem of developing a good measures set; that is, a set that will provide data containing the information needed to answer the analyst's question. As a consequence, this methodology has stressed the taxonomization and systems description analysis process stages because they lead into the final definition of a measures set. In this section we will introduce some considerations regarding measures, discuss the development process a little further, and discuss the final selection of measures to be actually used.

MEASURES CONSIDERATIONS There are several considerations which bear on the development of measures definitions but which do not fall easily under any one heading. These are discussed here.

<u>FUNCTIONALLY DIFFERENT TYPES OF MEASURES</u> Both systems analyst types of people and behavioral psychologist types often seem to have a rather large amount of difficulty in identifying any measures of the human component which bear a relationship to system performance or effectiveness measures, and vice versa. I would like to suggest that it is not that no relationships exist - they, in fact, do exist. One problem, however, is that few of the relationships are of the sort being sought, while many are of the sorts being ignored; and that those ignored relationships are functionally different, usually measurable, usually analyzable, and important.

Two general types of functional relationships between measures are of interest here: (1) The categories of cause-effect relationships and (2) Time relationships. There are three categories of cause-effect relationships:

* Determining
* Enabling
* Bounding (or, Limiting)

One of the causes of the problem discussed above is that there is a strong tendency, when seeking measures of the relationships between man as a "plant" operator, man as a member of the C&C element, and the system, to consider only those relationships which are determining in nature; that is measures of a man, x, which determine the variance of a measure y of the system. Man also acts, however, as both an enabling and a limiting agent in most systems, performing or withholding actions so that other parts of the system are enabled to operate and have their effect and, similarly, performing in a manner which will either prevent or constrain the effects of actions to an acceptable level. When the operator and the C&C element performs in these latter capacities a determining equation of the form $y = a + bx$, where x is a measure of the operator and y is a measure of the system, does not describe the action of x on y. Instead, some other form of expression, as in calculus or a simulation program, is needed in order to describe the boundaries within which things are constrained, allowed, or enabled to operate as a function of x. All of which is simply to point out that while plant-C&C-system relationships of a determining nature do exist, they are not the only ones nor the only important ones. The plant operator and, especially, the C&C element also perform as enablers and limiters - both on other system components and on the system as a whole.

The second type of relationship of interest here is that of time. For reasons of ease and simplicity of qualitative and quantitative expression, no doubt, analysts prefer that time not be a variable in the equation and not be otherwise considered except, if necessary, in the form of a mission timeline. This is reasonable of course only if everything that the operator and the C&C element does has an immediate effect on the system and if his effect does not vary as a function of time. This, unfortunately for the analyst, is not the case for much of what the operator does and for most of what the C&C element does. (Take, for example, the maxim that it takes two years to feel the effects of a new manager; or the contribution of the maintenance technician's adjustment activities to system reliability.) The point is again, as in the foregoing discussion regarding cause-effect relationships, that there are many important time relationships between the plant, the C&C element, and the system besides the immediate online relationship. And the problem of specifying measures of the operator, C&C, and the system which will relate to each other will be facilitated if the analyst will consider those relationships which either include time as a variable or else themselves vary as a function of time.

COMPOSITE VS. MULTIPLE MEASURES It is often the case that data can be collected on a composite measure, Y, and on some, if not all, of the variables, y_i, thought to be a part of the composite according to the following:

$$Y = a_o + a_1y_1 + a_2y_2 + \dots + a_my_m^*.$$

*The additive form is used here merely as a convenient example and its use is not intended to imply that it is necessarily the proper form of expression.

As an example, Y could be a rating job "goodness", while the y_i might include rate of pay, a working environment rating, a job interest rating, job work pace parameters, etc. (cf, e.g., Ref. 11).

Whether or not one wants to collect data on just Y or also on as many y_i as possible depends on several considerations:

a. How good (i.e., valid, sensitive, and reliable) is the measurement data on Y? And how completely known is the real definition of Y?

b. What is the question? Is the question strictly and forevermore just a status question, or will more detailed prediction and diagnostic questions also be asked?

c. What is available in the way of resources, what will it cost to collect data on additional measures, y_i and/or x_i, and what is the resulting information worth?

HOW WELL KNOWN IS Y? Very often, when dealing with measures of the human system component, it is very difficult to be sure that the measurement data are truly on the measure we originally defined (validity, sensitivity, and reliability problems arise if they are not) and/or that we fully understand the composition, i.e., the detailed definition, of Y. In the event that there is any doubt on these matters, it can be very helpful to also have data on measures y_i thought to form even part of the composite of Y. If, for example, data could be collected on y_2 of the above equation at little additional cost, and if y_2 was thought to be a substantial part of the definition of Y, then a regression of y_2 on Y could be performed and evaluated. If the regression (or correlation) proved to be substantial enough then one would have greater confidence in both the data on Y and the definition of Y. If the regression proved to be minimal or in the wrong direction, this would not indicate in itself wherein lay the problem - but it would raise a flag of caution in either using Y data for other purposes or interpreting what the data on Y actually said.

WHAT IS THE QUESTION? If the question is simply one regarding the status of Y and if the definition of Y is clearly known, then all that is needed is data on Y. This is the necessary and sufficient data. If, however, the question is, or will be, a prediction or diagnostic one then one may not only have to collect data on all the y_i possible, but also on any determining variables x_i, that are known:

$$y = a_o + a_1y_1 + a_2y_2 + \ldots + a_my_m = b_o + b_1x_1 + b_2x_2 + \ldots + b_nx_n{}^*$$

The reason of course is that variations in the y_i and x_i terms are the causes of changes in Y, comprising the question in prediction

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*While the additive form of expression may or may not be correct, depending on the individual case, the relationship of $f(y_1, Y_2, \ldots, y_m) = f(x_1, x_2, \ldots, x_n)$ is felt to be the correct general case.

questions of "What if ...?" and comprising the answer in diagnosis questions of "What is the problem?"

WHAT IS THE ANSWER WORTH? As directly discussed in Chapters IV and VI, and alluded to throughout other discussions, one does only that for which one has the resources and which is worth the cost. Collecting data on a measure, be it from an operational or test environment or from an existing data base of some sort, and then submitting it to analysis, is an expensive process. On the other hand, coming up with incorrect findings, because one did not do a sufficiently thorough job of measurement and analysis, could also be very costly. If the cost of data collection and analysis is the only concern and resources are limited, then one should deal mainly in composite measures, that is, in the fewest measures possible. If valid and complete information is the only concern, then one should deal with the complete set of both composite and multiple measures. Most real-world problems require an approach that is a compromise between these two extremes and the trick is to make the right choices.

EMPIRICAL VS. ANALYTICAL APPROACHES TO MEASURE DEFINITION There are two quite different ways to approach the problem of developing a set of measures, the empirical vs. the analytical. The empirical approach is the classical one (in the job evaluation and test development literatures at least) of developing large lists of evaluation items and then subjecting these items to standard methods of validation. The approach to developing the initial list is essentially a hit-or-miss one of "if it moves, measure it; if it doesn't move, measure it anyway!" The validation process is an empirical one and very expensive, but if the right measures were included in the original list, they are likely to be identified through the validation process. The problem is that the proper measures may never be included in the original list.

The analytical approach is to first gain an indepth knowledge of the system through systems and task analyses, and then to use these analysis materials as one basis for defining a set of measures. The cost here is in the development of the initial list of measures - systems and task analyses are expensive. The constraint is that the development and application of taxonomies for the system and task analyses are, in fact, the initial settings of the dimensions around which measures will later be defined. If the taxonomies are not adequate or are poorly applied then, again, the proper measures may not be derived.

These two approaches, empirical and analytical, differ in the sources from which the measures derive their validity - empirical test vs. an analytic knowledge of the system. Actually, to the extent that opportunity and resources permit and that validity is essential, both approaches should be taken. That is, the development of the original set of measures should be based on a thorough system and task analysis, while additions to and validations of the set should derive from empirical test. If obtaining the correct and complete answer is worth the cost then an iterative approach, cycling between the analytic and empirical stages, is best.

THE DEVELOPMENT OF MEASURES As shown in Figures 2 and 3 and listed in Tables 1 and 2, the analytic approach to the definition of measures is an evolutionary process. It begins with the initial taxonomization of subject areas (e.g., the development of a populations taxonomy) and very initial identification of what general kinds of measures might be appropriate (see figure 2), proceeds with the identification of the system through application of description methods (e.g., requirements analysis formats, system and task taxonomies) (see table 1), and concludes with the final evaluation and selection of those measures on which data can be obtained and which will provide information on entities, operations, and relationships such that the analyst's question can be answered (see table 1 and figure 3).

Although the foregoing may seem to be the obvious procedure to some readers, these readers are in a minority. Referring back to Figure 2, the more usual approach is to rather immediately jump into the system model contents and operations formulation stage, using whatever measures and measurement data happen to be handy. The approach outlined in Figures 2 and 3, in Tables 1 and 2, and on pages 6 through 12 is, in contrast, a very conservative approach. One that says, if the system is a complex and dynamic manned system and if the question concerns or revolves around the C&C element, then considerable care and attention should be given to the measures set development stages - the stages <u>prior</u> to system model formulation and analysis. The reasons for this conservative approach are simply that, under such circumstances, there are no well-known or standard measures, the relationships and processes that should be measured are not the easy or obvious ones (see, for example, the above discussions regarding cause-effect and time relationships), and the amount of information to be gained from subsequent analyses can be no more than that provided by the measures set. At the risk of being tiresome, the importance of the measures development process, and of the contributions of taxonomization and system description to it, is once again underlined. It is a creative process requiring talent to perform well; but it can always be improved upon by careful attention to system identification and the evolution of taxonomies. The adequacy of the results, that is, the amount and validity of information provided by data on the measures set, determines the adequacy of the answers that can be determined by any subsequent modeling or analysis efforts; so the effort to develop the necessary and sufficient measures set is worth whatever the answer to the question being asked is worth.

SELECTING THE MEASURES TO BE USED The final selection of measures to be actually used will result from (1) a comparison of what measures are wanted, what measures are represented by the available data (see page 5 for a definition of "available" data), and what measures can be taken in operational or test environments, and (2) an evaluation of the costs of obtaining and using data on various combinations of measures vs. the value of the information to be gained. The concepts and procedures for item (2), the utility notions, are covered in Chapters IV and VI. Here, a brief discussion of item (1) will be presented.

A flow between the question and the set of measures selected is depicted in Figure 7 so as to bring out the relationships between the desired measures set (i.e., the necessary and sufficient set of measures to answer the question under investigation), the already available measures set, and that set on which field or laboratory data can be collected (referred to here as the "additional" measures set).

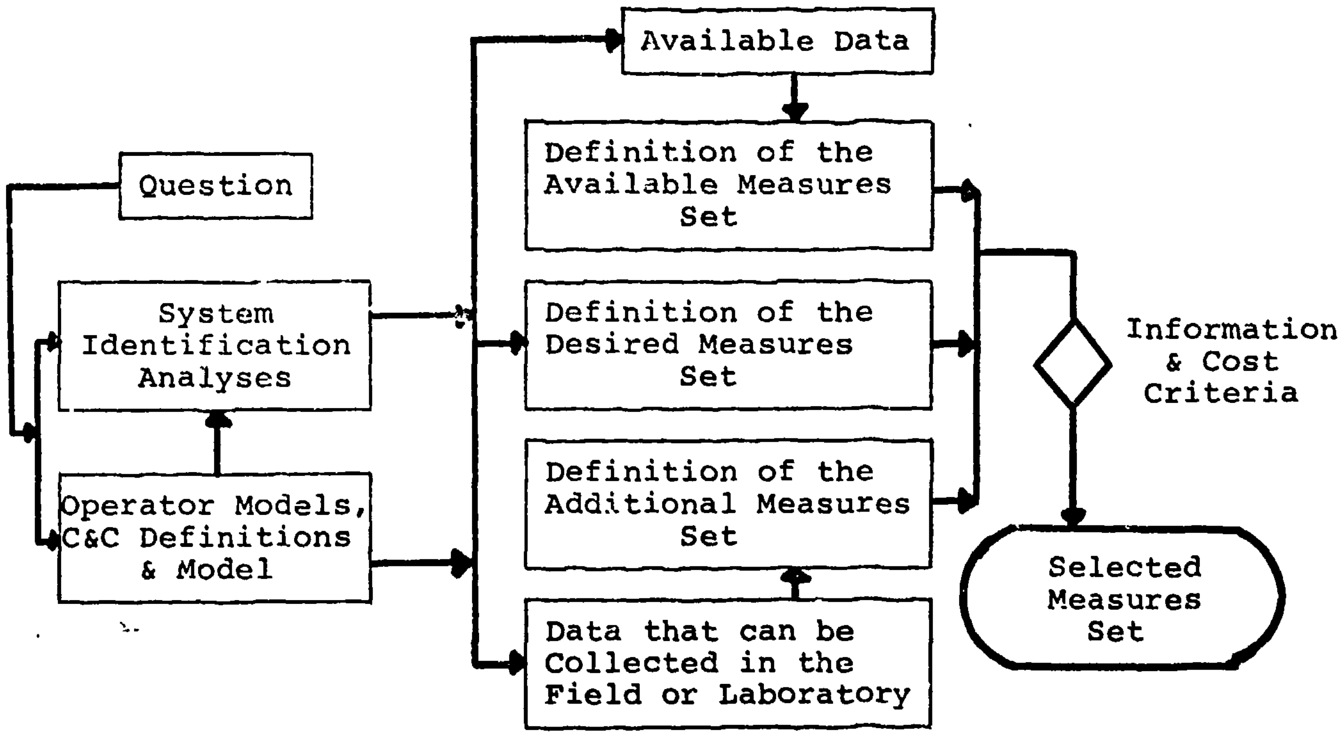

Figure 7. Determination of the Selected Measures Set.

What is being said here is simply that, based on all the inputs from the system identification exercises and from such foundational materials as operator models and the C&C Functional Model (Figure 4), the analyst will develop a list of desired measures; that is, a list of those measures of system and system component states, relationships, and operations which are necessary and sufficient to provide that data which can then be used to answer the analyst's question. Given the desired set, the next questions are, What is already available? and What more in the way of additional data collection is reasonable?

There are available to the analyst an enormous number of data bases of various degrees of "formalization"; one of the most informal, and often most informative as well, is the system operator himself. The more formal data bases are those contained in computerized data banks. The problem with available data, be it in a hardcopy file or a computer file, is that it often takes considerable analysis effort to determine the meaning of those data; i.e., to define the measures which those data represent. If the data are manned systems data then the analyses needed to determine the available measures set include system/task analyses regarding the system in which the data were collected; these may have been largely completed already as a function of determining the desired measures set. And, of course, analyses are also needed of the data collection instrument, of the measurement procedures, and of the sampling rates and time with respect to other events.

Also available to the analyst is the operational environment, which can be used to provide data on an "additional" measures set. This availability is at some cost, but the value to be gained is usually well worth the price if the question under investigation is important. The determination of what measures might be taken in the operational environment must also be based on a system/task analysis that has already been performed and was itself based on operational experience, and must be in consideration of the measurement capabilities in and costs to the operating system. The operating system will present some set of measurement possibilities unique unto itself, it cannot/will not brook any interference with accomplishing its mission, and the response of its personnel to any form of questioning, including questionnaires, will be a direct function of how sincere the analyst's quest for knowledge appears to them to be; i.e., is the analyst <u>really</u> concerned with helping resolve their problems and/or the Navy's problems and does he appear to also have a reasonable insight regarding the situation such that he might be expected to have some degree of success?

It is usually the case that the desired, available, and additional measures sets are overlapping sets; the analyst can get data that will answer his question of course only to the extent that the desired measures set is overlapped by the other two. The task is to select those measures from the "available" and "additional" measures sets which are either also members of the desired measures set or will provide some estimate of these measures; and to do this in a manner which is within costs but will provide as much of the necessary and sufficient data as possible. The making of this judgment will be assisted by the utility notions in Chapters IV and VI. It can be noted here however that the facts that the desired measures set may not be completely covered by the available and additional measures sets, and, further, that costs may serve to constrain the use of the available and additional measures sets, establishes a limit on the extent to which the analyst's question can be fully answered and answered with known validity.

A COMPUTER MODEL FOR COMMAND AND CONTROL ANALYSIS

One approach to the evaluation of manned systems and their C&C elements is direct empirical observation; however, direct measurement, and especially the study of system variables by systematically altering conditions within an operational manned system, are often impractical. A model of the system which allows variation and measurement may therefore be a cost-effective alternative, and consequently a method of developing system models for such purposes was sought. If the method realized at this point was further developed and refined, so that it could be described without reliance on example, it would constitute a generic computer model in and of itself. The method is therefore herein named the C&C Analysis Model.

The C&C Analysis Model was developed through the selection of what seemed to be the most suitable kind of programming language (a simulation language, GPSS in this case), applying it to an operational system (the Carrier Air Traffic Control Centers, or CATCCs), and developing programs, or system models, of this system at two levels of complexity. Since the purposes of developing the two programs were to develop, test, and evaluate an analysis method and to develop examples for method exposition, the programs were kept as simple as possible. Sufficient direct programming experience was accumulated so as to provide a basis for the establishment of general procedures and some evidence of the workability of the approach. The programming exercises, or CATCC models, also provided evidence that simulation languages do provide the means for common computer representations of both human and machine components so that subsystem and total system performance can be measured and integrated in terms of common computer parameters.

A complete technical report was produced during this investigation of computer models (Ref. 15) and in it were discussed the following areas: model development, guidelines for the developer, and discussion of the various uses of the model in C&C analysis. In the current presentation, however, the following will be emphasized: (1) the characteristics of the specific GPSS models of CATCC which were examined, (2) some comments about the task description process which were elicited by the model development process, and, (3) the relationship of these models to the overall C&C analysis.

<u>CHARACTERISTICS OF THE SYSTEM MODELS DEVELOPED AND EXAMINED</u> To be described in the following paragraphs are the characteristics of the selected programming language, the CATCC system, and the two models of CATCC which were programmed for method development purposes.

THE GENERAL PURPOSE SYSTEM SIMULATOR (GPSS) LANGUAGE The computer language chosen for model development was the General Purpose System Simulator language (Refs. 9 and 10). Based on a review of easily available languages, the simulation languages seemed to hold the greatest potential for C&C analysis purposes; GPSS was the one most readily available to the investigators for test and evaluation. GPSS is a language used for modeling systems in which there is a flow of some type and in which discrete events characterize the state of the system. It is often used for simulation of such things as traffic flow, assembly line production, and the formation of lines (queues) at toll booths and ticket offices. It seemed especially suitable for the simulation of the information flows which control, result from, and are affected by system events and C&C action.

GPSS is a block-diagram oriented language. When a system block diagram is prepared at a sufficiently molecular level using a GPSS-specific set of blocks, the computer program can be derived directly from the block diagram. The block diagram of a simple queue forming at a theatre ticket window is presented in Figure 8 as an example. In sequence, the block diagram indicates that the computer model should (1) GENERATE transactions (people) and cause them to be introduced at intervals according to a specified distribution, (2) form a QUEUE, or waiting line, for people waiting their turn and keep statistical records on the length of the line and waiting time, (3) SEIZE a facility (the ticket vendor) when an individual gets to the front of the line and the ticket vendor is not busy, (4) DEPART the queue, (5) ADVANCE the clock according to a specified distribution to account for the time needed for the ticket to be given and money exchanged, (6) RELEASE the facility for the next person in line, (7) TABULATE statistics (update frequency distributions) of system quantities for printout at the end of the computer run, and (8) TERMINATE the transaction (individual) from the system. This block diagram can be translated into a computer program along with specific system quantities. The computer model can then be exercised until a specified number of transactions are terminated; subsequently the run would stop with a printout of requested statistics.

GPSS involves a number of entities which are included in a system model simply by referencing them by number (as there may be many of each). First, transactions are entities which flow through the system block diagram. Transactions may be thought of as people, automobiles, airplanes, mail, etc., as one wishes. Each transaction carries with it twelve or more numbered parameters. Values associated with each parameter can be used to characterize the transaction. Facilities are entities which simulate the processing of transactions, with one transaction at a time being processed. Storages may process (or store) a number of transactions at a time, but a capacity for storage must be specified. Queues, as already indicated, are used to cause the GPSS system to maintain statistics on lines which form. Savevalues are numbered storage areas where special data may be kept until the end of a run. Standard Numerical Attributes (SNA) are system quantities which are automatically remembered. These and other entities are available to the GPSS programmer to create a computer model.

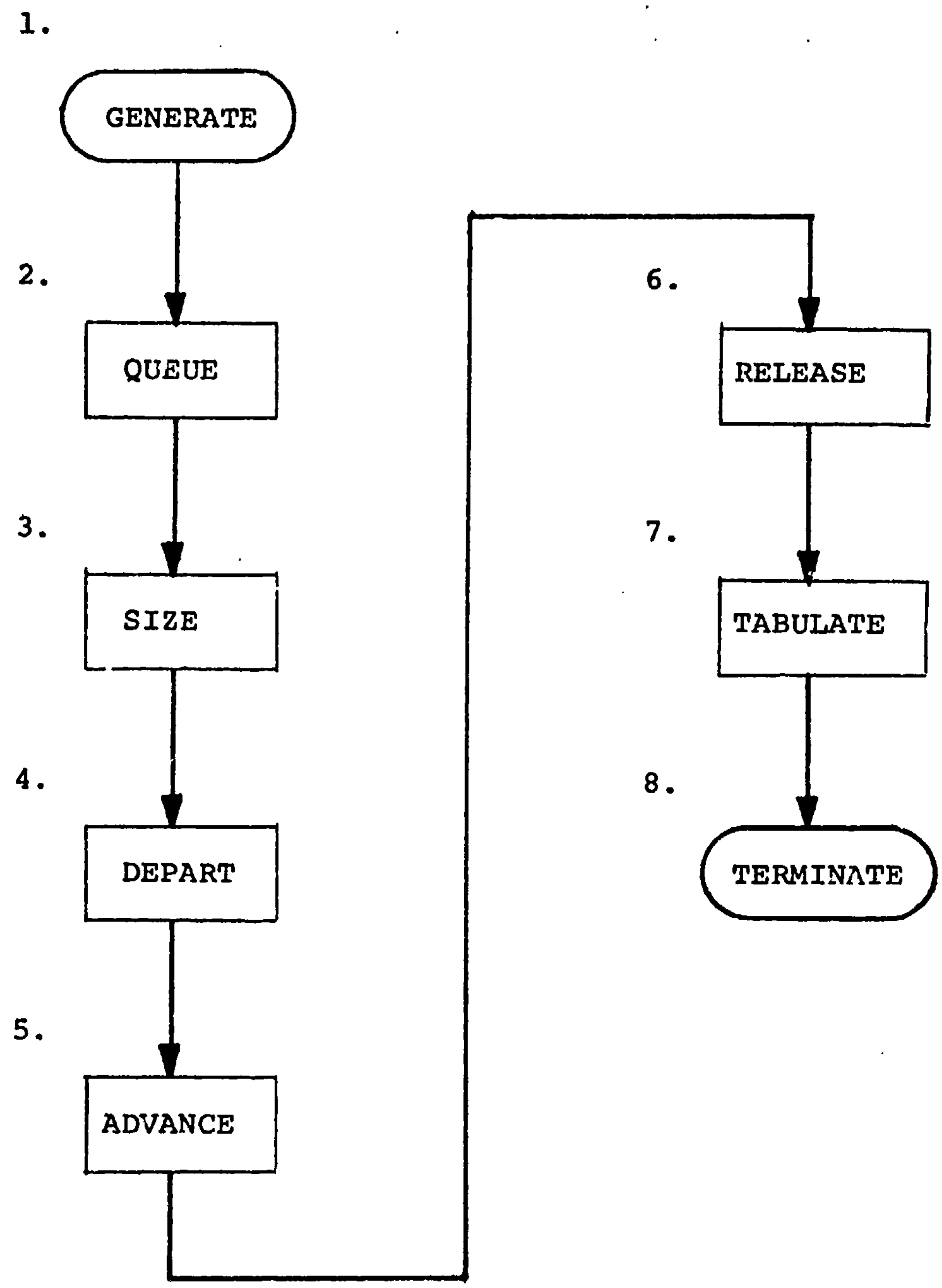

Figure 8. An Example GPSS Block Diagram
(A Queue at a Theatre Ticket Window).

THE CARRIER AIR TRAFFIC CONTROL CENTER (CATCC) MODEL The specific system selected for modeling was the Carrier Air Traffic Control Center (CATCC) (see Ref. 7 for a detailed description of CATCC). As may be seen in Figure 9 the model has five kinds of transactions flowing: (1) the aircraft flowing from the Marshal point down to the deck of the carrier, (2) data or communications flowing to or from the aircraft, (3) processing, or transformation of these data, and (4) requests for control actions flowing to the aircraft. Additionally, (5) command information may flow into the CATCC from external sources.

When using GPSS, continuous processes, like aircraft flow, must be simulated as a discrete approximation of the continuous process. This requirement for discrete approximations was considered to be acceptable because, however continuous a system process or the information regarding it may be, the human generally only accepts and operates on discrete samples of incoming information. And where incoming information is transmitted via radar or verbal communications, as in CATCC, the presentation of information is quite discrete in nature however continuous the underlying process may be.

During each discrete path segment used in the CATCC model aircraft errors, fuel depletion, position reports and control actions were updated in a cumulative manner. Two GPSS blocks are instrumental in this process: the SPLIT block transforms a transformation into two identical transactions, each sent along different paths. The LOOP block returns a transaction to the beginning of a series of blocks until the transaction has transversed the path a specified number of times. In this way, a simulated aircraft is caused to travel the specified distance down the flight path. The other flows are simple directed movements without looping.

When block diagrams are generated for each flow, and the programs are generated and executed on a digital computer, all types of GPSS transactions flow "simultaneously" simulating an information processing management system in which transformations and interactions occur in the same event/time relations as the CATCC. The GPSS software permits record keeping and the calculation of measures of performance and effectiveness as the analyst desires.

THE SIMPLE GPSS PROGRAM The initial example model was simple (for general block diagram, see Figure 10), having been developed to allow an initial test of GPSS capabilities on the CATCC model structure just described. As simulated aircraft were generated and sent to the Marshal point, each was assigned a time to start the approach to the carrier. Most of the aircraft were spaced 60-seconds apart, but 120-second spacing was introduced at regular intervals so as to create "holes" for the integration of holter/waveoff aircraft. A single "information processor" tested the spacing between aircraft, and if any were closer than

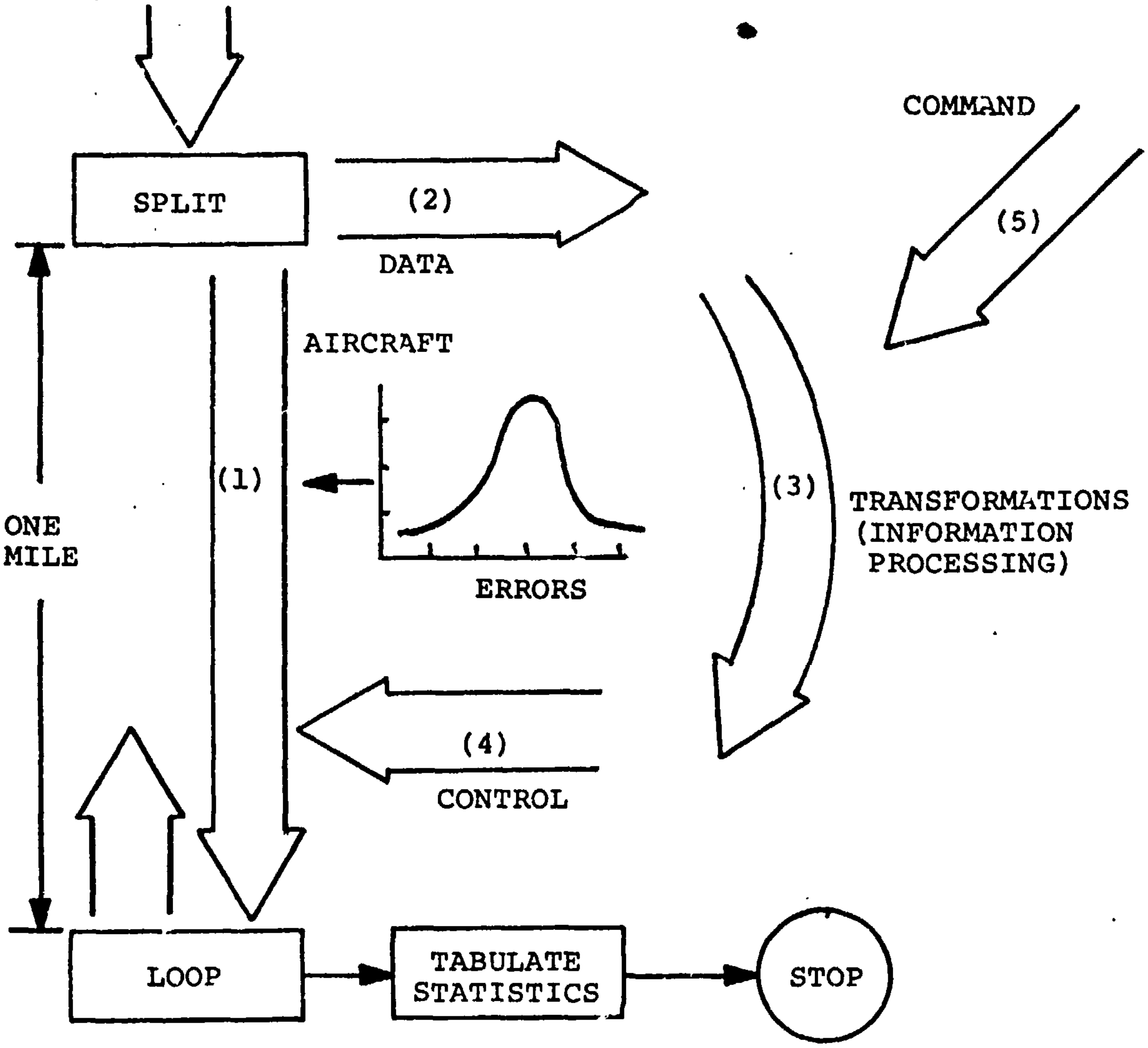

Figure 9. Information/Event Flow in a Simple GPSS Model of CATCC.

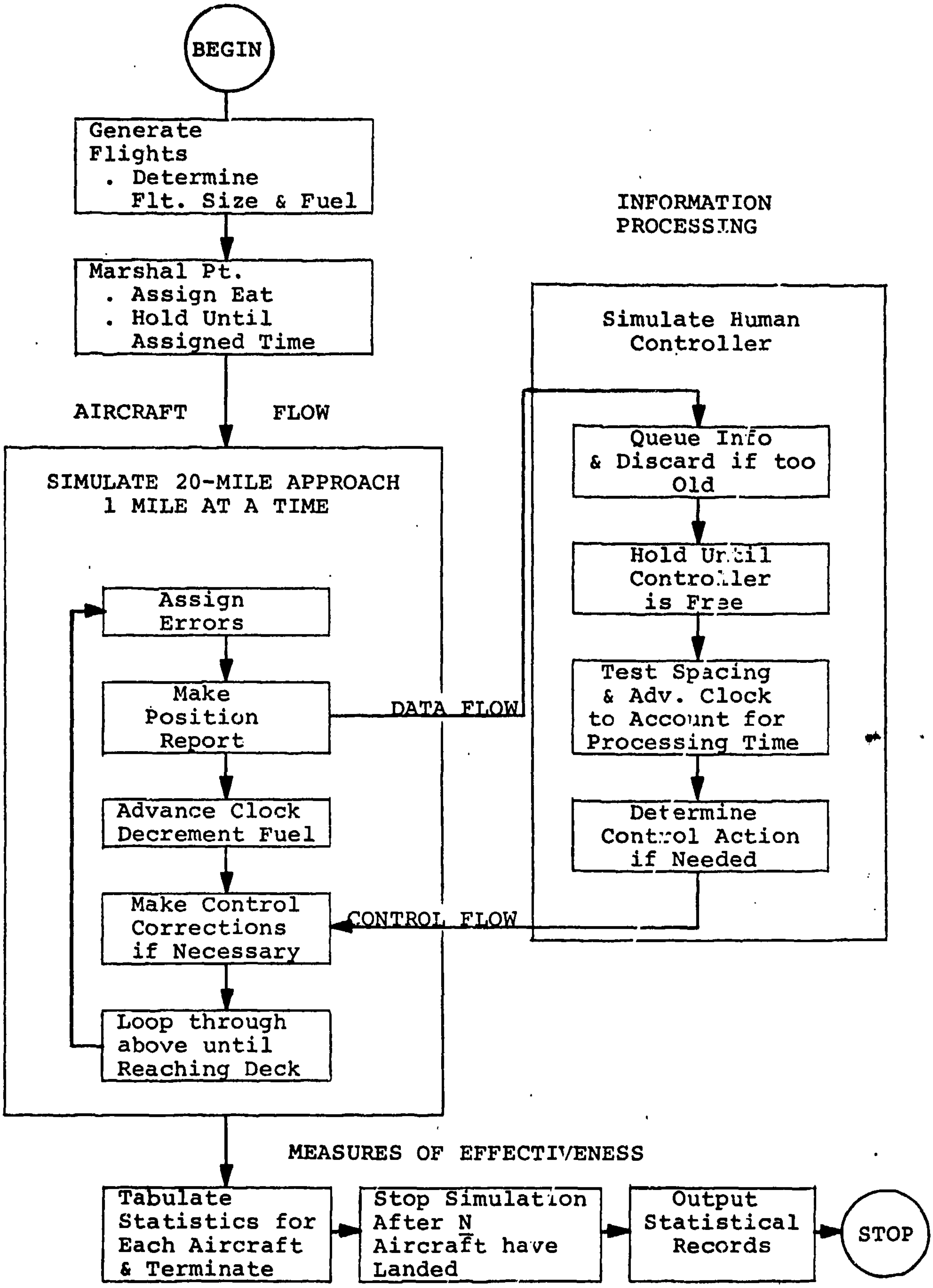

Figure 10. A Simple GPSS Simulation (General Block Diagram).

30 seconds the aircraft would be sent back to the nearest "hole" in the approach pattern. The amount of time and fuel were properly accounted for when an aircraft was diverted. In the simple example model, the approach was simulated in one mile flight path segments.

Each transaction (aircraft) in the aircraft flow had associated with it a number of parameters: flight number, flight size, type aircraft, serial number, seconds of fuel remaining, clock time storage, airspeed, heading, glideslope, checkpoint (miles to go), holding time, and clock time of arrival at the Marshal point. The value of each parameter characterizes each aircraft and becomes the basis for identifying and controlling information flowing in the system.

The simple model was tested with variations in the number of aircraft, frequency of arrival of flights, error distributions, and information processor rate. For each computer run with a given selection of values for each of the foregoing model parameters, a number of measures of performance and effectiveness were automatically computed for printout at the end of each run; these included frequency distributions for airspeed, heading, elevation, information processing time, aircraft spacing, aircraft transit time, and recovery time (the time from arrival of the first aircraft to the landing of the last aircraft). These tests indicated that the C&C analysis model structure used was quite satisfactory.

THE EXTENDED GPSS PROGRAM A second expanded example was developed to incorporate additional CATCC features to a sufficient extent that development of the full model of the system could be predicted and confidence gained in the analysis method.

Multiple controllers and communication channels were included in the expanded model (CATCC includes a Marshal controller, two control teams with an Approach and Final controller, and status board keepers). Consequently, handoff procedures were reflected in the programming to divert the flow of information and control from controller to controller. All tasks and communications were appropriately timed in the model, based on assessments made from operational sequence diagrams and task analyses.

Incoming information about the position of aircraft was stored in savevalue locations to simulate displays which could be accessed as often as the simulated human operators needed. The time for updating status boards was included so that this information was appropriately delayed. Radar displays were simulated in a fashion which permitted the realistic simulation of dropouts and fadeouts of information. As the type of control exerted on an aircraft will depend on the specific circumstances, alternative control actions were included in the extended model, but neither this nor any of the previous extensions posed any difficulty.

While in the simple example each operator task was initiated by some external transaction, it was noted that many CATCC tasks are operator initiated, or are continuously performed as often as time permits. At a given time a number of tasks may be simultaneously expected of an operator. The operator must therefore timeshare the performance of these tasks in some fashion. A number of examples of timesharing were incorporated into the extended example model, showing the capability of the method to handle these behaviors; however, it was difficult to derive the required task description to support such programming. This topic will be subsequently discussed in more detail.

Human operator parameters were also examined in the extended model to determine the parameters which might be varied to reflect changes in human performance; these included processing rates, types and rates of error, and the manner of task timesharing.

In brief, the extended model reflected the ability of the GPSS language computer model, the C&C Analysis Model, to include the salient features of a man-machine information processing system such as CATCC.

HUMAN OPERATOR TASK DESCRIPTION The manner of task description within the GPSS-language model is perhaps one of the model's greatest strengths and might well be developed into a new task description and analysis method. The GPSS language exhibited a capability for rich description of human operator tasks, permitting a number of time-sharing features to be incorporated with relative ease. For example, the PREEMPT block permits the immediate seizure of a facility (the human operator) by a transaction (information to be processed), with the built-in feature of returning the facility to whatever it was doing, picking up at the point of interruption. Further, GPSS permits assigning levels of priority to transactions, so that the higher priority transactions are serviced first, while competing transactions with the same priority are serviced on a first-come-first-served basis. Also, with some additional coding, it is possible to specify that a facility process transactions in specific sequences, or a little of each transaction according to a specified order of scanning. These features were all tested in the extended model and served to satisfy the needs for CATCC simulation.

As discussed in pages 33-34 and 50-51 system identification involves the application of a sequence of description methods. One employs these methods iteratively and more or less sequentially until one has built up the information base regarding system and operator behavior needed to specify measures and formulate system models relevant to the questior being asked. The development of the GPSS models of CATCC required the use of these description methods and, as expected, they supplied the information needed by the programmer in the sequence desired. A problem ensued, however, in that although the information supplied was necessary information and in the desired sequence, there was not sufficient information regarding task behaviors to permit full use of GPSS language capabilities; while traditional methods supply much of the information regarding system and task behaviors, they do not provide information on the timesharing and prioritization characteristics described above. It became clear from the questions asked by the programmer that the sequence of description methods needed to be expanded and/or the programmer needed to closely observe the operational system himself. It appears that the GPSS language could be the means of resolving the problem of incomplete task structure description by providing a vehicle for the expression of such information. In other words, a new task description method could perhaps be developed around the GPSS language, the application of which would follow the application of other methods in sequence and use the information base supplied by them as inputs. This possibility is further discussed on pages 32 - 34 in terms of information needs vs. cost constraints.

THE USE OF MODELS IN COMMAND AND CONTROL ANALYSIS While no extensive tests of the simulation language computer model were made in the conduct of C&C analysis, examination indicates that these models should be generally useful. These models should be useful in answering systems performance and effectiveness questions since measurement of system performance through the model is unrestricted and such performance can be determined as a function of many variations in system form and system parameters. The model can also be used to identify potential causes of system malfunction and means for correction, again through noting performance as a function of variations in system parameters or structure. New measurements can be attempted and tested on the model, with freedom for variation in the form of the measure until the desired result is achieved. The model structure also provides a testbed for the development of human operator models in a form which will assure that human performance variations can be tested along with corresponding measurement of subsystem and overall system performance.

However, such models are not the beginning or the end of analysis. Clearly system analysis in the form of taxonomization, system identification, and measures specification must occur before such models can be properly constructed (see Figures 2 and 3). When analysis skips the preceding steps and begins with the generation of models there is little assurance that such models have any relation to the real system or that the desired application of the models will be possible. Model development is also not the end of analysis, for empirical testing of model results is necessary to establish validity. Computer models of the type described here are useful at many places during analysis, especially as a tool for answering analytic questions.

INTEGRATIVE DATA USAGE

Given a set of measures on the system, the question arises of how to integrate them, with all of their different scale definitions, etc., into a data analysis package. Some of the problems and considerations involved in specifying the data analysis program, and approaches to it, are discussed here.

MULTIPLE MEASURE SETS In assessing data available from systems, it is apparent that not only are there large quantities of data available, but the data can be acquired from many different levels. Figure 11 depicts three levels of measure sets that can be determined from the personnel component of a system: system, task/job and behavior measures.

These three can be further broken down into six kinds of measures:

a. System measures
b. Subsystem measures, including those of the C&C element
c. Team task measures
d. Individual task measures
e. Attitudinal measures, and
f. Biophysiological measures.

Thus, in any C&C application, we may be confronted with at least six multiple measure sets.

Some comment might be added about attitudinal and biophysiological measurement. The value of attitudinal data seems to lie in the fact that it provides certain kinds of information that no other type of measurement can provide. Principally, it provides data on how system personnel perceive system effectiveness. While these perceptions may not be correct, if they are valid they are an attractive cost-effective source of data on system performance. Even if the perceptions are incorrect, that fact alone makes attitudinal data often worth collecting. Misperceptions by system personnel can lead directly to system performance degradation.

Biophysiological measures are becoming increasingly valuable in that they may be the only measures which provide an estimate of the "readiness" of the personnel element. Some give indications of effort expended and available at a given time. Past performance measures are perhaps not so good an indicator of these states.

In any case, the multiple measure sets and the data sets on them provide some serious questions about integrated data usage. Three, in particular, are difficult:

First, each set has multiple measurement alternatives within it. For system, task, or behavior measures there is no

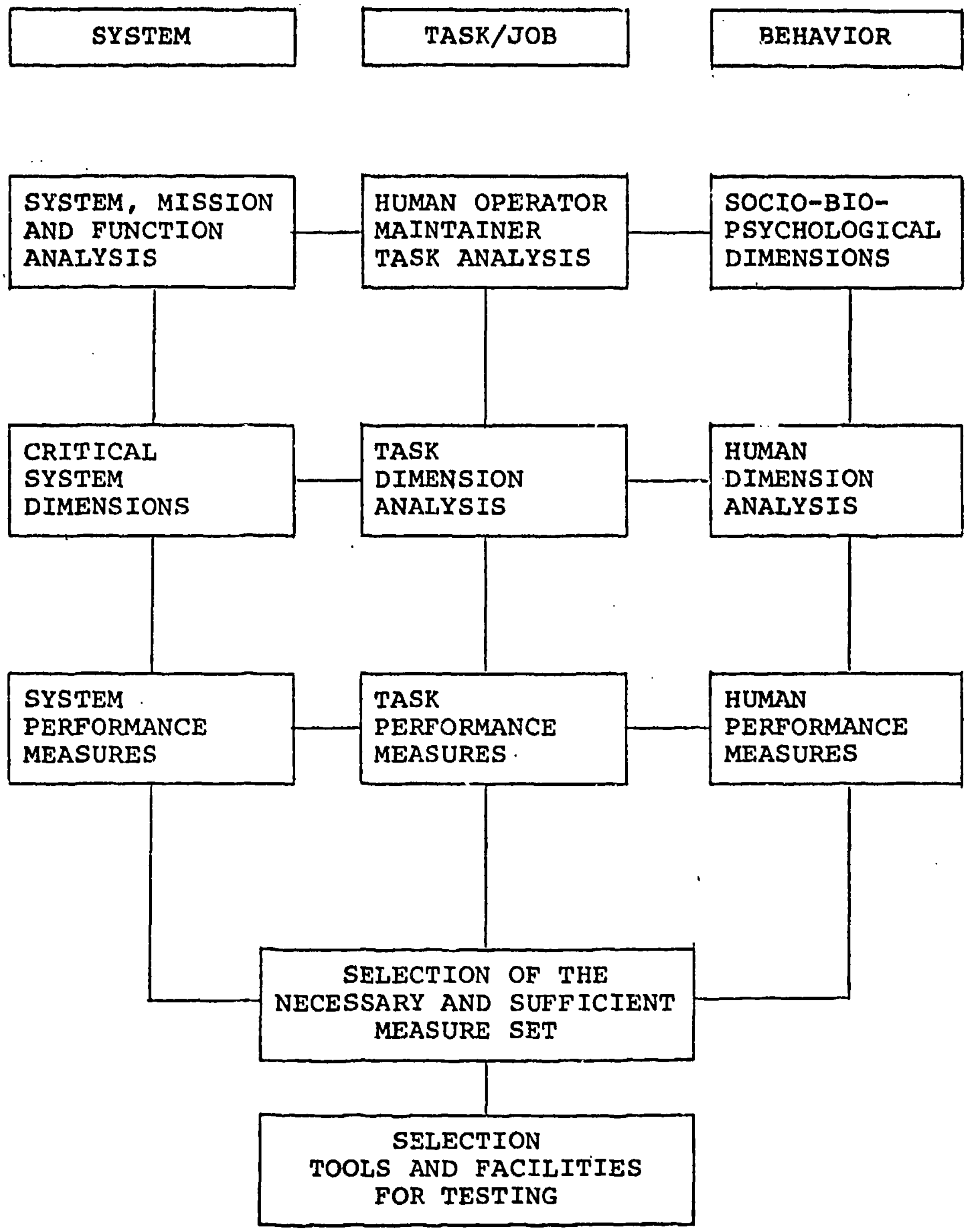

Figure 11. Multiple Measure Sets in C&C and System Evaluation.

standardization of measures. Indeed, among the many measures available, there is rarely any criteria for the selection of "best measure". The literature on comparative evaluation of alternative measures is a very small one. Another possible source of guidelines could be quantitative theory where measurement parameters would be necessarily specified. No such theory exists.

Second, the various measure sets probably are not mathematically commensurable. They are usually a combination of ordinal, interval and ratio scales. Recent mathematical investigations have suggested some serious potential problems in combining varied types of scales into formal equations. These problems are particularly pronounced in the assignment and use of differential weighting functions.

Third, Figure 11 implies the existence of formal relationships between system, task, and performance measures. While some results have been produced along these lines, they are usually mathematically weak, correlative, functions. Although informative and useful to a degree, they must be handled and interpreted with caution.

THE NECESSARY AND SUFFICIENT SET Figure 11 shows that the end point of each dimension is the derivation of the necessary and sufficient integrated measure set. It also implies a necessary empirical step in selecting integrated measurement.

Figure 12 presents a diagram of the empirical process of generating integrated multiple measure sets for C&C evaluation. The discouraging implication is that the analyst cannot, without caution, select some a priori measure set and expect satisfactory results. <u>In every case, the analyst would be wise to institute empirical checks on the integrated measure sets which he intends to use</u>. Fortunately, this can often be done while the analysis is underway. In short, however, the analyst cannot trust fully any known integrated measure set.

DATA ALGORITHMS Integrated data usage implies some formal (mathematical) or informal relationships between measures and allowable algorithms* for manipulating data. We must be concerned, therefore, about acceptable data analysis algorithms. In short, given a set of measures, how are the data points to be manipulated? This is the essential question of integrative data usage.

Some of the many problems in this context include the following:

*which may not be necessarily formally mathematical. Any manipulation or interpretation of multiple data sets, however, assumes some algorithms, explicit or unstated.

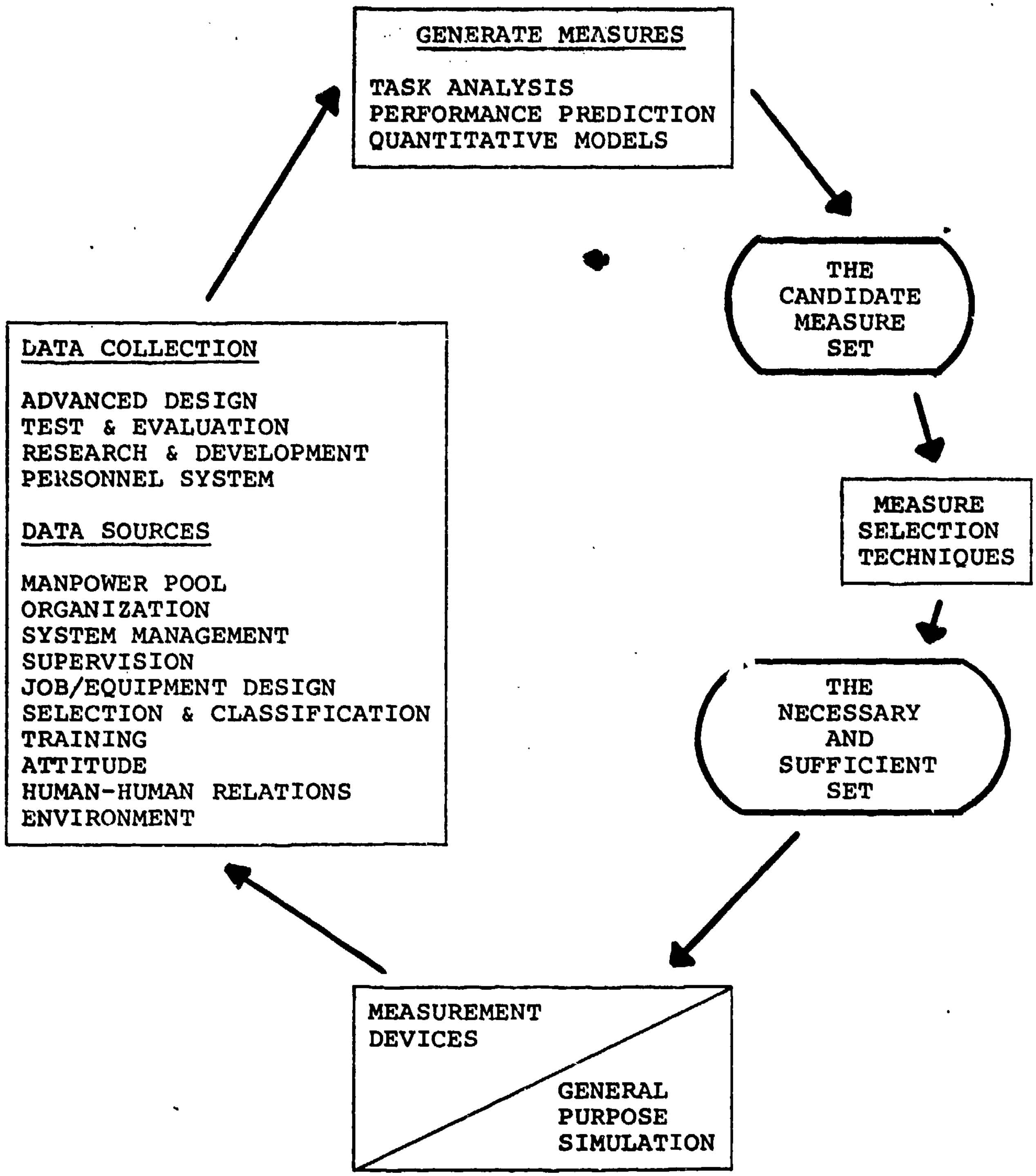

Figure 12. The Process of Generating Multiple Measure Sets in C&C Evaluation.

1. The terms "data algorithms" and "data analysis methods" are often taken to be limited to traditional descriptive and inferential statistics. For the kinds of measurement problems discussed here, these tools may have limited application. However, some questions could be put in hypothesis testing form appropriate for statistical methods, for example: Does the system status at this moment differ from a previously predicted system state? The answer must necessarily be "yes" or "no". Thus, techniques from inferential statistics may be useful for status questions provided that (1) either planned or desired states can be quantitatively expressed and (2) a binary answer is sufficient for the analyst.

2. The analyst may ask the very meaningful question: when have sufficient measurements been collected to provide adequate information? (Usually, of course, the answer is provided, not by measurement consideration, but by time available to make a decision.) In one sense, the question is analogous to the sufficient sample size. Assuming we know the right dimensions to measure, how often must we measure those dimensions? When can we stop measuring?

Although there are techniques available to handle these problems in a formal way (e.g., Bayesian models) perhaps one possible option should not be ignored. That is the perception of the analyst himself that he has sufficient, credible, data to answer his question(s). This procedure is followed more than any other; it would seem worthwhile to consider training analysts to be aware of systematically executing some credibility and/or "sufficiency" criteria.

3. With multiple measure sets, it is impossible to avoid the issue of the differential weightings of the measures. Many mathematical techniques are available for optimum assignments of weights. A pleasant surprise is the possibility that random assignments of weights may be almost as good for decision making as optimization (Ref. 3). Some limitations can be expected.

4. Evaluation is expressed in some set of criterion variables. This is true even if the judgment is "good" or "bad". Unfortunately, the real world of evaluation is never that simple; criterion variables abound in plenty. One example is the tremendous numbers of measures of effectiveness (MOE).

From the standpoint of integrated data usage, many consider it desirable to combine MOEs into a single measure of effectiveness. At issue here is the longstanding problem of multiple versus composite criteria. A composite criterion is simpler to understand, but it may disguise or even confuse detailed system performance achievement. The answer to this choice rests in the question: what does one want to know? This question will be reconsidered in the following Chapter (VI) in the case of assessing the operational readiness of a C&C element.

5. The basic system question being asked (e.g., system status, prediction or diagnosis) will influence presumably the data analysis algorithms that will be required. In many ways, it would appear that system status questions are perhaps the easiest (at least in form) to answer. The complexity of prediction questions will vary at least as a function of the relative stability of the system. In short, the more stable a system is the more predictable its future state will be. Diagnostic questions on the other hand, may pose quite different analytic problems and call for rather different techniques.

6. From the basic mathematical and operations research literature, we have available a staggering amount of analytic models and tools from which, theoretically, one can select. One classification distinguishes deterministic from stochastic methods. Deterministic model classes, for example, include (1) Linear models, (2) Network models, and (3) Dynamic models. Stochastic methods include, of course, any probabilistic model form which assumes distributions rather than values on parameters. One very fundamental question is: When should these models be used in C&C data analysis methods? Or, given a C&C question, what model is best for answering that question?

The answer may be found by considering: (1) the type of question the analyst is asking, (2) the precision of the answer he requires, (3) the nature of the data available, and (4) the stability of the system being evaluated. As the complexity of the question, precision, data and system increase, the analyst must proceed from linear, deterministic, models to non-linear, stochastic, methods. Utility demands that he select the simplest possible model even at the sacrifice of some depth in the obtained answers. The formal demands - mathematical and empirical - of complex models do not appear to provide sufficient value in the outcome except where system survival is at stake.

COMMAND AND CONTROL EVALUATION

The amount that one needs to find out about the C&C element, its system, and its environment is determined by what the question under investigation concerns and whether it is of the status, prediction, or diagnostic type. But, in any event, one thing is clear: the complete picture of a C&C element's capability cannot generally be obtained from any small set of measures. If one wishes to know about the C&C element - and if system performance and effectiveness is of concern, then the C&C element is a central consideration - then one must be prepared to deal with a large set of numbers and to perform some complex analyses. To be discussed in this section are some of the reasons why this is so, what is needed to obtain a complete picture, and what is said about C&C evaluation in other sections of this report.

WHY THIS IS SO The reasons why a large set of measures are needed in order to completely analyze and evaluate the C&C element are threefold: (1) C&C has several kinds of relationships with the system; (2) the ultimate criterion is C&C effectiveness; this is reflected in system achievement, but system achievement is also a function of many other things; and (3) if the question is of a predictive or diagnostic sort then one must also obtain measures of the performance and design of the C&C element itself.

The several relationships that the C&C element, the operator and equipment components of the plant, and the overall system can have with each other have already been discussed in pages 15-17, in terms of C&C definitions and models, and on pages 52 - 59, in terms of measures and measurement considerations. Suffice it to reiterate here that there are limiting and enabling relationships, as well as determining ones, and that time is a variable in many of these. The impact of having these several relationships is that measures, often more than one, are needed on each relationship - and that this can lead to a large set of measures.

System achievement is the responsibility of the C&C element, so measures of system achievement with respect ot any of its objectives is also a measure of C&C effectiveness. But system achievement is a composite measure and it is a function of several things. All of the multiple items making up the composite measure, plus the items exerting a determining influence on each of the multiple items are, in one way or another, the responsibility of the C&C element - but they are not all directly controlled by the C&C element. The determining items include, for example, mission environments (e.g., sea states and weather), mission scenario evolution (affected by such situational events as emergencies, enemy tactics, etc.), the performances and states of each of the system's components (e.g., equipment conditions, motivation and ability levels, performance characteristics), certain online actions of the C&C element itself, and system interfaces with other systems. In other words, while it is true that measures of system achievement are measures of C&C

effectiveness, they are also measures of the effects of other things and are multiply determined: some of these things are not under the control of the C&C element at all (e.g., sea states), while others may not be effectively controlled due to limitations beyond the jurisdiction of the C&C element (e.g., commands received from a point higher in the chain-of-command, resource constraints).

The implication of all of this is that a large number of measures of the system and its environment are also needed in order to completely evaluate C&C effectiveness. Data needs to be collected on many measures in order to get information on, first of all, all of those aspects of the system for which C&C is responsible and, second of all, on those other things which are also contributing to system achievement but may be beyond the control of the C&C element. It is only thus that one can get information on the several facets of C&C effectiveness and, also, on those things which can also vary the composite achievement measure but which are not "the fault of" C&C action. A much more concise way of saying all of the foregoing is to simply note that, for evaluation of C&C effectiveness, multiple measures are needed of system achievement, as well as measures of the composite and of some determining variables (cf, pp. 53 - 55). And to underline again that the C&C element is an integral part of the system, inseparable from it when considering C&C effectiveness questions.

All of the foregoing has had to do with only one aspect of C&C, that is, the status of its effectiveness. There are at least two other aspects which also need to be considered and measured, however, if one wishes the more complete understanding of C&C needed for effectiveness prediction or diagnosis purposes (e.g., an Operational Readiness Evaluation (ORE)). These other aspects are C&C performance and C&C design and functioning. If one wishes to know how effective a C&C element would be under a set of circumstances different from those which have already been assessed for status purposes - or if the C&C element is found to be less effective than desired - then one must consider that which determines C&C effectiveness; that is, the performance of C&C and, ultimately, the design and functioning aspects of C&C. What this means is that the set of measures must be further expanded; for predictive and diagnostic questions measures are needed not only of the system, its environment, and its plant components, but also of the C&C element itself. And the kinds of performance and the aspects of design found in C&C are such that many measures are generally needed to gain sufficient information.

WHAT IS NEEDED TO GAIN A COMPLETE PICTURE What all needs to be measured with regard to the system has been spelled out in general terms in the above paragraphs. What needs to be measured on the C&C element itself is discussed in detail on pages 15 and 16 where a definition of C&C is presented. For reader convenience, some facets of C&C effectiveness, performance, and design and functioning are summarized in Table 4.

Unless, however, a great deal more is understood about the system than is usually the case, its C&C element cannot be evaluated through a knowledge of just the one system by itself. Unless one understands the system and its C&C element sufficiently well to define a set of measures, all of which are defined by ratio* scales and have associated with them a standard, then one needs to be able to compare the system to other systems so as to gain at least ordinal** data on the C&C element. The kinds of comparisons between systems that may be useful in attempting to reach an ordinal judgment regarding the effectiveness of a particular operational C&C element include:

What was achieved in the system under evaluation?

vs.

What was achieved in other similar system situations?

vs.

What could the C&C element have possibly achieved with this system, given the resources available over a substantial preceding time period and the operational environment?

Another way of saying the foregoing is to note that the performance of an analysis is one thing and is needed to arrive at answers to each of the above questions individually. An evaluation, however, of how good or bad a C&C element is requires a comparison of that element against some standards of achievement. Since we generally do not presently have specific standards of achievement, performance, or design for C&C elements - and, as discussed in the foregoing section, standards existing for the system overall, if any, are not appropriate in and of themselves - an alternative is a comparison of the system and its C&C element against other similar systems and against analytic judgments of what should be possible. It should be quickly noted that if analytic judgments of the possible differ very much from what is being achieved in other similar systems then either the analysis has been incomplete or in error, or there is a widespread C&C problem (if the judgment of what should be

*that is, the distances between scale points is known and the scale originates from a true zero point. If standards have been defined then data on such scales will provide sufficient information for evaluation in and of themselves.

**ordinal scales of measurement provide "greater than" and "less than" relationships information.

TABLE 4. A LISTING OF ITEMS CONSTITUTING C&C EFFECTIVENESS, PERFORMANCE, AND DESIGN AND FUNCTIONING

C&C EFFECTIVENESS	C&C PERFORMANCE	C&C DESIGN AND FUNCTIONING
System Effectiveness System Performance System Reliability System Survivability/Vulnerability System States (e.g., organizational and psychological climates, component capability and motivation levels)	States the system objectives, roles, general procedures, priorities, and constraints. The general style, manner, and, especially, the timing of implementation of the above and online mission decision-making. Utilizes resources to maintain/enhance the plant, system interfaces, system environment, and C&C capability. Institutes changes in the foregoing so as to modify system parameters as needed or desirable. Performs planning activities to decide future system goals and states, and to identify/evaluate the requirements for achieving these future goals, goal changes, and states.	C&C element organizational structure and the associated authority/responsibility breakouts vs. the definitions of structure and operation possible for the system.* Design, management, and use of supporting information and data processing systems by nodes in the C&C chain-of-command.

*Definitions of C&C structure and of the supporting information and data processing systems must be in terms of system objectives. It is often the case that the system has two or more objectives and that each of these can be best achieved by a unique C&C structure; that is, that two or more C&C structures, or an integrated one, may be needed in a system if each of its goals is to be effectively achieved.

exceeds reality), or systems are achieving on the basis of superhuman effort (if reality exceeds judgment). The latter two cases are certainly grounds for action; in the one case the systems are not performing up to their capability, in the other case the systems are likely to fail at any given moment or under any further load; in either case, the capabilities of the systems need to be adjusted to an acceptable level of operational capability. (See Ref. 7, p. 28 for a discussion of overtaxed operational systems.)

WHAT HAS BEEN SAID ELSEWHERE ABOUT C&C ANALYSIS AND EVALUATION
Although this entire report is a methodology for C&C analysis and evaluation, only certain sections deal specifically with C&C itself. The reason for this is that an integral and essential part of any C&C analysis and evaluation is an adequate and appropriate analysis and evaluation of the system and its plant - manned systems analysis has therefore been a central concern. The goal of this section is simply to summarize the other sections in the report dealing more specifically with C&C analysis and evaluation per se.

C&C DEFINITIONS (PAGES 15 AND 18) It is very difficult, if not impossible, to specify measures, analyze data, or evaluate results on something which is not clearly and explicitely defined. C&C is neither a physical, a simple, nor a stationary entity and, consequently, has often been assumed to be undefinable and, therefore, ignored in most analytic studies. Under the assumption that we could proceed only if we defined more clearly what C&C is, and what it is not, considerable effort was devoted to the development of C&C definitions in this program.

THE USE OF OPERATOR MODELS (PAGES 35 - 43) An evaluation of alternative C&C management strategies and tactics is based on an analysis to determine the ultimate effects these strategies have on system effectiveness and performance. The use of operator models to evaluate the immediate effects of these alternative strategies, say on operator performance levels or task errors and omissions, and the consequence effects on the system is discussed.

THE C&C ANALYSIS MODEL AND SYSTEM RELATIONSHIPS FORMULATION (PP. 60 - 68) The problem of modeling systems in a manner which will permit a more realistic incorporation of both human and equipment components and, further, would facilitate simulation of those effects on the system that the C&C element is likely to have was tackled in this program. A solution was found through the development of simulation language programming techniques for tying together inputs from the earlier stages of analysis into a system model.

C&C ANALYSIS, EVALUATION, AND THE DECISION TOOLS AND UTILITY NOTIONS (PAGES 81 - 86) As already noted, the complete analysis and evaluation of a C&C element is a complex, lengthy, and, therefore, expensive process. Because time and resources are and always will be limited and competed for, the analyst must carefully consider what it is he really wants to know and just what that information is worth. The application of decision and utility concepts to an especially pressing problem, system operational readiness, is discussed.

VI. ANALYSIS PROCESS EVALUATION: APPLICATION OF DECISION CONCEPTS

DATA INTERROGATION

USING THE DATA BASE Assuming that the analyst and the decision maker have a large quantity of data available, the question is: how to use the data base? A passive response of using only (and all of) the data supplied will result in nothing but confusion. What is needed for the analyst is an active strategy of exploring the data base.

At least two such strategies may be distinguished: sequential data interrogation and sequential question interrogation. These will be described in the following paragraphs.

In both cases, the use of the term "sequential" implies that a single pass will not be adequate. It is very doubtful that answers to significant questions will be derived on a single request. Indeed, given the state of some current data bases, even very "simple" questions cannot be answered immediately. For example, it is apparently not easy to get the answer to the following question: "On this day how many people are serving on active duty in the U.S. Navy?" The analyst, therefore, should expect an iterative search procedure.

SEQUENTIAL DATA INTERROGATION So much raw data are now available to the analyst that he may be tempted to survey the data base looking for questions. This technique is effectively: Given the answer what is the question? At best, this is a formalization of searching for serendipity. While the analyst will possibly uncover accidental discoveries it is not probable they will be either desirable or useful. One should hasten to add it is not impossible. But it is not efficient.

Using the technique of sequential data interrogation, the analyst faces at least two problems: time and inadequate information. Manual data interrogation is an extremely slow process, and, while it may have some emotional rewards, will probably create an answer long after the answer is required. A recent innovation for scanning data bases has been the development of semi-automatic decision aiding techniques. But these methods assume that the analyst is asking some generic type of question (e.g., the links between kinds of data).

Inadequate information means that raw data are rarely in a form which directly answers questions. Forms of transformation on the data will very frequently be required, unless the question requires an elementary counting procedure or a known, conventional, algorithm. The most reliable computer information systems, such as for accounting or statistical analysis, are precisely of this kind. But even these systems assume a fixed set of "questions" for counting such as net profit or statistical significance of a variable.

SEQUENTIAL QUESTION INTERROGATING This entire report has stressed the point that the analyst should approach the C&C element and its system in a question mode. A previous section (pp. 48 - 50) has stated three general classes of questions:

STATUS:	How goes it?
PREDICTION:	How will it go?
DIAGNOSIS:	What is going wrong?

Sequential question interrogation demands that the analyst form his questions as precisely as possible before entering the data base. In short, the analyst should ask himself as clearly as possible: What do I want to know? But, it is rarely possible to state meaningfully any significant question before examining the data. Therefore, he must be prepared to revise and restate his question in light of the data. The analyst might keep in mind two methodological questions -

What Do You Mean? and

How Do You Know?

when he is employing the sequential question interrogation technique.

A MINIMIZATION AXIOM It should be understood that advancing from status to prediction to diagnosis questions will have two adverse consequences on data demands: (1) there will be a marked increase in data requirements and (2) there will be a significant increase in analytic (transformation) steps.

Therefore, the analyst should attempt to minimize the information he demands from the C&C element and its system, consistent with the questions he is asking. Diagnostic questions should never be asked unless the answer to a status question reveals a clear and significant deficiency.

For system control and planning, the most significant type of question the analyst and the decision maker will ask concerns system prediction. It is in the nature of the prediction of most process events that the longer ahead one wishes to predict the less valid and reliable the prediction.* The analyst should ask whether or not five and ten year prediction requests, for example, are meaningful. The minimization axiom applies to the time duration of prediction.

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*A fact which makes one envy the predictability of astronomical events. This success, however, is based on (1) good quantitative theory, (2) over 3,000 years of data collection, and (3) a reasonably stable process. These conditions do not prevail for manned systems.

The minimization axiom also applies to the depth and precision of prediction questions. Answers can be, and are, invented for detailed prediction questions of time-distant events, but their validity and usefulness are doubtful. Indeed, they may be harmful in that they may well be incorrect. For example, five and ten year facilities predictions for a system are of value only in so far as the predicted functions of the system are reasonably defined. Facilities have been created for systems which, in the meantime, have disappeared.

The minimization axiom seeks to reduce data demands on a system and, at the same time, to structure techniques for meaningful data search. Vague and continual system interrogation is a costly process, and can result in degradation of system performance. Time spent collecting useless data is time not spent in performing system functions.

SYSTEM OPERATIONAL READINESS

AN EXAMPLE Many of the problems raised in this report can be exemplified in a very common question: What is the operational readiness of the command and control system? Some of the difficulties encountered in answering this question may be illuminating.

THE QUESTION First of all, the general question should be restated as follows:

STATUS:	Can the overall system meet the present threat?
PREDICTION:	Will the system meet future threats?
DIAGNOSIS:	If not, why not?

It is to be noted that the questions, as re-stated, refer to the ability of the total system to respond to an external threat. This is consistent with definitions of the functions of the C&C component with regard to total system performance (see pp. 15 - 16). Questions about the C&C component are not of most immediate and general interest; the internal performance of the C&C component is only a part of total system performance, contributing to it as do the other system components. It is only if the answers gained from total system status questions provide insufficient information or are not acceptable, that one proceeds predictive and diagnostic question forms; and it is only here that one begins to measure and evaluate such system components as the C&C element.

THE MODEL Quantitative models for the above questions have generally been stated in the form of a linear multiple regression equation:

Criterion Variable(s)		Predictor Variables
y	$=$	$a_1x_1 + a_2x_2 + a_3x_3 \quad \cdots \quad a_nx_n$

That is, some set of system component (predictor) variables are used to predict system performance (criterion variables).

In fact, this model is of most use with respect to diagnostic and tradeoff prediction* questions. If the criterion variable value is unacceptable, then the causes and basis for change are presumably to be found somewhere within the predictor variables. For status and straight prediction problems, only the direct expression of operational readiness (a single criterion variable) is normally desired.

THE SINGLE CRITERION Most users of information desire a simple expression of readiness. Examples are (1) availability of the system, (2) percent capability, or (3) amount committed. All of these are composite criteria. They provide a quick and easy to understand measure of system operational readiness.

However, they may not be meaningful. To say that a system is 50% operationally ready is insufficient to answer the status question. That value is neither good nor bad per se. The question remains: Is 50% sufficient to meet the present threat? If the answer is "no", then diagnostic interrogation will be necessary.

MINIMIZATION AXIOM APPLIED A common mistake is to assume that any "low" composite criterion value (50%, 75%, etc.) will mean an unacceptable system state. This may not only be wrong, it may also lead to unnecessary data demands.

What must be done is to evaluate the composite criterion. It would be desirable to set a mini-max threshold of acceptability. This would add the binary judgment of "acceptable-unacceptable" to the composite criterion. If acceptable, no further data interrogation is required. If not acceptable, then further investigation is obviously warranted.

The minimization axiom calls for a minimum call on data demands. It seems particularly appropriate in this specific case.

*If one wishes to perform tradeoff estimations of prediction processes, then the predictor variables must be identified as they are for diagnostic questions so that alternative values on these parameters can be manipulated.

But, to be applied, external threshold criteria must be developed; some technology is available from computer-based management information systems.

MODELLING PROBLEMS Assessment and evaluation require modelling. In the case of systems several problems can be noted:

1. Multiple criterion variable sets are probably necessary for questions other than basic status questions. As an example, in C&C, in addition to some "availability" measure one might also wish to assess "responsiveness". A system can be available for use, yet be incapable of quick and competent response.

2. If a linear multiple regression model is used, then the question may be raised if that is the appropriate form. It is doubtful that predictor variables in a command system combine in an additive fashion. But, as noted before (Chapter V) the simplest, most reasonable, model is the best choice. And, "reasonable" is measured by the degree of acceptability that the model provides. Answers to the fifth decimal are not cost-effective when the whole number provides an acceptable answer for decision.

3. Assignments of weightings to the predictor variables (and criterion variables if a multiple criterion is used) has been a very difficult technical problem. These can be generated either through (1) analysis, (2) expert opinion or (3) empirical data (Ref. 22). As mentioned before (pp. 69-74) it may not be necessary for precision at the level previously assumed.

BENEFIT AND COST

VALUE OF INCREASED INFORMATION No one knows for sure what impact increased data and information have had on C&C and management information systems (Ref. 5). The impact just has not been subjected to empirical test.

This report has been concerned with the potential negative impacts of demanding too much data and improper generation and utilization of data. On the positive side, it has emphasized systemati strategies toward collecting information.

But, the objective demonstration of the benefits of more information on C&C remains to be performed.

BENEFIT ANALYSIS We should like to be able to determine the cost-effectiveness of data collection in C&C. Unfortunately, past attempts have stressed cost without adequate consideration of effectiveness (benefit).

One approach (Ref. 4), however, has structured a model for benefit assessment. Three vectors are established:

$$\text{Realized Value (Benefit)} = \text{Potential Contribution (P)} \times \text{Received Value (R)} \times \text{Utilization Value (U)}$$

stressing the value of the information based on specifications (P), user receipt of the information (R), and receiver utilization of the information (U).

A number of transformations are possible within this model but two seem particularly important:

1. It is desirable to compare what is obtained relative to what could be obtained. This is termed the "realization/potential ratio" and is expressed by:

$$\frac{\text{Realized benefit}}{\text{Potential contribution}} = \text{Index of Potential Realized}$$

2. Fundamental are the perceptions of the users; this is expressed by:

$$\frac{\text{User's perception of realized benefit}}{\text{Producer's perception of realized benefit}} = \text{Congruence Index}$$

Emphasis here is placed on the continual dissonance between producers and consumers. And it places a focus on systematic evaluation of user's perceptions. In the final analysis, the benefit of any system rests ultimately upon that perception.

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