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AIR FORCE

HUMAN RESOURCES

TEAM TRAINING FOR COMMAND AND CONTROL SYSTEMS: RECOMMENDATIONS FOR RESEARCH PROGRAM

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The purpose of this paper is to recommend research topics for a long-term research program in team training (T^2) for operators other than aircrews in Air Force command and control (C^2) systems. This paper is one of a series presenting the results of a survey of T^2 in Tactical Air Command and recommendations for improving AFC^2T^2. Strengths and weaknesses in C^2T^2 were analyzed into issues and problem areas. They are the objectives to which the recommendations are directed. The other technical papers in this series are AFHRL-TP-82-7, AFHRL-TP-82-9, AFHRL-TP-82-10, and AFHRL-TP-82-11.

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PREFACE

Throughout the text of this paper, reference is made to volumes I through V. These volumes have been published as separate technical papers identified as follows:

Volume I

Baum, D.R., Modrick, J.A., & Hollingsworth, S.R. *Team training for command and control systems: Status*. AFHRL-TP-82-7. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, April 1982.

Volume II

Modrick, J.A., Baum, D.R., & Hollingsworth, S.R. *Team training for command and control systems: Recommendations for research program*. AFHRL-TP-82-8. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, April 1982.

Volume III

Baum, D.R., Modrick, J.A., & Hollingsworth, S.R. *Team training for command and control systems: Recommendations for application of current technology*. AFHRL-TP-82-9. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, April 1982.

Volume IV

Hollingsworth, S.R., Modrick, J.A., & Baum, D.R. *Team training for command and control systems: Recommendations for simulation facility*. AFHRL-TP-82-10. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, April 1982.

Volume V

Baum, D.R., Modrick, J.A., & Hollingsworth, S.R. *Team training for command and control systems: Executive summary*. AFHRL-TP-82-11. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, April 1982.

This paper is the second of five volumes prepared by Honeywell to document the results of a research program to evaluate the current status of team training (T^2) for operators of complex Air Force command and control (AFC^2) systems, and to make recommendations for enhancing the AFC^2T^2 process. The research was performed for the Air Force Human Resources Laboratory under contract F33615-79-C-0025. This research effort supports a major new Air Force Human Resources Laboratory (AFHRL) research and development program whose primary objective is to improve T^2 technologies in areas particularly relevant to Air Force combat readiness. The program objective requires the establishment of a baseline data base on how T^2 is currently conducted in the Air Force; how it is developed, implemented, and evaluated. Because Air Force teams vary greatly in size, structure, and functions, it would be impractical to collect data on the training provided to all of them. Rather, the scope of this research effort had to be directed at an area with potential high payoff for increased combat readiness and effectiveness. The area of command and control was chosen as a point of departure for the research because C^2 teams tend to be well-defined structurally, are of manageable size, and perform functions highly representative of Air Force mission needs. Furthermore, as the research effort unfolded, limited time and resources made it necessary to focus on tactical and air defense C^2 systems to the exclusion of strategic C^2 systems. Thus, the C^2 systems surveyed are, or in the case of planned systems will become, Tactical Air Command (TAC) resources.

The goal of this effort was to develop a picture, through interview and observation, of how AFC^2T^2 is currently developed, implemented, and evaluated, and what C^2 training needs will arise in the future. Based on this picture, strengths and weaknesses of AFC^2T^2 were identified, and recommendations were developed in three areas:

- T^2 research and development program (Volume II)
- Resolution of issues using current techniques/technologies (Volume III)
- Simulation technology development for C^2T^2 (Volume IV)

These recommendations will form the foundation for future research by AFHRL into the performance of C^2 teams and systems. The research will encompass training technology, performance measurement techniques for C^2 teams and systems, human resources issues in the design and operation of C^2 systems, and training of command/decision skills. The ultimate goal of this program is to improve technologies in areas of team and human factors related to the combat effectiveness of Air Force C^2 operations.

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LIST OF ACRONYMS

AAR	After-action report
ACCAT	Advanced command and control architectural testbed
AFC^2	Air Force command and control
AFC^2T^2	Air Force command and control team training
AFHRL	Air Force Human Resources Laboratory
AFSC	Air Force specialty code
APQ	Automatic positionally qualified
ASOC	Air Support Operations Center
ATC	Air Training Command
AWACS	Airborne warning and control system
C^2	Command and control
CAFMS	Computer-aided force management system
CAI	Computer-assisted instruction
CATRADA	Combined-arms training development activity
CATTS	Combined-arms tactical training simulator
CRC/P	Control and reporting center/post
ECM/ECCM	Electronic countermeasures/electronic counter-countermeasurers
ESD	Electronic Systems Division (Honeywell)
FME	Force management enhancements
JSS	Joint surveillance system
KNOBS	Knowledge-based system
OASIS	Operational applications for special intelligence systems
OJT	On-the-job training
ONR	Office of Naval Research

LIST OF ACRONYMS (concluded)

$P_{(k)}$	Probability of kill
SAGE	Semi-automated ground environment
T^2	Team training
TAC	Tactical Air Command
TACC	Tactical air control center
TACDEW	Tactical advanced combat direction and electronic warfare
TACP	Tactical air control party
TACS	Tactical air control system
TFC	Tactical fusion center
TMT	Training methodology for teams
WD	Weapons Director
WOC	Wing Operations Center

CHAPTER I

INTRODUCTION AND OVERVIEW

The status of team training (T^2) programs in tactical air and air defense command and control (C^2) is characterized in Volume I of this report. The methods used to define, develop, implement, and evaluate these T^2 programs were described, analyzed, and evaluated. The description was based on survey data collected through interviews with C^2 training personnel and observations of training in Tactical Air Command (TAC) and Air Training Command (ATC). The systems surveyed were Airborne Warning and Control System (AWACS), the Semi-Automated Ground Environment (SAGE), and the Tactical Air Control System (TACS). The organizations surveyed in TACS were the Tactical Air Control Center (TACC) and Control and Reporting Center (CRC). Basic and Automatic Positionally Qualified (APQ) training programs were also surveyed.

The analysis and evaluation of the survey data permitted the identification of strengths and weaknesses in tactical air and air defense C^2T^2. The weaknesses were consolidated into issues and problem areas which were grouped into the categories of definition and development, implementation and evaluation, and modification of training programs and training devices or personnel policy and resource constraints.

These issues and problem areas were sorted into two categories: those amenable to solution in the short term using existing technology and those requiring more research and solvable in the long term. Some of the issues and problems can be addressed by both approaches. The topics requiring research are analyzed in this volume and translated into recommended objectives and projects. The analysis of the topics within current technology is reported in Volume III.

Sixteen objectives for long-term research were derived from the issues and problem areas in C^2T^2. Both the issues/problems and objectives are listed in Table 1. Derivation and selection of the research objectives were done by an analysis of the technical literature in team training and information gathered during our survey and observations. The purpose of this volume is to summarize the process and outcome of that analysis.

OVERVIEW OF THE REPORT

The starting point is a brief summary of the status of team training as found in our survey of C^2 systems or organizations in tactical air control and air defense. The summary is followed by a statement of problems and needs in C^2T^2.

The operational setting of the C^2 organizations visited will be described for the purpose of identifying an operational and organizational focus for the proposed research. The focus should be realistic and representative of real-world problems; a strategy for ensuring that these conditions are met is to work back from the applied setting to the research plan and facility. The proposed research would be carried out in a simulation facility representing operational settings for control of tactical air C^2, depending on the specific objectives of a study. The operational focus will serve as a basis for identifying the required functional capabilities of the simulation.

TABLE 1. RECOMMENDATIONS FOR LONG-TERM RESEARCH

Issue or Problem Area	Long-term Research Objectives
Definition and Development	Determination of deficiencies in performance and training for C^2T^2
1. Lack of a definitive framework for analyzing team skills and designing team structure and function.	Develop a conceptual model and framework for the descriptions and analysis of C^2 team functions and behaviors. (1*)
2. Lack of objective criteria and standards for evaluating team-oriented skills, individual and team readiness, and system effectiveness.	Develop comprehensive performance objectives for C^2T^2 at the level of preteam, team, and superteam exercises. (2)
3. Lack of analytic techniques and empirical data for determining institutional and operational T^2 requirements and objectives.	Develop and evaluate a set of performance measures that will assess competence of C^2 teams and battle staffs and relate team competence to system effectiveness and individual proficiency. (2)
4. Lack of comprehensive, systematic procedures for defining training objectives for simulated combat missions.	Develop a set of standardized C^2 team exercises which are graded in difficulty and cover the range of C^2T^2 operational activities. (2)
5. Inadequate planning and analytic techniques for defining T^2 simulation/simulator fidelity and functional requirements.	Develop analytical techniques for deriving T^2 requirements and compile supporting data. (3)
6. Failure to define and develop formal training for C^2 system supervisors.	Develop and evaluate systematic procedures for determining the skill and knowledge requirements for simulated combat missions for C^2 teams and partition them over the categories of indidual, preteam, team, and superteam exercises as most appropriate vehicle for training. (4)
Implementation	
7. Deficient simulator capabilities including a lack of facilities for combined systems training.	Develop data for simulation of operational situations for C^2 teams and battle staffs which identify the a) independently controllable features of the simulation; b) necessary and sufficient conditions of fidelity to reproduce the desired behaviors; c) cost-benefit relationships for inclusion of each feature in a simulation. (5)
8. Mismatch between entry-level requirements and Air Weapons Controller Fundamentals Course syllabus.	
9. Lack of empirical data regarding the optimal instructional methods and sequencing for subteam, team, and superteam skill training.	Develop and evaluate techniques for defining the required components, functional capabilities, and level of fidelity for simulation of C^2 teams in a weapons system. (7)
10. Lack of training for personnel who simulate interceptor pilots.	Develop and assess feasibility of a psychometric research plan to identify selection criteria for entry into a career field of air weapons controller. (8)
11. Lack of AWACS-oriented block of instruction in Air Weapons Controller Fundamentals or Automatic Positionally Qualified (APQ) courses.	Identify and evaluate in a controlled fashion existing instructional strategies. (9)
12. Lack of instruction for supervisors, battle staff, and decision makers.	Identify new topics and data for research when existing technology does not provide appropriate or adequate instructional strategies. (9)
Program Evaluation and Modification	
13. Lack of valid evaluation measures.	Develop techniques for interpreting measures of team performance to identify deficiencies in skill and knowledge and to select appropriate remedial action. (13)
14. Incomplete use of existing evaluative data.	
Personnel Policy and Resource Constraints	
15. Low retention rate of experienced C^2 system personnel.	Develop techniques for analysis and interpretation of team performance measures in terms of the combat readiness of teams and systems. (13)
16. Shortage of live flying events/activities for T^2.	Conduct research studies on the comparative cost-cost-effectiveness of live and simulated combat exercises--and mixes of these events. (16)
17. Inadequate instructor training and evaluation in operations training programs.	
18. Difficulties posed in training and evaluating "soft" as opposed to "hard" teams.	Conduct research to evaluate the comparative strengths and weaknesses of hard and soft C^2 teams on performance of critical C^2T^2 tasks. (18)
19. Lack of T^2 guidance for C^2 training program managers.	*Numbers in parentheses indicate the related issue or problem area.

The state of knowledge in team training is summarized with the objectives of identifying major themes and issues and evaluating the state of knowledge and methodology as a foundation for the proposed research. There have been several surveys of the research literature on teams, team training, and small groups during the past few years. It has also been assessed for its usefulness in addressing practical problems of team performance and training and found to fall substantially short of what is needed. There is little need to survey it again but there is a need to begin some critical interpretation and integration, with an objective of developing technology for the design, management, and training of teams.

Finally, recommended long-term research objectives and research projects are discussed. The specific research topics are rated against criteria of feasibility, utility, probability of success, and the availability of the facilities and skills required. Each project is assigned a priority based on these ratings and the top third of the projects is recommended for implementation.

CHAPTER II

BACKGROUND TOPICS RELATED TO RESEARCH IN AFC^2T^2

The purpose of this chapter is to summarize topic areas which provide a frame of reference for developing and describing specific research:

- Status of team training in C^2 as found in our survey and observations during site visits
- Summary statement of problems and needs in C^2T^2
- Discussion of the operational settings of C^2 organization that control tactical air operations for the purpose of extracting a focus on a representative context for the research
- Discussion of the status of knowledge in teams performance and training

The domain of potential C^2T^2 research topics and areas is large. There is substantial literature on the characteristics and operation of teams and groups as indicated by recent reviews (References 1 through 5). The recent report on training by the Defense Science Board (Reference 6) has given an impetus and higher priority to research on team training. Team training was identified as a major weakness and a high-priority research program was recommended.

However, the amount and content of the research has not been sufficient to provide a systematic body of knowledge on which to base a technology for team performance and training. The research has often not been focused on the solution of problems in man-machine operating systems; however, when it has been oriented toward these problems, the laboratory tasks and constraints have been seriously unrepresentative of the operational problems and conditions.

STATUS OF TEAM TRAINING IN C^2

Our survey of C^2T^2 in tactical air command revealed that there are no formal training programs for team training in command and control. The lack of formal training reflects an absence of T^2 requirements and objectives during development of systems and exercise programs for maintenance of system readiness. There is no requirement to describe and report job tasks for teams nor to do a task analysis to provide requirements for human engineering design or training. Systematic definition and development of training for teams and team skills is virtually non-existent. There is no formal training for supervisory and battle staff personnel, who are critical to the effective operation of teams.

Simulation is used for systems like AWACS and CRC/CRP but the number and capability of these devices is less than adequate. The simulation facilities in AFC^2T^2 are significantly behind the state of the art; the lack of adequate data on C^2T^2 jobs, tasks, and training requirements significantly impairs the definition of needs and capabilities for simulation. Facilities which can provide exercise of units as integrated teams and joint exercises of two or more units or commands, such as Blue Flag, have serious limitations.

This summary is brief and global; an extended and detailed treatment is contained in Volume I. It is sufficient to substantiate the point that the level of AFC^2T^2 is less than what is needed and what is possible within the state of the art. Furthermore, there are many opportunities for technical development and research to make contributions which can increase training effectiveness, improve the design of man-machine interfaces and personnel subsystems in C^2 systems, reduce costs, and increase system effectiveness. There are major needs in the development, implementation, and evaluation of:

- Team training
- Performance measurement
- Simulation
- Tools for design and analysis
- Instructional strategy

SUMMARY OF PROBLEMS AND NEEDS IN AFC^2T^2

The state of AFC^2T^2 is summarized in a set of issues and problem areas presented in Table 1. They are discussed in Volume I. They are grouped into four categories:

- Definition and development
- Implementation
- Program evaluation and modified action
- Personnel policy and resource constraints

Many of the issues and problems have been mentioned or alluded to in the preceding discussion. The lack of a definitive framework for team phenomena is listed under definition and development but it is applicable to all areas. The lack of an agreed-upon and standardized terminology and concepts is an impairment for typical system personnel in recognizing, reporting, and analyzing team behaviors and in planning and implementing supporting programs. The resulting lack of technology weakens all related areas of human factors: design of man-machine interfaces, design of team structures, identification of personnel requirements and qualifications, performance measurement, simulation and training. Thus, the design of systems for effective use and support of teams of operators is seldom adequate except by trial-and-error evolution.

Measurement and evaluation issues are a recurring topic with an emphasis on the need for criteria and standards. The need for procedures, techniques, methods, and supporting data is a frequent theme. The need is typically not one for developing methodology; existing human factors methods are probably adequate if adapted to the application to team design and if team phenomena are appropriately structured.

Several of the issues and problems can be alleviated with relative ease if resources are made available, even though definitive solutions might require additional research. For example, courses and instructions can be provided to meet the specific training needs of instructors in operations training, supervisors and battle staff, AWACS weapons controllers, and personnel controlling simulated aircraft. The mismatch of the syllabus for the Air Weapons Controller Fundamentals Course and the entry requirements into this course and career field can be corrected.

The incomplete use of existing evaluative data from exercises and after-action reports (AARs) can be improved by developing or adapting methods and procedures for collecting, analyzing, reporting, and interpreting performance data for individuals, teams, units, and systems. This effort might be a more intermediate than a short-term effort, however, since it is dependent on developments in establishing criteria and measures. It might also entail significant costs in automated data processing to handle the potential large body of data and provide computer aiding for the evaluators and analysts.

Similarly, the use of simulation could be greatly improved by applying the state of the art in simulation technology, modeling, and war gaming. Developments in the areas have made it feasible to achieve much greater capability and useful fidelity in simulation and to achieve it at greatly reduced costs per function. These trends will continue with development of technology in integrated circuits and it is important to project the research to meet the needs of future systems. However, it is important to structure adequately the C^2T^2 simulation requirements. Structuring will require an understanding of team, C^2, the threat tactical doctrine, the functional characteristics of the systems, and the person-system transactions. Failure to structure the application adequately falls under the old computer axiom of "garbage in, garbage out."

The set of issues and problems under Definition and Development (Table 1) is fundamental in many ways to the other areas. Research on them will address needs for knowledge and techniques which must be resolved before progress can be made in the other areas. In addition, they will have wide applicability.

The problem area of instructional methods for team training may seem to be superfluous since there is a substantial technology for instruction. However, this technology has been developed and evaluated for individual training. The methods may be applicable directly or with modification to team training but there is little data to that effect. The first step in developing a technology for team training is to review the methods for individual training for applicability. Then methods and strategy specifically for team training should be investigated.

Personnel Policy and Resource Constraints (Table 1) is a bothersome area because it contains issues that have a major impact, often negative, but there may be little that can be done about them through research or technological applications in human factors and training. Studies can be done to generate information on the effect or causes of a shortage of live flying events, loss of experienced personnel, and poor understanding of C^2 training by program managers. But changing those conditions and constraints is difficult because the policies, allocations of resources, and constraints are the responsibility of persons in other areas who must also weigh other priorities. One can develop and recommend alternative man-machine configurations and manpower practices to alleviate the effects of the constraints. One can also use research results to recommend and lobby for changes. But the decision falls under the charter of someone in another chain of command.

That pessimistic observation leads to a concluding comment and caveat about recommending a research program. The comment is that a research program which is successful in the long run must consist of solving problems of applications, managing political relationships to generate a supporting consensus, and lobbying/selling to have an effect on how things are done and the cost-effectiveness of doing them. Human factors has been outside the engineering design process but must ultimately become integrated into it. "Good" research in a parochial sense is not sufficient although it may be necessary for success.

The caveat is that the subsequent discussion of research issues and recommendations will deal with the research options primarily in terms of parochial criteria as the state-of-knowledge, theory, and experimental feasibility. The discussion has an applications orientation as a source of the problems to address. However, the issues of consensus and having an impact on the real world of systems and use of manpower involve complex processes depending on local conditions. They are outside the scope of this effort.

OPERATIONAL SETTING FOR C^2 TEAMS IN TACTICAL AIR COMMAND

The objective for this topic is to define the domain of C^2 team activities and settings for the purpose of focusing on or selecting a set of experimental conditions for this research. The conditions should be representative of AFC^2 activities and provide the capability to generate behaviors, tasks, variables, and constraints such that results of studies can be interpreted in terms of implications for operational performance. The level of examination is largely an organizational and functional description of C^2 systems. The organizations described are from Tactical Air Command and therefore are in the operational area of air defense and tactical air operations. A comparable description of other operational areas should be undertaken before one attempts to generalize the tactical air context to other situations.

The organizations in TAC ground operations discussed are:

- Control and Reporting Center (CRC/CRP)
- Semi-Automated Ground Environment (SAGE)
- Airborne Warning and Control System (AWACS)
- Tactical Air Control Center (TACC)

These are the systems with which we are familiar as a result of our survey; they were chosen to be representative of a major area of AFC^2. The aircraft of the squadrons which they support are also integral parts of their operational activities. The personnel and activities of the organizations provide a variety of teams and applications.

There are other C^2-related organizations in TAC. The Wing Operations Center (WOC), for example, manages tactical units in the executions of missions. The personnel in the WOC also do detailed mission planning and defense analysis. The Air Support Operations Center (ASOC) processes requests for air support. It coordinates the provision of close-air support with Army maneuver units through the Tactical Air Control Parties (TACPs). Scramble orders are prepared in response to the requests and transmitted to the WOC for execution. These activities are clearly C^2 ground operations in support of air operations.

However, we believe that the functions, jobs, and tasks in the selected systems are representative of those in the other organizations. All C^2 systems perform some subset of activities such as data acquisition and analysis, planning, resource allocation, detecting and evaluating threat, executing or implementing an operational plan, and so on. Knowledge of the specific situation and local boundary conditions is necessary for application but it is assumed that component tasks and behavior in these activities are the same or equivalent.

There are also large-scale joint exercises involving several organizations and very large scenarios. They are also assumed to consist of an aggregation of functions and activities of component elements. They are too complex to be the starting point for a research program. They may be an objective for later phases. However, we should first get a better comprehension of the problems and issues of the components.

Studies and development of joint exercises could be undertaken on an ad hoc basis because a systematic, man-machine approach can make several contributions within the current state of the art. They are not discussed here because they are systems engineering rather than research.

A research program in team training for C^2 teams must focus on some part of all the types of activities and tasks in these systems. Only such a focus will ensure that realistic conditions and constraints are represented in the research plans. Thus, the research plan must be built around problems and situational contexts in these organizations.

Each organization will be described briefly to give an overview of the kinds of activities and factors relevant to selecting an appropriate vehicle for research.

Control and Reporting Center/Control and Reporting Post

The purpose of these organizations is to control and manage air traffic in an assigned region of air space. These areas of responsibility consist primarily of directing aircraft flying on air defense against hostile aircraft, close-air support for ground operations, interdictions, defense suppression, and reconnaissance. Air defense consists of protecting friendly aircraft on the other missions as well as protecting ground targets; it may be against fighter and bomber aircraft. Air refueling is an important special operation in these activities.

The direction of intercepts by a Weapons Director (WD) and technician is the principal function. The operation of a CRC and CRP are basic examples of the implementation of this function. The pilot of an intercepter, WD, and technician form a team for the purposes of executing an intercept course from which an attack can be flown against the hostile. The WD follows the hostile and interceptor aircraft on a radar scope. He gives the pilot continuously updated range and bearing on the hostile and heading for interception. The intercepters may fly from either an airbase or the position of a Combat Air Patrol aircraft, assigned to a region of the airspace near an anticipated avenue of approach of a threat.

The weapons direction is supported by functions of targeting and surveillance. Targeting consists of differentiating among friendly and hostile tracks, assessing the priority of threat, and assigning interceptors to threats in accordance with the rules of engagement. For example, the rules of engagement in one scenario were: engage hostile aircraft at maximum range, engaging high threat targets first, then aircraft emitting electronic countermeasures (ECM), and, finally, any other unengaged hostile targets. High threat targets were unengaged targets near critical areas (CRC, CRP, TACC, air bases, and cities). Surveillance consists of detecting and reporting unknown tracks on a radar scope. A surveillance operator and technician are usually assigned responsibility for surveillance in a region of the airspace.

A battle staff provides supervision, coordination, and support of these activities. Their responsibility is management of the air battle in their assigned portion of the airspace. They must allocate and deploy resources in accordance with the operational order and developing tactical situation. They provide the leadership for teams.

The "picture" of the air battle is depicted on a large vertical plastic display surface on which alphanumeric and graphic data are manually recorded from the back surface of the display. The tracks of bogey flights and interceptors are plotted on a geographic map. Information about scheduled flights and flight status is maintained in tabular form. Plots are maintained by two sets of people: tellers who sit in front of the display at the section for which they are responsible and plotters behind the display. Data to be plotted are given to the tellers in written form or voice; they relay the information in voice by telephone to the plotters.

This large display contains the information used by the battle staff and their support personnel. The surveillance operators and WDs have automated situational moving-target-indicator displays on their radar scopes. Typically, the user has selected only the limited geographic area for which he is responsible and he does not look at the total battle. These displays are not provided for the battle staff and not used by them.

Semi-Automated Ground Environment

The operations of SAGE are very much like those of the CRC and CRP. The roles of the systems in air defense differ. SAGE is responsible for continental air defense in conjunction with NORAD; the CRC and CRP are responsible for air defense in support of tactical operations in the airspace of a combat theater.

SAGE has larger numbers of personnel and computer support for most operator and command positions; however, it is also somewhat obsolescent, having been designed initially to the state of the art in computers, sensors, and weapons available in the period of the 1940's and 1950's. It is being phased out to be replaced by the Joint Surveillance System (JSS). Further information on SAGE can be found in References 7 and 8.

Airborne Warning and Control System

AWACS is similar in function to the CRC and SAGE. It is different in two ways: it is airborne rather than ground-based, and its air traffic control staff is smaller. The radar and computer equipment are also built with more recent electronic technology.

Tactical Air Control Center

The TACC is an integration and planning center using entirely manual operation in its present configuration. The manual vertical plotting board described earlier is the situational display. Some sections, such as intelligence, use an acetate overlay and grease pencil for analysis and planning. Information and messages in and out of TACC are transmitted over voice channels.

The activities in TACC are heavily dependent on knowledge of terminology, operating, and reporting procedures in a multi-national force structure and limitations of equipment and logistics. This characterization can be illustrated by the following list of training objectives for Blue Flag 80.1:

- Be familiar with fundamentals of C^2
- Know the NATO 2 ATAF C^2 structure
- Understand theater terminology
- Know NATO/USAFE reporting procedures and report formats
- Understand COMSEC/OPSEC procedures
- Understand the Warsaw Pact threat and friendly force counterthreat
- Know the NATO stages and states of alert
- Be familiar with theater documents
- Be familiar with vulnerabilities and limitations of allied communications systems
- Be familiar with logistics operations and limitations

Some automation of the TACC is in progress and development. An initial attempt to develop an automated TACC, the 485L program, has been abandoned. The current attempt consists of developing minicomputer support systems to aid specific functions within the center. The Computer-Aided Force Management System (CAFMS), for example, is an aid for resource allocation developed by the Honeywell Electronic Systems Division (ESD) and being implemented and evaluated by the 4442nd Test Squadron at Eglin AFB in Blue Flag exercises. Other support systems under development at ESD are:

- Force Management Enhancements (FME)--Various decision-aiding techniques for planning and commitment, primarily resource-to-target assignment. It was formerly called Tactical Operations Planner or TOP.
- Knowledge-Based System (KNOBS)--An artificial intelligence processing technique known as "production rules" for weapon-to-target assignment. It has the capability to change rules for target assignment in the field without reprogramming. It also permits the user to trace the logic behind a trial assignment to determine whether he concurs, and if not, to modify the assignment.

Thus, the nature of the TACC will be undergoing major change. Research on team activities in the current manual TACC will be inappropriate because many of them will soon be modified significantly.

The recommended operational settings on which to base a research program in team training are the CRC, CRP, and AWACS. They encompass a representative range of types of teams and C^2 activities within common tactical missions. The situations are also stable enough to serve as an external reference for designing and evaluating research studies.

The TACC is not an appropriate setting in its present form because it will be undergoing major changes. Neither the scope nor the impact of these changes is yet known. Research studies could be done on the next-generation TACC by extrapolating current knowledge and plans and anticipating future problems. The worth of such an approach is dependent on the adequacy of the data base which one extrapolates; its adequancy is presently unknown.

Research on computer support and aiding for TACC-type activities would be more appropriate. It could provide information on what activities need support and how to aid them. The research would also contribute to formulating concepts of the next-generation TACC.

SAGE is not an appropriate vehicle since it is obsolescent and being phased out of the inventory. The development status of the JSS, the replacement for SAGE, would have to be assessed for suitability.

The CRC/CRP functions and personnel structure should be broken down to identify the teams and structure of teams within it. Of course, the description of a team must include C^2 activities. The selection of teams and conditions to simulate and issues to investigate can be made. The selection would be influenced by local circumstances of a supporting consensus and availability of resources as well as research criteria.

STATE OF KNOWLEDGE IN TEAM PERFORMANCE AND TRAINING

The purpose of this topic is to summarize or characterize the state of knowledge in the area of team research. The objective is to provide a preliminary framework for thinking and discussion in the context of military C^2 activities rather than a comprehensive analysis of the research literature. The ideas expressed are an outgrowth of reflections on the research literature and the content of the reviews.

The needs for knowledge about performance and training of teams are many and broad; further, the state of the existing knowledge is so unstructured that better focusing and delineation of problems is a necessary first step. This literature has been reviewed several times in recent years (References 1-5). There is a consensus among investigators on global areas or topics. The general findings have been that the amount and content of the research has been insufficient to provide a systematic body of knowledge on which to base a technology for team performance and training, especially in military applications. The research has often not been focused on the solution of problems in man-machine operating systems. When it has been oriented toward these problems, however, the laboratory tasks and constraints have been seriously unrepresentative of the operational problems and conditions. Goldin and Thorndyke (Reference 4) summarized the consensus among participants in a workshop on team performance consisting of eight sessions. The issues that emerged were subsumed under the topics of defining team characteristics in relation to team effectiveness, organizational constraints and determinants of performance requirements, team structure, communication, and training techniques for teams.

Representative conclusions are presented by Collins (Reference 2) following a review of research on small groups for potential contribution to team training. He identified needs in understanding of group interactions, technical and social dimensions of team tasks, variables and relationships in the input-process-performance of team tasks, the compatibility between individual and group goals and how they are set, the roles of hedonistic individual orientation and altruistic commitment to a group, and processes for integrating individual performance into team accomplishment. This list is a very broad and comprehensive coverage of this area of research.

Definition of a Team

There are several definitions that differ from each other in the attributes and properties chosen. However, a statement of the minimum conditions necessary for a team to exist is a first step. There is a consensus in the literature that all teams must have the following properties as a minimum:

- An objective, goal, or mission toward which the team is working. This objective implies a product or output by which the adequacy of team performance can be evaluated.
- Roles assigned to individual. Roles are the functions or activities that are the responsibility of the individual. They represent a division of labor among team members. Each role contributes something to the product of the team or control of the team processes. Supervisory and leadership roles are predominantly in the control functions.

The roles vary along a continuum of homogeneity-heterogeneity functions. Increasing heterogeneity is accompanied by increasing interdependence. The functions of teams with heterogeneous roles are partitioned among team members into tasks that are very different; for example, piloting, intercept direction, and target detection. Interdependence is high because each team member has an essential part of the team's function which cannot be adequately compensated for if missing or below standard. Homogeneity and low interdependence exist in a surveillance function where multiple operators perform the same task of detecting targets in separate geographical areas.

- Structure. The positions in the team are an interconnected network. The team can be viewed as a distributed processing network of stations, each contributing an increment to the flow of work. The structure has two segments: production and control/management.
- Internal communication among members of the team. The coordination and control of team activities requires communication.

These are minimal conditions and they are highly interrelated. Many different kinds of teams can exist within these four conditions. This framework needs to be supplemented with concepts and variables that permit differentiating between different teams and team activities.

One capability that must be achieved is to be able to differentiate among team and individual behaviors and the behavior of multiple individuals acting independently or in parallel. An apparent interrelatedness of behaviors among individuals can be produced by a common external driver which acts to synchronize behaviors that are in fact independent of each other. The intuitive idea of a team includes a sense that the team is more than a collection of individuals. It includes an interdependence and intentional interaction for the purpose of working together toward a common, shared objective. The mechanism of the interaction has not been identified, however.

It is commonly stated in the technical literature that teams must have a shared goal; this is a necessary property of a good team. However, we believe that it is more important that teams have a shared plan or schema. The shared plan is an internalized (mental) scheme for organizing and integrating team activities in performing the operational tasks required to accomplish their mission goal. The goal is usually imposed by an external agency in the form of a required output and it provides little information for the team process beyond scoring output of the team's performance. However, the shared plan can be used by individual members of the team to adjust their behaviors to the needs, style, competence, and other characteristics of team members. The shared plan connects the operational tasks and team behaviors.

Team Performance Dimensions

The activities of a team can be separated into two types: operational tasks and team-oriented behaviors. This distinction is not usually made explicitly in the literature although team behaviors and skills are assumed and discussed.

A team is a decernible, functional unit; it is a set of two or more individuals who must behave in a coordinated manner to perform some work measurable as a countable output. The most visible and concrete activities of a team are the operational tasks that achieve the team's output. The operational tasks are related to the mission or objective of the team. The objective is achievement of an output or product. It is measured by indicators such as percent kills, attrition, survivability, and objectives gained, for example. Performance on these tasks is measured primarily through product measures.

However, there is a second set of team-oriented behaviors that includes the ways in which the team members interact and relate while performing the operational tasks. These behaviors, rather than the operational tasks, differentiate a team from a collection of individuals working independently. They must be differentiated from the operational tasks and measured separately from those performance measures. The team-oriented behaviors are the behaviors of interactions, coordination, and integration that constitute the operating plan or schema that the team members use to accomplish their operational tasks. The team schema may include several modes corresponding to different operational conditions.

The performance of both the operational tasks and team behaviors must be evaluated in terms of both product and process measures. Product refers to a quantitative accomplishment or output while process is a more qualitative indicator of how the product is achieved. For example, an operational product measure might be the proportion of intercepts accomplished; a process measure might be how the weapons controller established priorities. The adjustment and equalization of workload among team members might be a product measure in team behaviors, and the speed of recognition or anticipation of changes in workload might be a process measure. The identification of product and process events in team functioning is needed to clarify the behavioral processes in the functioning of teams.

The contribution of team behaviors to accomplishing the objective of the team is unknown. It is generally assumed that some level of mastery of team behaviors is necessary for higher levels of performance on operational tasks. Extensive technical knowledge alone is not sufficient for a team to function well; it is also doubtful that competence in team behaviors alone will be adequate for performance of operational tasks. However, there is no empirical evidence to support such an assumption. The interaction between these two behavioral classes needs to be determined.

Current practices in team training do not emphasize these team competencies; they are, in fact, exercises in the operational tasks. There seems to be an assumption, at least by default, that team competence must emerge via working together on the operational tasks. Some good teams will emerge but such an unsystematic approach is inefficient.

A complicating factor is that team behaviors cannot be observed separately. One cannot observe a team just being a team; it must be doing some operational tasks. Since the competence of a team is a product of the level of mastery of both the operational tasks and team behaviors, the evaluation of deficiencies in performance requires that the two components be differentiated in the flow of behavior and assessed separately in order to identify the source of poor performance.

Team Identity

This discussion treats the team as a collection of individuals. Our observations and analyses have led repeatedly to the conclusion that the interactions between team members depend upon individuals who have skilled behaviors which they use in reaction to cues generated by team members or situational events. The team behaviors are individual behaviors integrated through the shared plan. In contrast, it is a common assumption that a team exists as an emergent entity and develops an identity as a team. Its performance is assumed to improve as this identity grows.

If such an identity exists, it could serve as a useful index of the level of team development. The effect of the team identity on the individual would also be an important relationship in understanding, designing, and training teams. The growth of a team identity may be correlated with level of understanding of the shared team plan. However, team identity as a causal factor on team performance, rather than or in addition to individual factors, should be viewed with skepticism.

The individual team member does not lose his identity or accountability in a team setting. The skills in team behaviors are individual skills; at least there is no data that invalidates this statement. Coordination and timing, for example, are behaviors that require an individual to use sensory cues to perceive conditions and adjust his behavior to them. A skillful team member, we contend, is a person whose experience enables him to adjust to a wide variation in team settings, strategies, and work styles of team members.

The emergence of a team identity is associated, however, with a number of attributes which group dynamicists have been pursuing for years. They include attributes like cohesiveness, loyalty, and belonging. They are manifested in commonplace behaviors of teams such as adopting common articles of clothing, insignia, in-group references, jargon, and codes of conduct. Team members set performance standards and exercise an internal discipline for the good of the team. Commitment to the group sometimes competes with personal goals and values.

These factors may not be relevant to team training, design, or proficiency maintenance. It is improbable that building these attributes is sufficient to produce adequate team behavior. Rather, these attributes develop after the basic team behaviors and operational tasks have been mastered to a level where the team exists as a functional unit. Therefore, they might be useful as indicators for assessment of team development or to differentiate between well- and poorly-performing teams.

Types of Teams

A final general issue is the existence of different types of teams. The idea that there would be only one kind of team is counter-intuitive. Teams having different numbers of members and different configurations of communication links would undoubtedly differ in the relative frequency and importance of the team competencies and behaviors.

Teams should be differentiable in terms of their standing on independent dimensions. There seems to be a tendency in the literature to treat all teams as either the same in some existential sense or as different and unique. However, it should be possible to partition the domain of teams into a limited number of types that are operationally different. Differences in performance among teams within a type are attributable to differences on these dimensional attributes.

Differences in team types are important only if there are associated differences in performance or training requirements. Differences in performance can be reflected in either the level of achievement on specific activities or the capacity to do some things but not others. Differences in training requirements can be in either the knowledge and skill or in the instructional strategy.

Differences among teams can be characterized in at least two ways:
1) the type of application or operational mission they perform, and
2) variation on team attributes such as structure, operational processes, and composition. Type of application includes the C^2 functions performed,

characteristics of the tasks, the internal/external organizational structure, and the input/output links with external organizations.

Different kinds of teams can be defined by fixing values for the team attributes. An heuristic device for focusing on relevant team structures would be to describe some existing teams. For example, the surveillance section of a CRC operates by dividing the airspace into regions with a technician detecting and "picking" tracks in his region. The target tracks are passed on to the identification section. This team has homogeneity of functions, medium to low level of interdependence, and infrequent, medium-critical coordination and communication. In contrast, the team of weapons director/technician and pilot flying an intercept has a high degree of heterogeneity and interdependence, and communication is a critical area of behavior.

Similarly, operational missions of teams can be examined to determine if they can be categorized into distinct types. If different types of teams and applications can be identified, the degree of association between these two sets can be determined. A first approximation could be made by attempting to compile a matrix of teams x application in order to highlight a relationship. Permuting and ordering the rows and columns, for example, might reveal a pattern of contingency. The contingency would then permit a user to conclude that application type x "requires" team type a. If the properties of the team could then be determined by a table-look-up, the systems analyst would have a valuable aid in addressing team design problems.

Thus far, we have identified no types of teams or applications beyond the level of some preliminary speculation. The problem of choosing a level of discourse is an initial stumbling block. One tends to shift among different molar/molecular levels and some consistency needs to be imposed before reporting these ideas. However, some of this speculation will be shared with the reader for the purpose of illustrating the thinking.

Some types of applications are: 1) intercept direction as representative of a class consisting of directing or vectoring a system to a target or other objective, 2) surveillance for and tracking of potential threats, 3) evaluating and targeting in accordance with an operational order or plan of maneuver, 4) deployment of sensor systems, 5) allocation of resources of weapons in accordance with a tactical plan and current conditions, 6) management of workload and throughput, 7) anticipating and adjusting to emergencies or unanticipated conditions, 8) real-time monitoring and evaluation of team or system performance, 9) managing external/internal coordination, and so on until one's free-associative capacity is exhausted. These activities consist of sets of tasks which are performed at least in part by collections of individuals who must act in concert to achieve some product, objective, or goal.

There are fewer types of teams to suggest. One is a horizontal structure consisting of individuals who perform the same tasks but divide up the workload. There is a little interdependence and little differentiation among members. Surveillance and air traffic control tend to be of this type; the workload is divided by geographic area. Another way of dividing workload is to take items on a basis of first in queue, first out to the first available person.

A team that has its members highly differentiated in function, and highly interdependent, is represented by the combination of intercept controller/ intercept pilot. There are variations in the situation of one controller directing two or more pilots against a single hostile and one controller directing several one-on-one intercepts concurrently.

A hierarchical structure exists in supervision and management. For example, a surveillance or weapons supervisor can be managing several operators or sections of operators. The supervisors may, in turn, be under the direction of one or more levels of battle staff management.

Some teams process things in a serial or mixed parallel/serial order. The sequence of activities of detection, identification, evaluation, and action selection is carried out by a team arranged in this manner. There are teams within each of those activities.

These examples are speculations which we intend to verify and extend when an opportunity presents itself. How to get them into a matrix format is puzzling. Better definition of the properties and uses of the matrix may be the next step. Also, it seems relevant to consider how one determines whether a pairing of teams and application is good, effective, optimal, or some other evaluative criteria.

CHAPTER III

RESEARCH AREAS AND RECOMMENDED LONG-TERM RESEARCH TOPICS

Research areas in C^2T^2 will be discussed for the purpose of establishing a context and background and developing specific research recommendations. The discussion is intended to address the recommended long-term research topics and objectives in Table 7, p. 54, Volume V (Executive Summary).

The topics are organized into six categories for convenience in presentation. They are listed in Table 2 under those headings. The numbers in parentheses refer to the issues and problem areas in Table 4, Volume V.

The categories are used only for convenience in organizing the text to avoid a long, unstructured list which could induce deeper levels of boredom. They are not intended to be definitive, comprehensive, nor exhaustive. They are also not mutually exclusive and other partitionings of the topic are easily devised.

The format for discussing the topic areas consists of a brief statement of the area, discussion of problems or issues, recommendations of a specific project intended typically as a starting point, and an outline of the approach and resources needed. They consist of an approach, major steps, types of resources and personnel required, and a level of effort.

TABLE 2. LONG-TERM RESEARCH TOPICS

- Determination of deficiencies in performance and training for C^2T^2 (all)

- Develop a conceptual model and framework for the descriptions and analysis of C^2 team functions and behaviors. (1)

- Methodology for analysis of C^2 team behaviors:

  --Develop analytical techniques for deriving T^2 requirements and compile supporting data. (3)

  --Develop and evaluate systematic procedures for determining the skill and knowledge requirements of simulated combat missions for C^2 teams and partition them over the categories of individual, preteam, team, and superteam exercises as most appropriate vehicle for training. (4)

  --Develop and evaluate techniques for defining the required components, functional capabilities, and level of fidelity for simulation of C^2 teams in a weapons system. (7)

  --Develop techniques for interpreting measures of team performance to identify deficiencies in skill and knowledge and to select appropriate remedial action.

- Performance quantification and measurement of C^2 behaviors for individuals, teams, and systems:

  --Develop comprehensive performance objectives for C^2T^2 at the level of preteam, team, and superteam exercises. (2)

  --Develop and evaluate a set of performance measures that will assess competence of C^2 teams and battle staffs and relate team competence to system effectiveness and individual proficiency. (2)

  --Develop techniques for analysis and interpretation of team performance measures in terms of the combat readiness of teams and systems. (14)

- Man-machine design for C^2 teams:

  --Several of the topics sorted into other categories are applicable here as well, especially Methodology and Performance Quantification.

  --Conduct research to evaluate the comparative strengths and weaknesses of hard and soft C^2 teams on performance of critical C^2T^2 tasks. (18)

TABLE 2. LONG-TERM RESEARCH TOPICS (concluded)

• Development and implementation of training requirements: --Develop a set of standardized C^2 team exercises which are graded in difficulty and cover the range of C^2T^2 operational activities. (2) --Identify and evaluate existing instructional strategies applicable to T^2. (9) --Identify new topics and data for research when existing technology does not provide appropriate or adequate instructional strategies. (9)
• Simulation for C^2 exercises --Develop data for simulation of operational situations for C^2 teams and battle staffs which identify the a) independently controllable features of the simulation; b) necessary and sufficient conditions of fidelity to reproduce the desired behaviors; and c) cost-benefit relationships for inclusion of each feature in a simulation. (5) --Conduct research studies on the comparative cost-cost-effectiveness of live and simulated combat exercises--and mixes of these events. (16)
• Personnel requirements: --Develop and assess feasibility of a psychometric research plan to identify selection criteria for entry into a career field of air weapons controller. (8)

The statement of approach and resources is more global than is ultimately needed for planning and implementing a research program. However, a more detailed statement requires at least one more iteration of the recommended projects. That iteration would provide more information on the specific topic or sequence of topics to be investigated, the informational objective, study design, methods, types of data collection, and amount of data analysis. Then, man-hour requirements and budget could be estimated. This information is not available at this time nor are there resources to support the analysis.

What is needed at this stage of developing a research program is the formulation of and agreement on research avenues and strategies. The strategies then become the basis for more detailed planning of studies. Successful formulation of the strategies may be possible only in working sessions where the options, topics, goals, and approaches are "wrung out."

FURTHER DETERMINATION OF DEFICIENCIES IN PERFORMANCE AND TRAINING FOR C^2T^2

An early major step in a research program should be a systematic study to define deficiencies and problems in team performance and training more precisely and in more detail. This further definition is dependent on some progress in developing a conceptual framework for C^2 teams. It will provide a better basis for formulating queries, identifying appropriate behaviors and issues, and interpreting data and observations. The survey in the present study provided information but the major accomplishment was to identify problems and needs. We did not get sufficiently detailed information on conditions to analyze the problems in depth. A subsequent study could build on the survey and develop probes to provide deeper analysis.

The potential impact of these deficiencies on system effectiveness can be assessed and cost estimates could be made for specific research studies and projects. They can then be evaluated on the basis of cost-benefit comparisons.

The most objective way to evaluate command team performance is to assess performance on an exhaustive set of terminal behavioral objectives for team and operational tasks. The most practical and feasible way to assess performance is to use technical experts as raters or judges.

The performance objectives will have to be developed. There are some existing objectives and standards from the STAN/EVAL program, for example, which can be collated for this purpose. Course training standards would also be useful; however, they must be evaluated for adequacy in terms of coverage, comprehensiveness, metric properties, interpretability, and appropriateness for the research objectives. It will probably be necessary to refine and supplement them. Team behaviors in particular will not be available.

Such a project would take three years or more to produce usable results. Data collection would have to take place in operational units and schools during preteam, team, and superteam exercises. Judges will have to be trained and massive quantities of data will be accumulated for analysis and interpretation.

The complexity of the effort dictates that the initial project be a study of a small number of limited situations rather than a broad coverage of the entire command. Coverage can be extended in subsequent studies for as long as the results are useful for the purposes of research planning.

A simulation facility for command and control teams, similar to the US Army's Combined-Arms Tactical Training Simulator (CATTS), would be useful in evaluating team under more controlled conditions. However, development of the facility would cost several million dollars and be costly to support and operate. Therefore, it must be a longer-term objective.

The outcome of the field studies, or series of studies, would be a set of research needs and objectives. They will be a prioritized set based on objective, empirical performance data, and on evaluation of the potential contribution to operational effectiveness.

DEVELOP A CONCEPTUAL MODEL AND FRAMEWORK FOR C^2 TEAM PERFORMANCE

The development of a framework for team phenomena is a fundamental need that underlies all research topics and would be highly beneficial to planning an integrated program. This need has been identified by others. For example, in a workshop on team performance held by RAND under sponsorship of the Office of Naval Research (ONR), a need for a taxonomy was identified (Reference 4). Although a taxonomy is not a model, this statement reflects the need for a conceptual framework for describing, discussing, and manipulating team phenomena.

The term framework is ambiguous. We have chosen it to mean a model in the sense of symbolic, mathematical representation or a model which can be represented in software as a set of relationships and rules run on a computer. These statements are objectives; the early stages may not be well-defined or may have little mathematical power. However, the formulation should be mathematical in form.

A taxonomy is another meaning of framework. It is typically a set of terms that can be used for sorting and labeling things. A good taxonomy would provide mutually exclusive categories which are an exhaustive partitioning of some specified domain. More sophisticated taxonomies have a hierarchical structure.

Taxonomic classification would be an early stage of developing a model. The model would also represent the team phenomena and processes as a functional network through which information is processed. The model permits the user to insert input data on initial conditions and calculate an output when suitably quantified relationships and algorithms are incorporated into the model. The user can run "what-if" problems. Therefore, we opt for the model even though it can be a difficult and complicated undertaking.

Developing a taxonomy is itself a difficult undertaking with some significant pitfalls. Taxonomic efforts must be proposed with some reservation and concern for their usefulness. Their history is less than satisfying. They have tended to provide some useful tools but they also seem to depend on arbitrary rules, to be incomplete, and to absorb unlimited resources.

However, some functionally-oriented taxonomic structure is needed in order to impose some order on this problem area. It is not feasible to develop a classification scheme that is exhaustive of team phenomena and mutually exclusive in its categorization. However, it should be feasible to build a useful taxonomy for a defined set of applications within a reasonable cost.

The key to feasibility and tractability of a taxonomy is to identify explicitly a domain of applications and phenomena of teams to be addressed. One approach, for example, might undertake to describe the team structure and behaviors in a CRC or a TACC. The resulting taxonomy could be extended to and tested by application to related team situations, such as the WOC. Taxonomies should always be built as terminology for specific purposes. The comprehensive and general approach may be an investigator's Holy Grail, which may consume several lifetimes in an ineffectual pursuit.

The other side of the issue is the consequences of not having some kind of framework. The lack of a systematic, comprehensive framework for describing and analyzing teams and human factors requirements for team operation is a fundamental deficiency underlying all research issues on teams. This deficiency is manifested, for example, in a lack of adequate terminology and taxonomies for describing teams and behavioral phenomena in teams, definition of the types of activities done by teams and team behaviors in performing them, definition of the types of teams that occur in military systems, and differentiation between teams and multi-individual aggregates of people working independently. They are a necessary precondition for formulating and implementing a research program to support human factors of teams. If there is no framework which can serve as a common reference, it is not possible to assess what is currently known about teams; it is difficult to compare studies and integrate the results because even studies differ on more than one variable and processes. The conceptual framework would provide a means for establishing equivalencies and differences among related studies, for identifying relevant variables and relationships, and for evaluating the adequacy of experimental designs.

Development of a model of C^2 team behaviors is proposed as a basic first step in a research program. It should be a continuous effort with the results of analyses and experiments being fed back into the model to improve its accuracy. The model will go through iterations in accordance with the results of field studies, analysis, computer simulation, and experimentation. In addition, evaluation and feedback can be obtained through its use in preparing aids, guidelines, data, and methods for use by developers, designers, and managers of systems and training.

The following section contains a discussion of a proposed approach to building the model. The immediate objective of developing the model would be to establish the nature of teams in four ways:

1. Structure of teams using a set of dimensions or attributes on which teams can vary with a corresponding variation in team performance.

2. Processes by which teams accomplish their functions and work.

3. Internal and external variables that affect the processes and performance of teams.

4. Team behaviors and skills by which the activities of teams can be described.

This information is needed for devising a taxonomic and functional network and would also be useful in other research studies.

The approach to developing a model of behaviors of C^2 teams is depicted in Figure 1. The process of model development is represented inside the dashed-line box. The model is tested by experimentation to verify hypotheses derived from the model or interpretation of the model to an application. The end point of model development is a conceptual framework for the description and classification of C^2 teams. This framework presumes that the model includes a classification of types of C^2 applications and types of teams; C^2 team behaviors are identified within the context of application and team type. An inventory of C^2 team behaviors would be obtained by taking the logical union of these classifications.

There are several caveats to be made concerning Figure 1: There are many feedback links and interrelationships not shown. It is not a structural, functional analysis of C^2. It does not define the information to be gathered. Rather, it is a representation of the major components of an approach; it has an input level at the top, processing in the center, and output at the bottom.

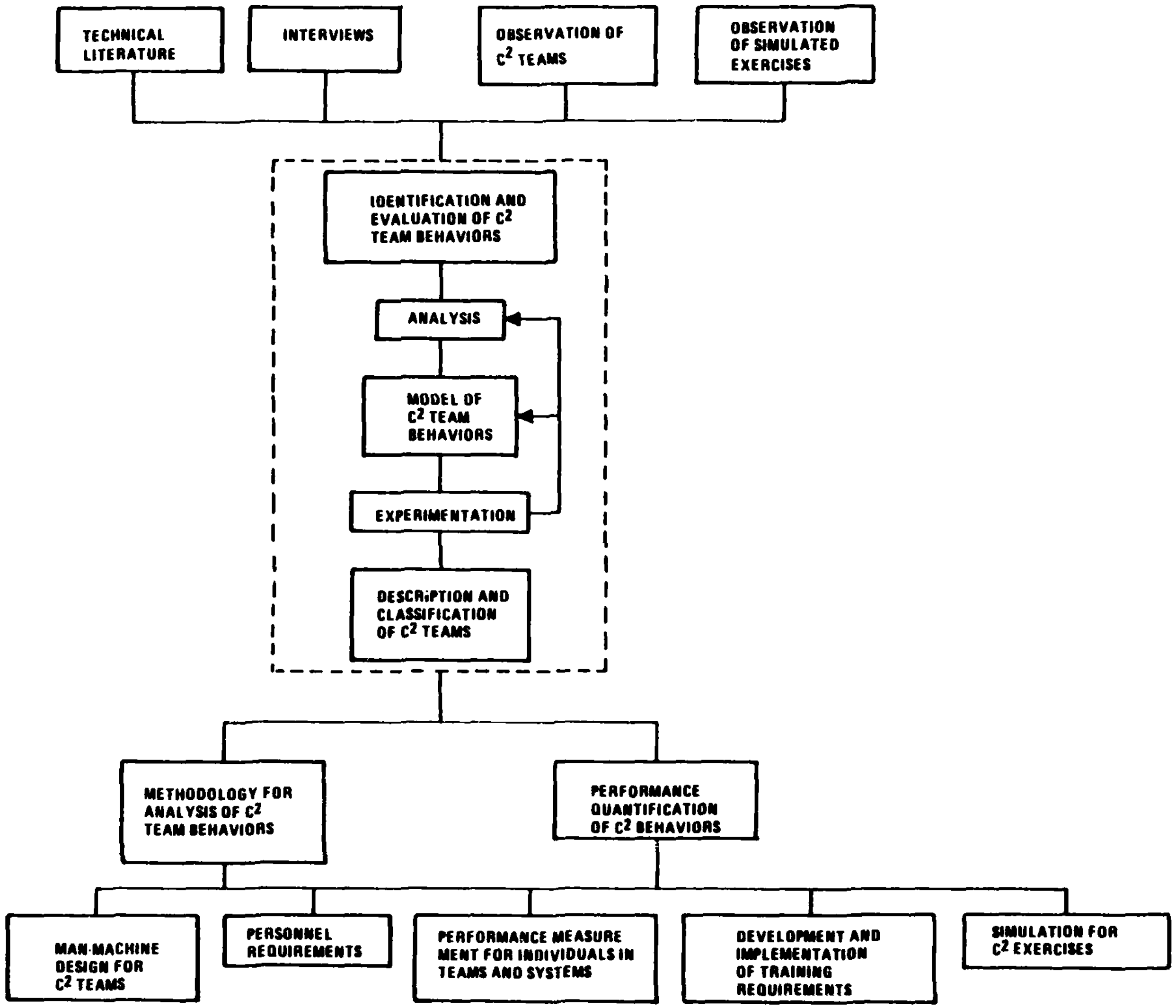

Figure 1. Approach to Development of a Model of C^2 Team Behaviors

The approach is tied to an empirical data base at the input end and to technical human factors areas in weapon system development at the output end. The empirical data base is derived from four sources:

- Observation of C^2 teams
- Observation of simulated exercises for C^2 teams
- Interviews with C^2 personnel
- Technical literature

The approach to model development is also tied to human factors areas in weapon system development. Two methodological developments are needed first: a methodology for analysis of the behaviors of C^2 teams, and a performance quantification of the behaviors of C^2 teams. These methods are then extended to the design and support of weapon systems. The human factors objectives and technology in system design are grouped into five areas:

- Man-machine design for C^2 systems/teams, including team/man-computer interface requirements
- Personnel requirements
- Performance measurement for individuals in teams and systems
- Development and implementation of training requirements
- Simulation for C^2 exercises

Inadequate attention is paid to team behaviors in part because few people know what they are. There is considerable lore about techniques for team building. Much has been written about teams and team behavior but there is little consensus or explicit standardization of terminology, definition, and usage. Terms such as cooperation and communication are recurringly used, but it is very difficult at best to interpret them as quantifiable behaviors that can be stated as performance objectives and performance measures.

The desirability of studying teams in their operational environments is discussed in the previously-cited RAND report (Reference 4). This is because laboratory research on small groups and teams has had little applicability to operational problems and there is a pressing need for improved team performance and methodology of team training.

We agree with the RAND symposium participants that studying teams *in situ* is necessary but also maintain that it is not sufficient. The position has merit in that it forces an orientation to operational tasks and conditions, ensuring relevance of the findings. A research program on team training should start with observation and analysis of teams in operational settings for the purpose of defining the domain of teams to which one wishes to generalize and apply the findings of research. Definition of the domain would be in terms of team structures, behaviors, processes, and variables that affect these things.

However, research in operational settings is often both very costly and impractical. The costs arise from personnel and from the inefficient use of time due to the lower priority of research vs operational activities. The impracticality arises from several sources: limitations on the control of variables, lack of freedom to manipulate conditions to provide an adequate test protocol, and inability to reconfigure systems and procedures to evaluate alternatives. Further, ability to generalize the findings is limited because two operational settings may be no more alike than either is to a laboratory setting.

The consequence of these shortcomings is that one observes what is available to observe rather than what should be observed to advance the state of knowledge and develop solutions to practical problems.

An alternate strategy consists of starting with observation in operational settings and abstracting from them to construct models, simulations, and experimental conditions that are necessary and sufficient to test hypotheses. This strategy is outlined in Figure 2. The figure is an elaboration and rearrangement of the upper part of Figure 1. Observation of a C^2 application leads to identification and description of the team structure, behavior, processes, variables, and skills. Interviews and analysis of the technical literature are used as ancillary techniques to facilitate the analysis of the observations. It is postulated that several application-specific descriptions of teams can be collapsed into more generic descriptions of types of teams and applications. If there are n applications, there would be less than n types. Modeling, simulation, and experimentation would be done within the context of these types, leading to improved systems for description and classification of C^2 teams. The description/classifications are iteratively refined through application and evaluation to operational settings.

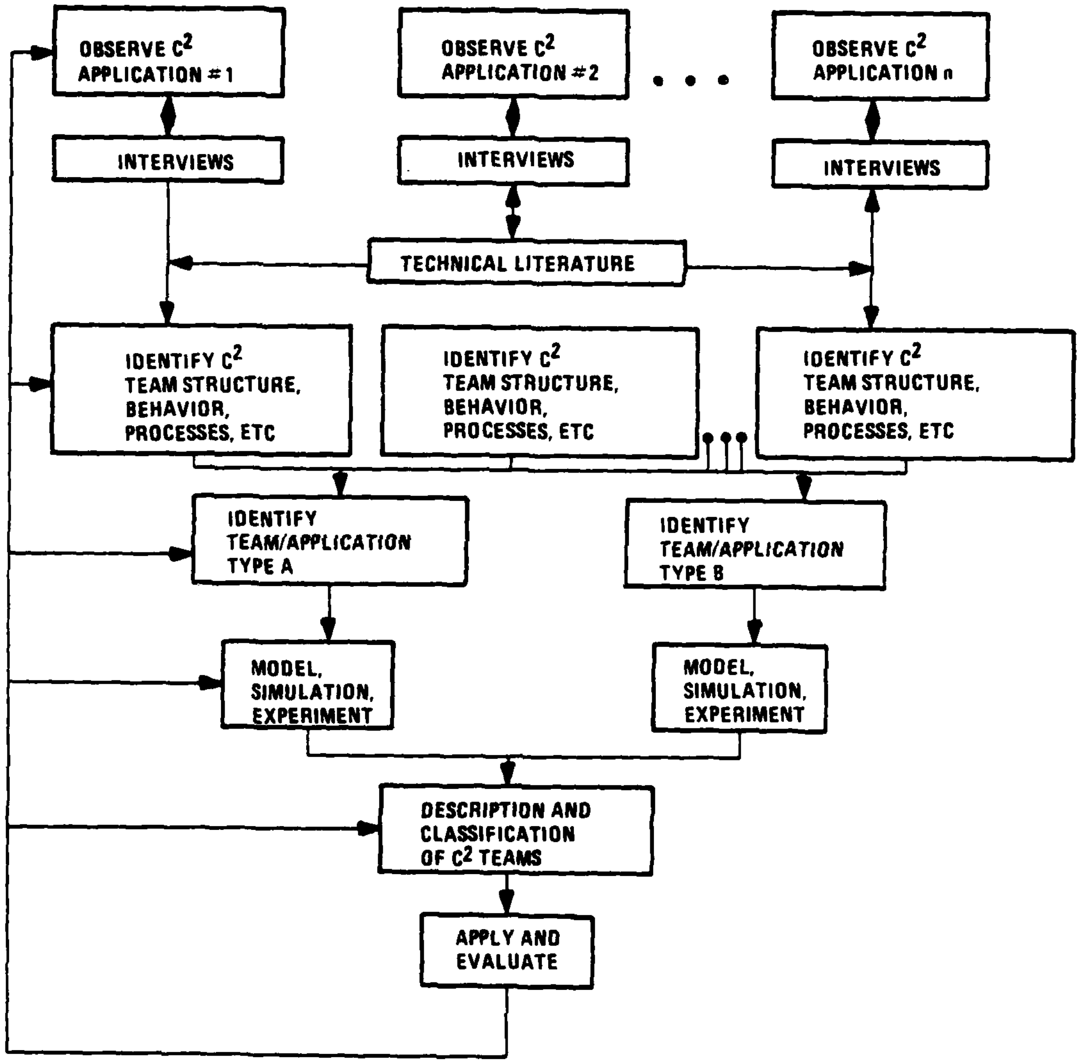

Figure 2. Strategy for Research on Command and Control Teams

The second approach, abstracting from operational settings to better-controlled and more flexible conditions of modeling and simulation, is recommended. Working from the more specific operational setting to a more general representation in the laboratory provides anchors in the real world that can promote representativeness and reality in the analysis and experimentation. Further, the application to operational settings in the form of solutions to operational problems and system design provides an evaluation against needs and conditions of the real world.

The indicated scope of the model-building activity is much too large to be taken as an immediate, as opposed to an ultimate, objective. The work must be broken into phases which will ultimately provide a comprehensive analysis of the Air Force's needs in a technology for design and training of teams. The program should be initiated with an analysis and model development for one or more specific situations, such as a CRC or TACC.

The approach for the initial phase would consist of the following steps:

1. Analyze a C^2 organization, (CRC or TACC) to identify and describe team phenomena, particularly those involving teams in processing information and decision-making. These activities should be described for representative segments of an operational cycle during a combat scenario. The descriptions should include the type of task/function, how the processing/decision-making is done, data required, and the form of output. The structures of teams in the organization and the interactions among team members should be identified.

2. Review existing concepts and data applicable to C^2 functions, man-machine interfaces, tasks, and team performance to identify relevant concepts, terminology, decision processes, variables, and nature of the relationship between variables. The purpose of this step is to provide systematic terminology for analyzing the C^2 team activities. This step should be concurrent with and iterative with Step 1 in order to get a synergistic interplay between concepts and observations.

3. Formulate a conceptual framework for C^2 team activities and processes. This framework is the best statement one can make at that time.

4. Test and evaluate the framework by applying it to the description and analysis of specific C^2 team applications. Generate hypotheses about command team behaviors and performance and test by experimentation and observation.

5. Identify deficiencies in the framework and revise as appropriate. Iterate cycle of apply, prediction, test, and revision.

The resources needed to support this effort are difficult to estimate. It is a long-term project with several intermediate products that can be useful in their own right.

The approach to estimation is to develop a strategy for model building with long-term, multi-year objectives and a sequence of intermediate objectives. Specific projects can be defined for each objective and the level of effort estimated for those projects.

Development of the long-range strategy is probably a one to two man-year level of effort. However, extensive interaction is necessary among the strategy developer, sponsor, proponents, and potential users. This kind of effort depends heavily on creativity as well as observation and analysis. The difficulty of scheduling insights and breakthroughs generates problems for planning and management.

Precursors of a Model for Command Teams

Some ideas for a model grew out of our research. Our need to establish a working framework for planning the research was a stimulus to this thinking. We will present these ideas as a starting point or first approximation to a team model. The level of development of the model at this point is primarily a basic framework that can be elaborated into a detailed description of team operations and processes.

The C^2 team model consists of four principal modules:

1. Team module
2. Tactical situation model
3. Command team behavioral module
4. Driver scenario module

A preliminary conceptual structure has been provided for each module. They need to be expanded and differentiated in more detail by a top-down analysis and application to one or more specific situations.

The Application Situation--We will start with an unspecified team in a tactical combat situation as part of a Blue force. The Blue force is opposed by a Red force, which is executing a tactical plan. Red's tactical plan is a scenario that serves as an external driver of events impinging on the Blue team.

The Blue force has been tasked with an operational objective. A plan of battle has been developed and the tasking has been broken down into more specific tasking for subordinate units. The team being modeled has been given its specific tasking.

When a military command, such as a numbered air force, wing, or squadron, is given an operational tasking or mission, it is given an objective to reach or hold, a threat to counter, resources to allocate, and assets to protect. An Air Force objective broadly is control of specific airspace or strike against a target complex. The assets have a value reflected in priorities.

A tactical plan must be prepared and implemented. It consists of:

1. Deployment of forces to counter threat
2. Allocation of resources for the deployed forces to expend against the threat
3. A scheme of maneuver to protect assets

The activities of the command team are organized to support the preparation and implementation of this plan. The acquisition and evaluation of intelligence and the logistics to support anticipated operations are examples of activities of analysis and planning, which are part of developing the tactical plan.

Team Module--A team can be described in terms of two sets of properties or attributes: architectural dimension and functional properties. The architecture dimensions are attributes of group structure, operational processes, and composition. These properties are determined by the operational tasks and organizational structure. Functional properties are the competencies, skills, and knowledge required for team operation; they are the team skills. They are determined by the shared plan or schema. Tables 3 and 4 contain a listing of these properties. The items in each list are derived mainly from the research literature and are a collation of attributes attributed to teams. The principal criterion used in compiling the lists was comprehensiveness; the items are neither mutually exclusive nor well-defined at this time.

The lists represent hypothesized candidate attributes. Each item is a potential research variable. To be useful each item should be related to observable, quantitative measures of team process or product.

The operational mission determines primarily the architectural attributes of the team. The functions required to perform the mission break down into tasks and behaviors of a command group and determine the substantative content of the tasks.

TABLE 3. TEAM ARCHITECTURAL DIMENSIONS

Structure:

- Assignment of individuals to roles
- Type of network
- Lateral-vertical hierarchy configuration
- Allocation of authority, responsibility, or control: centralized or distributed
- Rigidity vs flexibility of the relationships between roles
- Geographical distribution of team members: dense vs diffuse; adjacent vs remote
- Internal vs external determination of structure

Operational Processes:

- Goal, objective, or purpose
- Product or output
- Partitioning of functions, responsibilities, activities, tasks
- Structure of subgoals or intermediate products as indicators of team process
- Roles of operation, managing, decision-making
- Proportion of procedural and non-procedural activities
- Interdependence of functions
- Degree of social/emotional support to members

Composition:

- Number of members
- Types of specialty codes
- Variability of competence of team members
- Redundancy of overlap of functions
- Turnover, rate, continuity, or stability over time
- Compatibility among team members
- Stability of assignment
- Personal visibility

TABLE 4. FUNCTIONAL PROPERTIES OF TEAM

Coordination--what, how, timing

Interaction--interdependence

Cooperation

Compensatory adjustment among team members

Ability to modify actions in accordance with team goals and progress to them

Adjusting one's performance to work flow within team network

Improvization of impromptu and ad hoc responses in relation to team goals and other team functions

Knowledge of the team operation and interdependence

Knowledge of relationship between or contribution to team goals from one's own function or role

Mechanism to detect and correct errors

Adjustment mechanisms

- Emergent mechanisms
- Unexpected conditions
- Emergencies
- Overloads

Cue and alerting to change in condition

Anticipatory change in conditions

Discipline in communication

- Relevance
- Appropriateness
- Timeliness

Allocation of resources and workload

Management of workload and overload

Team memory, data storage, recordkeeping

The operational tasking determines the processes necessary for the group to react to the external event and produce an output. These processes determine the number of team members, the kinds of people (AFSC), the role of each team member in terms of the duties and tasks assigned to him, and the connections between members. These components thus determine the size, composition, network structure, functional heterogeneity, and interdependence of the team.

The functional properties in Table 4 are attributes describing how well the team performs or the quality of team performance rather than what the team does or what it accomplishes in output. These process attributes are of two kinds: those associated with the tasks of the operational mission and those devoted to management and control of the team process. Allocation and adjustment of workload is one of the latter, for example.

The attributes are determined by a shared plan or schema, which is distinct from a tactical plan. The shared schema is the team's usually unspoken agreement on how they will interact to accomplish the operational mission. Each team member must understand the schema, what it requires of him in terms of control and adjustment of his behavior to coordinate with other team members, and what adjustments other team members must make with respect to each other. The existence of a team entity and the quality of team performance are an increasing function of the level of understanding and participation in the shared plan. The relationship between team quality and amount of output, quantitative or product measure, is unknown.

Tactical Module--The focus of the discussion until now has been definition and characterization of the term "team." Another key aspect a C^2 team performance model must deal with is the tactical situation. A tactical command operates to exert force against an adversary force. We will not get into military theory and doctrine for combat or use of resources, although they are a body of principles that shape and constrain C^2 team behavior. Only defensive and offensive situations will be treated here, leaving further analysis until later iterations of the model development.

The tactical module of the model represents the goal of a tactical plan as establishing and maintaining a steady state of balance between opposing forces. The steady state may be a non-zero value. The Blue command seeks to maintain it. The external driver scenario produces disturbers in the form of enemy action which tend to upset the steady state.

When cast in this form, the tactical module becomes a control module which has the objective of controlling and modifying the process of a system to keep a state or output within some specified bounds. The output is often defined as an optimum for some functions. This type of problem is in the domain of control theory, a mature area of technology. There are standard methods, techniques, and models within existing control theory. They should be useful for this application and should be reviewed for the purpose of assessing the feasibility and value of mapping the tactical module into some available model.

The information the command team receives is incomplete and unreliable. The command team is attempting to determine the state of the world at some remote point in terms of threat to the tactical plan and to implement counteraction at that remote point. A functional breakdown of these processes is represented in Figure 3.

The information the C^2 team receives at a TACC, for example, is in the form of alphanumeric messages. The messages contain data about battlefield and airspace events. The data is received sequentially and without indicated correlation between related events. The data is only a sample of the information in the situation and it is thus incomplete. It contains inaccuracies which must be identified and removed by cross-correlation and internal consistency among sets of data. This data must be used to construct the events of enemy action that have occurred. This tactical picture must be interpreted in terms of the enemy's intentions and possible actions.

Another area of activity of a command and control team in development and implementation of the tactical plan consists of two phases: force generation and engagement. A summary of these phases and their characteristics is presented in Figure 4, adapted from Wohl (Reference 9). Force generation is the preparation of the scheme of maneuver and the initial allocation and deployment of resources and forces. Engagement is the control of forces in response to enemy action and execution of the scheme of maneuver. These two phases involve functions and tasks such as assessment of threat, evaluation of alternatives, correlation of intelligence information, and preparation of operational orders at a more detailed level.

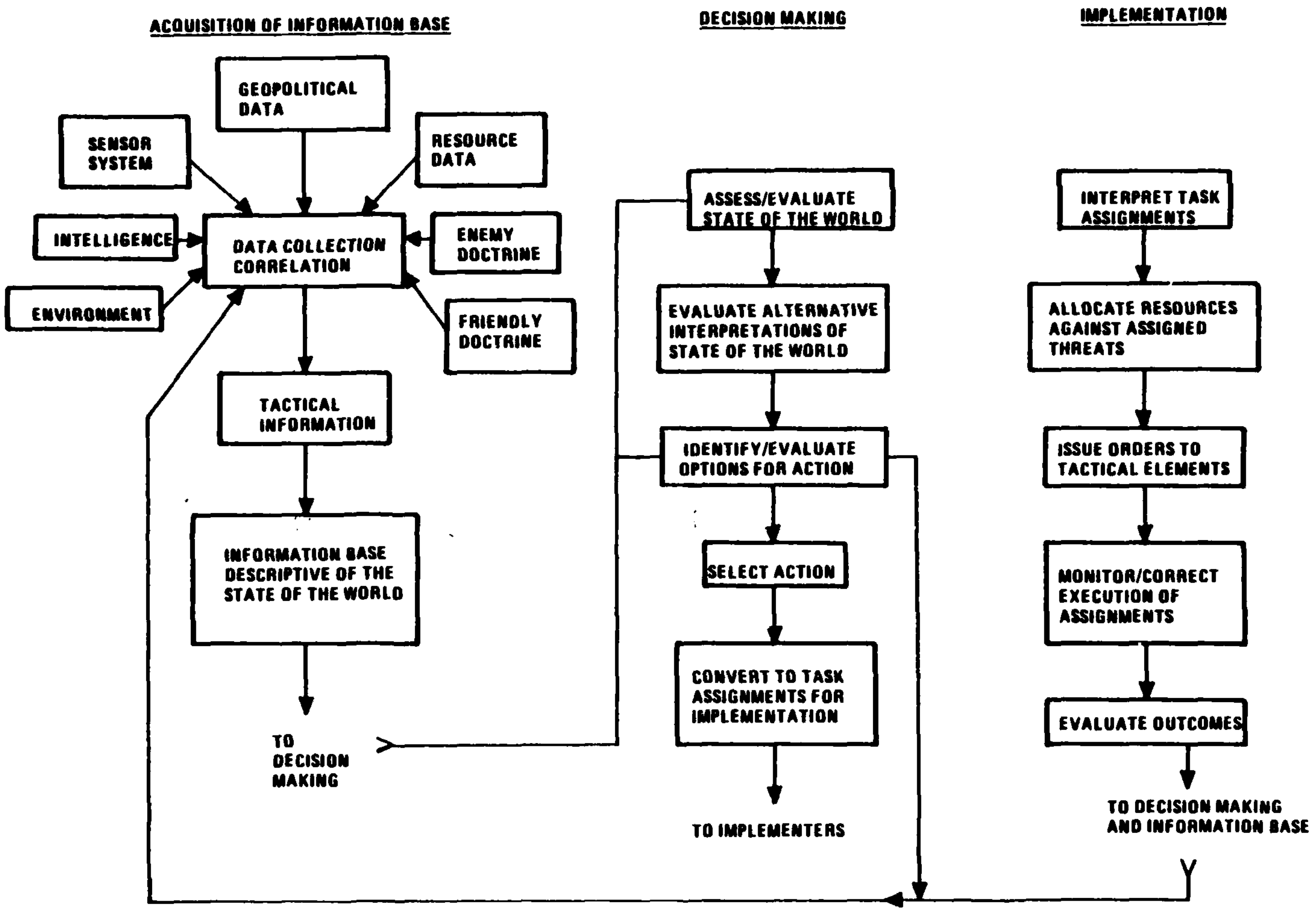

Figure 3. Functional Areas of Command and Control

PHASE	FUNCTIONAL AREA	DECISION FUNCTION	TIME AVAILABLE FOR DECISION	DEGREE OF INFORMATION AGGREGATION REQUIRED
FORCE GENERATION	PLANNING AND COMMITMENT DECISIONS	APPORTIONMENT ALLOCATION TASKING DETAILED PLANNING	(MORE TIME) ↕	(MORE INFORMATION, (LESS DETAIL) ↕
ENGAGEMENT	CONTROL AND COORDINATION DECISIONS	RESOURCE REALLOCATION TARGET REASSIGNMENT TARGET UPDATE/ INTERCEPT CONTROL THREAT WARNING	(LESS TIME)	(LESS INFORMATION MORE DETAIL)

Figure 4. Summary of Critical Tactical Command and Control Decisions (adapted from Reference 9)

The C^2 team operates in two phases: planning and current operations corresponding to force generation and engagement. The team's function is to implement a tactical plan that establishes the steady state and monitor it to detect and nullify disturbers. The team can respond in one of two modes: reactive, in which the team detects and fashions responses in real time; and anticipatory, in which the team identifies possible or probable disturbers during planning, establishes a search routine, and preplans the response. Planning and implementation can be intermixed temporally.

The objective of the team in a defensive situation is to keep the forces in balance of equal force or null the steady state.

The steady state is established by evaluating Red's capabilities and intentions and countering them by depolying forces against them. The factors considered in deployment are control of critical airspace, areas of surveillance, assignment of sectors for patrol, nature of the threat, and other factors of tactical value.

The function of the team in attack is to develop and implement a tactical plan which maintains a positive steady state to provide the required momentum. In an attack mode the steady state would be maintained with a positive force ratio to give a momentum to the combat element. There would also be a sequence of positions or postures which are sub-objectives or subgoals en route to the objective of the attack. They probably have associated times by which to reach them as in the concept of phase lines. They must also detect and neutralize disturbers.

Command Team Behavioral Module--The next steps in developing the model are to develop a module for C^2 and team behaviors on the skeleton. The module would consist of the functions and tasks performed by members of a command team. The content would be predominantly the C^2 activities in operational tasks. The activities will contain functions and tasks performed by individuals, multi-individual aggregates, and teams. Several teams may exist and the team composition and configuration may be different for different functions. These characteristics will be determined during the particularization of the model to specific applications.

Our level of development of this module is embryonic. We know there must be one for the purposes of research on manned C^2 systems and we have some preliminary ideas. Some of the material presented on the tactical module belongs here but we have not yet sorted it out. The concepts in the tactical module may have dual facets; one facet is the tactical function and the other facet is the behaviors of the operators.

Adequate descriptions of C^2 behaviors are not readily available. Performance objectives are not available for command teams. Some work does exist, though, which can serve as a prototype or paradigm for defining C^2 team behaviors. Table 5 contains a list of 12 tasks from a simulation for Army battalion command teams (Reference 10). The first four correspond roughly to the pre-engagement phase and the remaining eight correspond to the engagement phase. These tasks are further broken down into more detailed behavioral elements. The Army has had some experience in using this task list and the simulation for training and research in the CATTS. This work can be used to provide guidelines and lessons learned in identifying team behaviors and developing performance objectives and standards.

TABLE 5. TASKS FOR BATTALION COMMAND GROUPS FROM ARMY TRAINING EVALUATION PROGRAM

Force Generation	Task 1.	Develop plan based on mission
	Task 2.	Initiate intelligence preparation of the battlefield
	Task 3.	Prepare and organize the battlefield
	Task 4.	Troop lead
Engagement	Task 5.	See the battlefield during the battle
	Task 6.	Control and coordinate combat operations
	Task 7.	Employ fires and other combat support assets
	Task 8.	Concentrate/shift combat power
	Task 9.	Manage combat service support assets
	Task 10.	Secure and protect the task force
	Task 11.	Troop lead during battle
	Task 12.	React to situations requiring special actions

Sources with which to begin developing descriptions of AFC^2 tasks are existing task inventories cited in Volume I, Chapter II; TACM 50-9, Training Tactical Air Control System (TACS), 1980; STAN/EVAL behavioral checklists; and the scenarios and objectives for Blue Flag exercises. The team behavioral module can be best developed by using the existing literature and observation exercises to postulate further details of the modules.

Driver Scenario Module--A driver scenario must be provided to generate the tactical events to which the Blue Command team responds. Again, our thinking is still at the embryo stage. The scenario must include realistic threat levels, tactics, movement constraints, and other components of a conflict. It is desirable that the Red force be an intelligent adversary who has options for varying his responses and plans in accordance with emerging tactical conditions. However, the complexity and cost of the scenario module increases with the level of intelligence and flexibility; practicality may dictate that the scenario be restricted in these attributes.

METHODOLOGY OF ANALYSIS OF C^2 TEAM BEHAVIORS

This area of research is tool development for designers, developers, and managers of C^2 systems. The methodology must be usable in system development, management of resources during deployment, and maintenance of combat readiness. It must be applicable to weapon system acquisition during conceptual, advanced, and engineering development and to the design of man-machine interfaces, workspaces, personnel subsystems, training and training devices.

It is recommended that a research project be initiated with the objective of developing analytical tools appropriate to the design of teams and C^2.

The methods must permit the user to identify the behavioral data needed for these applications and select or generate that information from engineering design data, statements of required operational capability, or mission requirements. The methods would be an extension of current techniques of task analysis and compatible with Instructional Systems Development. The sequence from MIL-H-468552 (Reference 11) should be maintained. It establishes an analytical procedure consisting of the steps of defining and allocating system functions, information flow and processing analysis, estimation of potential operator/maintainer processing capability, allocation of functions, analysis of tasks, loading analysis and design of system and subsystems. A human engineering program plan and a test and evaluation plan are also required. The application to C^2 teams will require that design of individual work stations and man-machine interfaces be supplemented with design of person-to-person interfaces within the configuration of the team itself.

The data to be extracted is determined by the uses to which it will be put in design and support of systems. Generation of only task-analytic data is not enough. The user must also be provided with techniques and algorithms for processing the task data to provide solutions to the problems of design of team structures, man-machine interfaces, personnel requirements, and training.

There has been recent work oriented in this direction. It has mostly dealt with C^2 systems and emergent situations involving semi-structured tasks. For example, guidelines for requirements definition and design of man-machine interfaces in C^2 systems have been prepared by Smith (Reference 12) and by Ramsey and Atwood (Reference 13) for man-computer systems. The reports contain excellent summaries of design options and illustrations as well as the techniques for performing the analysis. Another relevant effort is the review of performance models applicable to evaluation of man-machine systems (Reference 14). The report is a compendium of descriptive information on the models with evaluative analysis. Research recommendations are also provided.

Two conditions are necessary for the effective use of the task analytic tools: Data item descriptions (DIDs) must be prepared to specify the format and content of the task data to be provided and the task data must be specified as deliverable items under a procurement contract for a system. Contractual obligation to deliver the data will ensure its availability in useful form.

A training analysis requires more detailed breakdown of task descriptions in order to provide the level of detail needed to determine training requirements and develop or procure training courses and equipment. The skills and knowledge required for competence of the team and tasks behaviors should be determined and translated into terminal and enabling performance objectives. The levels of competence should be defined in terms of levels of mastery associated by skill levels of the Air Force Specialty Code (AFSC). These levels entail a partitioning of behaviors among skill levels within grades of a specialty. These analyses should be an extension of, based on, or compatible with the procedures and regulations for Instructional System Development, which has become a standardized practice in the training community.

The development of techniques for task and training analysis for C^3 teams will have to confront the challenge that the operational tasks for C^3 teams are semi-structured rather than proceduralized tasks and are performed in emergent situations. Conventional task analysis is best suited to proceduralized tasks and cannot adequately handle the contingencies and dependencies of the information flow in emergent situations. The variability of events that can occur may require analysis in terms of functions, content, and sets of equivalent behaviors rather than fixed sequences of responses. The problems entailed are similar to those encountered in computer-assisted instruction (CAI) authoring languages and the design of man-computer dialogues.

Task analysis is a very labor-intensive undertaking even for the more tractable analysis of procedural tasks. This condition will become much more serious for the semi-structured tasks. Tasks will have to be represented as networks or tree structures in which task options are represented as alternative behavioral chains and the situational factors on which the branching among them depends are identified and associated with each chain.

Data processing aids for the analysis of information flow, function allocation, and task description will be needed to reduce the manpower requirements and increase the cognitive scope of the analyst to comprehend the structure of the tasks. Such aids will increase the feasibility of doing these analyses while reducing cost and increasing effectiveness.

The magnitude of an effort to develop these techniques and the investment required is often a deterrent to planners, and raises difficult problems of priorities. There is often a search for quick-and-dirty, low-cost techniques that, though inaccurate, are precise enough for most applications. However, these techniques are risky because the analyses are difficult to replicate and their limitations in terms of errors and their consequences are unknown.

The approach to develop these methods should consist of three major phases:

1. Identify the extended procedure or sequence of analytical issues and steps necessary to go from an operational need or system concept to completion of development of the man-machine components for C^2 teams such as operating procedures, interfaces, personnel, training, and simulation. Provide techniques for implementing MIL-H-46855 and define DIDs for each of the man-machine components of C^2 teams.

2. Develop or compile the data bases, algorithms, models, data processing aids, and procedures for implementing the systems and task analysis.

3. Shorten the extended procedure by developing more efficient and powerful techniques or generating new knowledge through research on command teams that permit simplifying and shortening the procedure.

Developing these procedures should draw on concepts and techniques for analysis and solution that are available in operations research, systems analysis, and management information systems. Task analysis entails problems of determination of requirements, allocation of resources, analysis of work flow, and evaluation of outcomes that are standard procedures in these disciplines. It is very probable that existing techniques can be readily adopted to the task analysis. In addition, computer models and simulations should be examined for adaptability to human factors planning and incorporation to the task analysis procedure.

The facilities required to develop these techniques are principally data processing equipment to implement the procedures as developed. Tryout and evaluation by users among the designers and developers of systems and training will be needed.

The work should be done both in-house and on-contract. Mixes of specialized skills will be needed but will vary in composition from project to project. The best way to get this flexibility is contracting for the short-term availability as needed.

PERFORMANCE QUANTIFICATION FOR C^2 TEAMS

There is a near-complete lack of adequate, objective criteria and standards for evaluating team-oriented skills, individual and team readiness, and system effectiveness in C^2. Two types of evaluations appear to be used. One is an observer's judgment or rating of performance, usually on an individual basis rather than team or unit. The other type of measure is completion of a specified number of actions in some time period, such as direct x number of live intercepts during a month, quarter, or other time interval. Systematic records are kept at squadron and wing. However, the entire approach to performance evaluation is neither objective nor well-controlled and gives little information directly interpretable in terms of the real operational effectiveness and training needs of individuals, teams, or units.

The primary research topic is development of performance measurement techniques for teams. It involves complex psychometric issues and information about the system application in a tactical situation. In addition, the measurement of team performance should be done in the context of system and individual performance and should be consistent with them.

The desired characteristics of a performance measurement system are discussed in the following section. The discussion is organized into the topics of product/process measures and predictive/diagnostic measures for system, team, and individual performance.

Product/Process Measures

Two kinds of measures of the competence of a team should be developed: 1) product or output process or 2) process measures.

Product or output measures are the observable or computable indexes in terms of numbers such as intercepts completed, targets detected, attrition imposed, etc. They are related to system or mission measures of product. Process or procedural measures reflect goodness of the processes used in accomplishing tasks and duties. Process measures should assess performance in terms of appropriateness of the action taken relative to the information available to the actor.

Process measures have a connotation of conforming to protocol or a fixed procedure. This property is in apparent conflict with the semi-structured nature of tasks in emergent situations. However, there may be a working solution to the conflict. It is hypothesized that the incumbents in semi-structured and unstructured situations evolve some established procedures and methods. These procedures are standard or typical ways of proceeding and strategies for dealing with the tasks at hand. They are applicable to the representative conditions that arise. These procedures evolve usually to make efficient use of time, minimize errors, minimize risks, and increase the likelihood of success.

The team member at each position must know not only these procedures but the conditions under which and how to deviate from it. Process measures should then assess ability to use the procedures appropriately, recognize circumstances under which they are not appropriate, and adjust to an appropriate measure.

Measures of team performance must differentiate between those behaviors related to functioning within the team and those related to the operational tasks. The two sets of measures should be kept separate because they represent independent domains of team performance.

The team behaviors give process measures reflecting the degree of appropriate interaction, interdependence, and coordination. There are also product measures for teams: equalization of workload, discipline in communication, and number of emergency conditions handled successfully might be such measures. The idea of product measures in team performance is not a common one and it is not yet adequately defined. There fore, it is difficult to formulate examples.

This approach provides a profile of scores on several attributes or dimensions to characterize a team. A single index of team competence, capability, or readiness is desirable. However, the usefulness of the index is a function of the extent to which all things assigned the same number behave in the same manner. When values on two or more dimensions are combined to give a single index of status, the same status score can be produced by many combinations of values. Further, the weights and combinatorial rules for deriving a single score from these dimensions are not presently known.

Predictive and Diagnostic Measures

Measures of team performance must be related to measures of system performance; the ultimate motivation to measure team performance is to know its effect on system performance. There are two kinds of team measures of interest: predictive measures of system performance and diagnostic measures of team operation.

Predictive measures account for some portion of the variance in measures of system performance. These measures may have to be identified on the basis of expert judgments of criticalness, importance, or impact on the system's mission objectives. They are quantifiable in terms of some contingency measure such as correlation or linear regression. Unfortunately, many uncontrollable factors affect system effectiveness and limit the proportion of variance that any single factor can contribute. A C^2 team can perform very well while the system loses the battle as a result of the effect of other factors. Competence of a C^2 team is a necessary but not sufficient condition for system success.

Another way of evaluating the effect of team competence on system performance is sensitivity analysis as the term is used in systems analysis. The approach of sensitivity analysis is to vary values of an input variable and to determine the value of an output variable. If the output is relatively little-affected by a broad range of variation in the input, then the system is insensitive to the input variable. If there is a wide range of levels of team competence, for example, which have little effect on system output, this result indicates a range of team performance that is acceptable and sets a lower limit on competence that must be attained through training. Teams better than that level do not increase the level of system performance. Other factors affecting the system account for the variance in system performance and should be addressed first. However, if there is a high positive correlation between team and system performance, then more team competence is always better and selecting the level to be attained is a matter of cost-benefit tradeoff.

Measures which are diagnostic or indicative of difficulties in team operation are needed to improve team performance. They can be interpreted further to identify the kinds of operational tasks and the conditions under which team performance will be inadequate. Ideal diagnostic measures will identify areas of weakness or unsatisfactory performance and the deficiencies in knowledge and skill which underlie the weakness: they will identify both the terminal objectives, on which performance is unacceptable; and the component enabling objectives, on which mastery is incomplete. The cost of resolving power to the degree of specifying knowledge and skill may increase disproportionately with level of detail. Therefore, it may be necessary to select the level of resolution in accordance with the criticality of the tasks.

Determining the relationships between team and system performance will require conceptualizing the information flow network, of which the system and team are a part, and interpreting performance in relation to the functional responsibilities in the network. The amount, relevance, and timeliness of information throughput would be appropriate measures of the network's performance. This approach lends itself to analysis by approaches such as queuing models, linear programming, and network analysis.

Individual capability and performance are also a factor in team performance and a useful system of performance measurement must provide these kinds of relationships.

Functional relationships should be developed between measures of team performance and measures of:

- Combat readiness of individuals
- Individual competence on terminal objectives for operational tasks and team behaviors
- Individual mastery of enabling objectives of skills and knowledge

Combat readiness is a complex and elusive topic; we have no ready or easy answers. A starting point is to identify necessary behaviors and assume an individual to be combat-ready if he demonstrates mastery of them. A difficulty is that the behaviors should be assessed under something like combat stress or conditions predictive of performance under combat stress.

The development of performance measures should start during system development. The body of data about teams in the system needed during system development should be identified in order to produce an adequate battery of performance measures for evaluation of the learning of skills and maintenance of proficiencies. Analytical techniques should also be identified for use in analyzing requirements for measurement of team proficiency to define the content and structure of performance measures.

Research Strategy

The objective of this area of research is to develop a performance measurement system for TAC C^2 teams. Performance measures will be developed which can be interpreted in terms of team competence, effect on system effectiveness, and diagnosis of individual and team needs for remedial training.

The approach consists of four major steps, as follows:

1. Identify dimensions of performance covering both operational tasks and team behaviors.
2. Construct product and process measures and indexes of team performance.
3. Determining the relationships between team measures and system effectiveness.
4. Develop diagnostic measures of team performance in terms of individual deficiencies and needed remedial training.

Operational experts will have to be used to identify performance dimensions and evaluate performance. Candidate measures will be tried out by application to operational units during exercises. Observation of C^2 teams will also be necessary.

A simulation facility is needed so that teams can be exercised, observed, and evaluated in selected aspects of performance under realistic scenario conditions. The facility should be in-house in order to provide continuity of research, adequate control, easier access to operational experts, and availability of experienced subjects. The facility might be operated under a support contract, however.

Specific research studies, development of measuring instruments, and field studies for data collection and evaluation can be done on-contract. Contracts will provide increased manpower and specialized skills for a short term such as one or two years.

The analytical phase can be done either on-contract or in-house. Availability and ease of access to the experts, and sites for observation, should be the determining factor. The experimental evaluation should be done in-house because it will require periods of extended access to the simulation facility.

MAN-MACHINE DESIGN FOR COMMAND TEAMS

The human factors design of man-machine interfaces for teams in general, and C^2 in particular, is an area that has received little attention prior to the last few years. Conventional human factors has been oriented toward a one-man/one-console approach in designing interfaces and it is not applicable to teams. While each team member is placed at a workstation, the person-person interfaces and team architecture are equally important aspects of team design. Concurrent design for all positions within the team as a unit is important to ensure interoperability among positions.

The traditional human factors approach of knobs and dials for operator positions is another limitation when applied to C^2. Much of C^2 is involved in processing, evaluation, and interpretation of information. Information exists in the form of discrete verbal messages, data bases, tabular formats, and graphic situational plots. The human factors considerations involve knowing how the user uses the information, what he does with it, and how his use can be supported and facilitated effectively. These topics entail consideration of mixed initiative dialogues in man-computer interaction, decision support or aiding, knowledge representation, and decision processes.

The approach to the human engineering of teams must rely on the analysis of information flow in the tactical operations of the team. The team should be viewed as a distributed network for information processing. The objective in team design is to partition the information processing of the system into functional areas and allocate these functions to team members. The functions within a position can then be allocated over man, machine, and software. The design of the team must also include the interconnections among positions which are necessary for the interdependence and coordination needed to support the operational tasks.

The traditional approach of designing disjunctively in terms of man or machine is no longer appropriate and the preceding paragraph should be modified accordingly. The major human factors problems are functions performed jointly by man and machine. Many functions are performed by computer-aided man or man-aided computer rather than by either component alone. Distributed computing systems, intelligent terminals, and distributed data bases with multiple access are accelerating this trend.

There is a multiplicity of potential issues related to the architecture and properties of teams. Scanning the lists of architectural dimensions and functional properties in Tables 3 and 4 will readily stimulate thoughts of some of them. Selection among them depends on an analysis of some specific C^2 application to identify a type of team of relevance to Air Force needs. A meaningful research question exists when there are alternative designs or configurations for an application.

Some topics concerned with the nature of teams have been selected from recurrent issues in the literature for brief discussion of potential directions of research. They are summarized under team composition, interaction between task type, stability of team composition, and automation of C^2 functions.

Team Composition

Team composition can be markedly affected by the nature of the team's members and the functions performed. The existence of a type of individual who is a good team member is a critical question. Comments about good and poor team "players" are commonplace but the concept is wholistic and has little predictiveness. One would expect to find the differentiating attributes of good team members in the team skills rather than the operational tasks. It is part of our folklore that technical excellence is not sufficient for good team functioning. But the necessary and sufficient attributes, skills, and knowledge that characterize good team members and differentiate them should be identified and evaluated for their contribution to team effectiveness. The feasibility of selecting or training for these characteristics can then be investigated.

Other questions of team composition are the effect of heterogeneity of functions and heterogeniety of competence across team members on the output and processes of teams. It may be that heterogeneity forces the development of good team skills because coordination becomes more critical.

Team size is a property of interest; it determines cost of personnel and support, which are major components in the cost of ownership. The changes in team properties, processes, structure, interaction, and competence with changes in size is a research area that would provide relevant information. Reduction in team size may be possible as developments in solid-state electronics increase the amount of aiding and automated support that can be provided in "smart" displays and terminals; therefore, team size could soon be a key issue.

Interaction of Team Type and Task Type

The interaction of team type and task type has implications for the design of teams. The appropriate type of team may be different for procedural, semi-structured, and structured tasks. If these types of tasks require different team processes and multiple task types are present, it is necessary to know if a team is capable of some kind of dynamic reconfiguration to adapt to these conditions.

It is also desirable to know in emergent situations if and how team processes are adaptable to changing operational conditions and events. Adjustment to variations in workload, unexpected events, and emergencies require coordinated changes on the part of all team members. Different team types may be differentially effective in making these adjustments.

Compensatory mechanisms in team processes would be a useful property if weaknesses in one area of team behavior or operational tasks can be offset or compensated for by strength in the other domain. Similarly, it is desirable to know if team members can coordinate or reassign responsibilities to compensate for weaker members.

Stability of Team Composition

Stability of team composition is undoubtedly important for team performance. Maturity develops under stable conditions over time. The team that stays together develops a characteristic kind of performance. However, personnel turnover is a reality. New team members come in and the change is assumed to be disruptive. Knowing the mechanism and effect of this change on team performance, it may be possible to develop ways of introducing new members that minimize the disruptive effects of personnel turnover. Being able to set some standards of individual competence before a person can assume a position in the team is a potentially significant way to reduce disruption.

The practice of using soft vs hard teams is a special case of personnel turbulence. Soft teams vary in membership from operation to operation, depending on the operational conditions, rules for forming teams, and availability of people when the duty roster is made up. Hard teams maintain the same roster and configuration of members for an extended period of time. The effect of rotating members is unknown but it does pose some management problems.

For example, a performance score for a soft team is of uncertain utility since the particular combination of individuals is unlikely to occur again except by some luck of the draw in availability of manpower. The team score cannot be generalized to another team. Further, there is no reason to believe that a team's proficiency can be derived as a function of proficiency scores assigned to individuals. Finally, if meaningful performance measures cannot be assigned to teams, it is impossible to develop an indication of the combat readiness of a unit.

It is also possible that the effect of deployment of soft teams elevates the level of proficiency that can be achieved. It is a reasonable assumption that hard teams in which a fixed combination of individuals exists for an extended period of time can achieve a higher level of integration and coordination and these levels would be reflected in a higher team proficiency. There is also some evidence that personnel turnover on teams is accompanied by degradation in performance. Activities that involve timing would be particularly sensitive to this factor.

On the other hand, there may be a two-stage process at work. Hard teams may represent an early stage and increasing competence arises from the increasing strength of intra-team connections. However, the soft configuration may, in the long term, result in still higher levels of proficiency. The individuals may develop very generalizable and adaptable team skills as a result of experience in a broad range of team combinations. A highly proficient team member may be a person who can function well in a broad range of conditions.

Research could be initiated to determine the relationship between proficiency for soft and hard teams and between individuals and team. Such a project would be long-term, costly, and dependent on knowledge of C^2 and team activities that we do not have at this time. Such a program could provide data on the advantages and disadvantages of the two team compositions. Sound personnel policies could then be established.

Automation of C^2 Functions

The trends in automation will have a significant effect on the design of C^2 teams for future systems. The effect will be primarily in the form of decision support systems incorporated into organizations like the TACC and CRC. It will change the roles and functions of the personnel and thus change the team structure as well as the operational tasks.

There is only one fully operational decision aid system in the 1979 Tactical Air Force's command and control structure. It is the Tactical Fusion Center (TFC), developed under an ESD/MITRE project called Operational Applications for Special Intelligence Systems (OASIS). It provides a capability of multisource correlation, information aggregation, and display of theatre operations and intelligence data. It aids in generating a "best estimate of the situation" for the Air Component Commander.

There will be an increasing number of computer-aided support systems for C^2 personnel and teams. They will be minicomputer and microprocessor systems designed for *ad hoc* applications. The impact and value of these systems on manpower and training requirements are unclear and uncertain at this time. They entail major significant issues of man-computer interaction on which there is not yet sufficient data to provide adequate decision for system design and training. They will also force changes in the doctrine for deploying Air Force systems. Introduction of a computer changes the way jobs are done and the organizational structure rather than merely automating activities that were formerly manual.

This area of decision-aiding is a potentially fruitful area for behavioral research. However, the first task must be to define the area better. The C^2 team model will provide some of the definition. Other subject areas include understanding the decisions and analyses that C^2 personnel make, the information used, how it is processed, and the form and use of the output. The increased automation entails extensive man-computer dialogues which will consist of mixed-initiative interactions, data base management, natural-language query systems, and graphic/tabular display of information and situations. The applications will require some form of knowledge representation and the parsing of dialogue statements.

The design of a decision aid is a complex interdisciplinary problem. It must begin with selection of a C^2 activity for which aiding would be beneficial and which is aidable with some available techniques. The procedure for developing an aid is well summarized by Siegel and Madden (Reference 15). A diagram of the procedure is presented in Figure 5. They have also summarized criteria for evaluating the utility of an aid. The criteria are presented in Table 6.

The complexity of this area in methodology, knowledge of required decision-aiding, and C^2 team activities indicates that research in this area should be deferred until adequate competence in these elements is developed and related research is under way. Coordination with existing programs such as those at ESD should be done.

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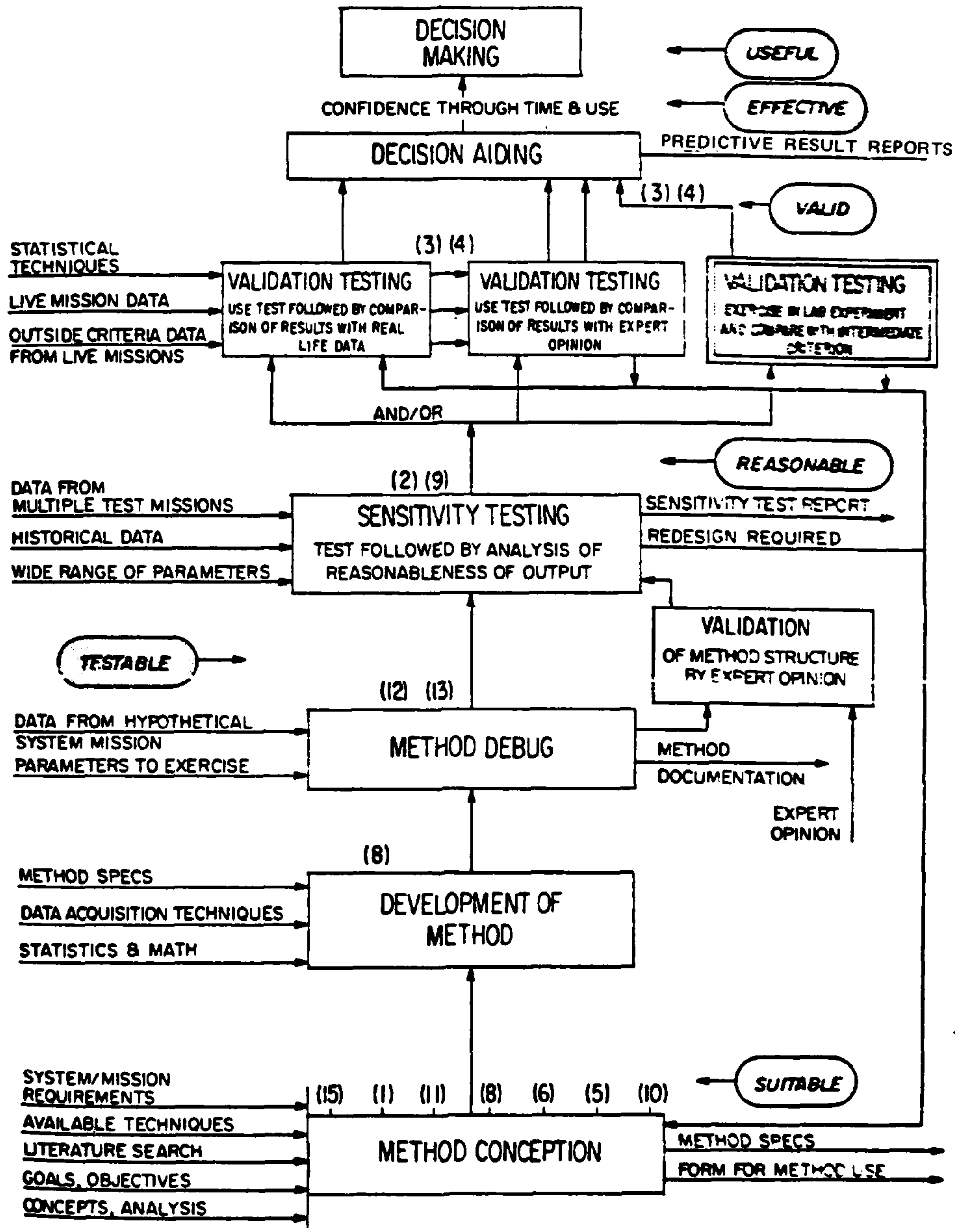

Figure 5. Sequence of Aid Development (from Reference 15)

TABLE 6. CRITERIA FOR EVALUATING THE UTILITY OF A DECISION AID (FROM REFERENCE 15)

Criterion	Definition
1. Internal consistency	Extent to which the constructs of the aid are marked by coherence and similarity of treatment
2. Indifference to trivial aggregation	Potential of the aid to avoid major changes in output when input groupings or conditions undergo insignificant fluctuations
3. Correct prediction in the extreme (predictive or empirical validity)	Extent of agreement (correctness of predictions) between the aid and actual performance at very high/low values of conditions
4. Correct prediction in mid range (predictive or empirical validity)	Like above for middle range values of conditions
5. Construct validity	Theoretic adequacy of the aid's constructs
6. Content (variable parameter) validity (Fidelity)	Extent to which the aid's variables/parameters match real life conditions
7. Realism or "face validity"	Extent to which selected content matches each attribute included
8. Richness of output	Number and type of output variables and forms of presentation
9. Ease of use	Extent to which an analyst can readily prepare data for, apply, and extract understandable results from the aid
10. Cost of development	Value of effort to conceive, develop, test, document, and support
11. Transportability-generality	Extent of applicability to different systems, missions, and configurations
12. Cost of use	Value of all effort involving use of aid including data gathering, input, data processing, and analysis of results
13. Internal validity	Extent to which outputs are repeatable when inputs are unchanged
14. Event or time series validity	Extent to which aid predicts event and event patterns

The objective of this discussion of decision-aiding is intended to illustrate an approach. It is not intended to be a comprehensive or even illustrative discussion of current research and knowledge. That discussion would be a major undertaking. However, the approach formulated by Siegel and Madden (Reference 15) is a well-formulated paradigm for design and implementation of decision aids.

Research Strategy

The recommended research project in this area is to develop a set of standardized laboratory tasks and exercises which can be used in laboratory research studies. A capability should be provided so that experiments can be conducted as needed on team operations, team processes, and the effects of specific variables. The standardized tasks are likely to be part-tasks rather than a global simulation of the operational context and activities of C^2 teams. Development of the exercises should include the hardware and software on which to run the studies as well as the substantive content of the tasks and experimental design.

The objective of this project is to provide realisitic experimental tasks that can be used flexibly to address a range of issues and hypotheses about teams, manned activities in C^2, and design of man-machine interfaces for C^2 teams. The ability to generalize to operational C^2 teams and systems is an important criterion; therefore, representativeness and relevance of the standardized tasks are important attributes.

The approach consists of the following steps:

1. Select representative functions and tasks for C^2 teams
2. Identify team variables to be investigated
3. Design standard C^2 team tasks
4. Determine the specifications for hardware and software to implement the tasks
5. Procure, build, install, and develop the hardware and software
6. Test and evaluate the tasks for comparability to operational tasks

The purpose of this project is to develop standardized laboratory tasks which correspond to operational tasks of teams. These tasks and their software would become modules in a simulation library. They would then be used as components in assembling scenarios and experimental exercises.

This project would interact strongly with development of the C^2 team model. The analyses performed to develop the model will provide data on tasks and the organization of tasks on which this project can build. Similarly, the standardization of tasks will feed data back into the model building.

This project should be done in-house in order to develop and sustain an interest in and a sense of ownership of an in-house capability and to ensure that the capability is responsive to the user's needs. Some specific projects may be broken out for contract or consultation and to provide support in operation. However, the main work and integration should be retained in-house.

Decision-making has not been mentioned as a research topic. Decision-making is an oft-cited activity in C^2. However, the position taken here is that the role of decision-making in C^2 is moot at best. Far fewer activities are decision-making than is commonly assumed and common usage of language suggests.

Command and control consists of information processing in a wide variety of contexts. These activities are made up of routines and algorithms for sorting, compiling, estimating, projecting, allocating, evaluating, and so on. It is admitted that the available routines are incomplete, often too slow, and overwhelmed by tides of data in current systems. Human judgment is used to fill the gaps and simplify the tactical problem to make it more tractible. However, the remedy lies in developing more and better routines and aids.

The position taken here is that attributing a C^2 activity as decision-making is a last resource. It will be done only when attempts to account for the activity by other processes have failed.

DEVELOPMENT OF TRAINING REQUIREMENTS AND IMPLEMENTATION OF TRAINING

A systematic training methodology for teams (TMT) needs to be developed. The methodology will be broken down for purposes of this discussion into the areas of derivation of training requirements, instructional strategy, sequencing of instruction, and performance evaluation. Specific research topics and issues will be discussed in each area except performance evaluation which was treated in a prior section. Transfer of training will also be discussed.

The domain of TMT must encompass subteam, team, and superteam exercises. A complete job task inventory associated with a position must include duties and responsibilities at all levels and contexts in which the individual plies his occupational speciality. Therefore, the training requirements must be analyzed for these three team levels as well as the individuals' behaviors.

It is assumed that the three team levels represent a cumulative aggregation of tasks. The core tasks are the individual ones required to accomplish the functions and responsibilities of a position. A set of basic team behaviors is added at the subteam level, and other sets are added for team and superteam. The addition of these team tasks has two phases of learning the task behaviors and the integration, intermixing, or timesharing of them with performance of the operational tasks.

A systematic training methodology for teams does not exist. Typical team training exercises consist of operational exercises in which the emphasis and evaluation are on operational tasks. Training on team behaviors is incidental to the performance of the operational tasks, and the extent to which it occurs is highly dependent on the awareness and initiative of the instructor in perceiving these behaviors and providing feedback on them. The principal factors contributing to this condition are the lack of a taxonomy and performance objectives for team tasks and a taxonomy and training objectives for team behaviors. These factors are, in turn, a function of the lack of a conceptual framework for team behaviors. Thus, the behaviors to be learned and the types of learning involved cannot be determined; and the existing literature on instructional methods, developed primarily for individual performance, cannot be used or evaluated.

The type of training involved is referred to as hands-on or practical experience. The character of team training has a strong connotation of performance rather than cognition; it is the use of synergistic behavioral interaction to facilitate or improve the productive performance. It cannot be taught as rules, principles, or fixed procedures; it must instead be understood as process, flow, and interaction. The hands-on training takes the form of some kinds of simulated exercises. These exercises in C^2 usually consist of the use of operational equipment, often in-unit, which is stimulated by computer in response to a computer-operated driver scenario. There may be related skills and knowledge which are taught in the verbal/ conceptual format in classroom settings; the use of the simulated exercise is to provide a vehicle for the integration of these skills and knowledge into more complex tactical behaviors. However, the verbal/conceptual component is minimal.

Derivation of Training Requirements

There is a need for methods to derive training requirements from the description of team functions and tasks. Existing methods as represented in ISD are inadequate in two ways: 1) they lack the behavioral structure to describe team tasks; and 2) they have not been adapted to the semi-structured tasks which occur in emergent situations.

The significance of the semi-structured character is that the tasks or subtasks fall into two categories. Some are fixed procedures or algorithms which are standard components for processing information; they are similar to the subroutines in a computer program. The other tasks are variable in the sequence and nature of steps, depending on the kinds of driving events to which the task performer must respond. However, the situation is not unorganized or chaotic. The performer must monitor information, recognize situations requiring action, identify the appropriate action and objective, select and combine the appropriate behavioral components, and adapt the behavioral sequence to the characteristics of the situation.

Procedures for training analysis must capture the data to describe these elements. The lack of terminology to describe these tasks will be remedied by development of the team model. The team behaviors will have to be defined in the context of C^2 activities and tasks since these two categories are confounded in observing the behavior of command teams. This interdependence will be achieved if the C^2T^2 terminology is developed in specific system application of C^2.

Techniques should be available to analyze team tasks into performance and training objectives which are then decomposed into skills and knowledge that are necessary and sufficient to produce the required behavior. The training analysis should include information by which tasks can be selected and priorities for the training assigned to them. This information should include, at a minimum, the trilogy of task characteristics: criticality, difficulty, and frequency of performance.

An area of weakness of ISD, at least as it is typically applied, is the lack of an adequate indicator of correspondence between the derived training requirements and job performance requirements. Perceived validity of the training requirements is based on the fact that they start from an inventory of job tasks.

However, existing task analysis is a linear, deductive, reductive process. The behaviors of job tasks are broken down into finer levels of processes, knowledge, and skill. The resulting training requirements are then classified by the type of learning, organized into instructional units, and paired with instructional strategies. The intermediate and final products of the training analysis are phenotypically quite different from the job task inventory, and it does not seem feasible to derive a practical technique for mapping instructional units into job tasks. One could reverse the analysis and trace the skills and knowledge back to the job tasks. This procedure would be unsatisfactory, however; errors in the initial decomposition would validate themselves.

The bridge between the training program and job performance requirements may be a set of calibrated or graded exercises. The rationale underlying conventional training programs presumes a building block approach in which components of knowledge and skill are learned and then integrated to provide behavioral capabilities needed in the job. The course of learning consists of a progression through a series of intermediate behavioral objectives that are increasing approximations to terminal performance objectives. Achievement of these objectives is evaluated through the use of performance tests or simulated exercises, depending on the complexity of the objective. Each test and exercise should be described at a minimum in terms of a performance objective and standard, the knowledge and skill being tested, and prerequisite knowledge and skill.

However, the sequence of exercises is not presented as or demonstrated to be a systematic progression toward job performance. The exercises are treated as discrete, nominal entities. The sequence of exercises is determined by the sequence of instructional units.

It is proposed that C^2T^2 exercises and operational activities be calibrated, scaled, and organized in a multidimensional problem space. The dimensions of this space are continua of knowledge and skill. The approach presumes that items of knowledge and skill can be ordered along a dimension. Items to the right-hand side represent higher levels of competence and greater difficulty. A primary factor in sequence is prerequisiteness: prior mastery of any item is prerequisite to learning the item to its right or farther out on the dimension.

A hypothetical example of a continuum might be "intercept direction." The difficulty of directing intercepts might be a function of variables such as ratio of interceptors to hostiles, number of hostiles, number of intercepts/hour, number of concurrent intercepts, and type of aircraft. A 1/1 intercept is assumed to be prerequisite of a 2/1 intercept; five intercepts/hour is prerequisite to 10 intercepts/hour, and so on. Similarly, interference conditions might be a dimension on which the levels consist of degradation of communication and data through signal-to-noise ratios, various types and levels of ECM, and equipment failures.

Exercises used in training and job performance tests would be points in this multidimensional space. Positions in the space would be determined by the skills and knowledge required by the exercise. The highest level item required within a dimension would determine the position of the exercise.

The relative position of problems in the space reflects the sequential relationship and the relative difficulty of the problems. Level of competence is a monotonic, increasing function of distance from the origin perhaps calculated as a vector. The last exercise in a sequence should be a job task or component of a job task. Equivalent exercises for any point can be constructed by changing the context of the exercise or attributes on dimensions that do not interact with the dimensions that define the problem.

The feasibility of constructing a C^2T^2 problem space should be explored by attempting to construct one for a limited set of problems that involve three or four dimensions. The approach consists of:

1. Decompose C^2T^2 exercises into knowledge and skill.
2. Arrange the knowledge and skill requirements with a Gagne-type diagram.
3. Form the items of knowledge and skill into dimensions and scale the items in order of competence, difficulty, or prerequisiteness.
4. Place the exercises in the space and determine sequences of exercises that constitute pathways to a terminal job performance objective.
5. Test the sequential relationships by experimental studies using simulated exercises.

There are two phases of the project: constructing the problem space and conducting experimental evaluation. The construction phase will not require special physical facilities. It is basically analytical. Access to experts and observation of operational and training exercises will be needed. The experimental phase, however, will require a simulator and appropriate scenarios. The specific capabilities of the simulator cannot be defined until more is known about the exercises to be used.

Effective instructional pathways through the problem space should be developed and validated. Pathways are sequences of problems with the use of specific instruction strategies. Each path has a transition time to job competence. Skill levels are defined as the number of dimensions on which one must be qualified and the level of competence that must be obtained. Training costs and efficiency can be defined in terms of the time and resources needed to reach those standards.

This idea and the associated research might get so complex that it is difficult to manage. It would also heavily rely on operational experts to provide the information needed to construct the dimensions. The existence of constructability of the dimensions is critical and uncertain. Identification of the knowledge and skills required by an exercise and prerequisiteness can be done using Gagne's (Reference 16) methods for representing the structure of a subject matter. The structure of the subject matter is represented as a hierarchical network. The networks consist of the set of knowledge and skills necessary to execute a training objective and the order in which they must be learned.

The merit of this idea is that it introduces order into a subject matter and relates performance in training to performance on job tasks. The capability of a graduate can be stated in terms of the job tasks he can do rather than the number of units or hours of instruction completed.

Instructional Strategy

Given training objectives that contain skills and knowledge that can or should be learned, they must then be paired with appropriate instructional methods to provide training. The combination of methods and the procedure for a meaningful unit or "chunk" of instruction will be referred to as an instructional strategy.

An initial step in selecting an instructional strategy is classifying the skills and knowledge into the type of learning involved. An appropriate instructional method can then be selected. It is commonly assumed that different instructional methods or strategies are differentially effective in teaching specific types of skills, knowledge, and performance objectives. Further, it is assumed that there is a best, more effective, optimal, or preferred method for each application.

Those relationships are known to some extent for teaching verbal, conceptual, and psychomotor activities; it is relatively straightforward to identify appropriate methods. This work has been summarized in several sources, such as Brock (Reference 17), Merrill and Tennyson (Reference 18), and Wulfeck, Ellis, Richards, Wood and Merrill (Reference 19).

These relationships are applicable to C^2 team training but are currently indeterminate since the skills, knowledge, and performance objectives for C^2 team training have not been adequately explicated. Some improvement can be made by extending the state of current instructional technology. If C^2 team activities can be decomposed into a taxonomy of knowledge and skill, they can then be referenced to appropriate instructional methods.

It is recommended that a research project be initiated to assess the usefulness of existing taxonomies for learning types and instructional strategies for C^2T^2. The approach should consist of selecting one or more of the existing taxonomies and classifying performance objectives, skills, and knowledge for team behaviors into these categories. A prior or concurrent effort to develop a taxonomy of team behaviors is necessary. The resulting distribution of team behaviors into learning types should be evaluated for comprehensiveness, ambiguity, and easy use of the process and rules for classification.

No special facilities are needed, but availability of operational experts and the opportunity to observe C^2T^2 operations would be useful. The research is appropriate for contract but could be done equally well in-house if the appropriate competencies are available.

Sequencing of Instruction

The items of knowledge and skills to be learned must be grouped into units and the units into sequences. The items are clustered into homogeneous segments, segments into lesson plans, and lesson plans into parts of courses or courses.

There are a variety of approaches to organizing and sequencing instructional materials but no technique that is adequate for practical use (Reference 20). Techniques are either complex and theoretical or common sense. The common rules for clustering and sequencing are at the level of relatedness of content, simple to complex, general to detailed, and logical sequencing.

The application to C^2T^2 requires sequencing within both the C^2 and T^2 areas since the two categories are interdependent. It is probably expedient to teach team behaviors in the context of C^2 activities, especially for initial training. However, it would be heuristically worthwhile to compare the two approaches: teaching team behaviors in the job context, and teaching them separately in a neutral context free of job content.

It is possible to teach team behaviors separately in a game context. The use of some job-free medium might be useful to highlight the interpersonal and process cues and to attend to response options available and the behavioral adaptions required to adjust to conditions within the team.

If team behaviors can be separated from the job content, they may be more generic and transferable than the skills of operational tasks. The techniques of interaction and adjustment are the same in a wide range of situations. We postulated that team behaviors were seperable in analysis from behaviors for operational tasks. If they can be formulated as independent of operational content or cast in a neutral context, they can then be investigated and taught separately. The potential merit of this approach is uncertain and a research issue; there is no clear a priori reason to expect that it would or would not be advantageous.

Clustering and sequencing of instructional material is ultimately dependent on understanding the knowledge structure of the subject matter. Clustering and sequencing implicitly impose a structure on the training, and it should be compatible or noninterfering with the knowledge structure. The knowledge structure does not exist in any absolute sense, but our best guess is that it is determined by the organization in the job system and operational environment. Thus, sequencing is part of the correspondence between training and job requirements.

A research project into the knowledge structure of C^2 team activities should be undertaken. The approach should include review of current practices and approaches to sequence; analysis of the skills, knowledge, and behavioral objectives to identify relatedness and connectedness among items; transfer of training between learning objectives; and identification of sequences of learning experiences to approach terminal performance objectives comparable to job performance requirements. These requirements should span the range over individual, subteam, team, and superteam and allocate the training for specific learning and performance objectives to these categories. The approach is very similar to the building of the problem space discussed earlier and should be treated as an extension or application of it.

Transfer of Training

Transfer of training is a basic tool in achieving effective and efficient training. The requirements for transfer determine the correspondence between the conditions of the job and the training situation in terms of what aspects of the job must be represented and the degree of relatedness. Transfer can also be a factor in sequencing of instruction; it is generally presumed that items of instruction which are alike in content to a preceding item are more readily learned than those which are disparate. The effective use of transfer also requires an understanding of perceptual-motor and cognitive-motor processes of the learner.

Our concepts of transfer of training are inadequate, however, for any application beyond very simple or contrived applications. Since formulation by Thorndike early in the century, they underwent considerable analysis and investigation in the area of verbal learning but with little practical accomplishment. The conditions for transfer were elaborated in terms of common elements in stimuli and responses between the learning and transfer situations. An increasing number of common elements were associated with increasing similarity, which was in turn associated with increasing transfer. However, both common elements and similarity have been resistant to operational definition and measurement.

An extension into cognitive similarity was attempted with an approach in which stimuli sharing a common response were treated as similar through mediation of the shared response. For example, the words "parka" and "igloo" might be similar through mediation of the common association "cold;" igloo and banana on the other hand would share very little between them. Several investigators have compiled lexical atlases of associations as a means of identifying mediating responses. However, this approach has yielded little of practical value.

Measures of transfer have been developed in terms of reduced time or errors to learn new material or reduced time or errors on initial exposure to new material. It seems to have been implicitly assumed that the slope and asymptote of the learning curve were unchanged, and only the initial point for learning the new material was affected.

These measures capture much of our intuitive sense of the accomplishment of transfer. However, they reveal little of the effect on the trainee's capacity for performance. For example, it would be useful to know how many other training or job tasks a trainee can execute, wholly or in part, after he has mastered a given task and the nature of the changes in task conditions under which performance is degraded or invariant. If a student has learned how to calculate the probability of drawing the ace of spades but cannot calculate it for the ace of diamonds, he shows a deficiency in transfer even though he might learn the second task in fewer trials. In contrast, the student who can then calculate the probability of throwing a six on a die shows a high level of transfer.

Knowledge about the range of conditions and applications under which behavior is available following given learning conditions tells us something important about an individual's competence and capacity to adjust in emergent situations. It is implicit in our belief that the inadequacy of "book learning" is its failure to transfer to practical situations and the corollary belief that hands-on exercises are superior and necessary. It also involved attempts to determine the limits at which behavior breaks down.

Concepts of transfer have been static for the past 30 years or more and have been provided very little in conceptual framework and algorithms for the formulation and analysis of applications in either research or engineering. There has also been a growing trend to challenge fidelity requirements on the basis of a general scepticism that reproductions of operational conditions have been overinclusive. However, we do not have data, principles, or algorithms that permit us to say which cues are necessary, useful, or relevant for cost-effective training. The instigation to reduce fidelity is driven more by a desire to reduce costs than by analysis of tasks, training objectives, instructional strategy, and conditions of transfer.

Research on transfer of training for C^2T^2 will have to be done in that context and is therefore dependent on progress in developing the conceptual framework to be used to identify and describe team behaviors. Its initiation should be delayed several years until progress has been made on the structure of the subject matter in C^2T^2.

Transfer of training is a key issue in the design of training programs. All training involves some degree of artificiality. The use of classroom instruction for verbal/cognitive material is highly dissimilar from a job context, but it is an economical method of delivery. Simulation also has artificial elements which are simultaneously its advantages and disadvantages. It gives the instructor control over task conditions and permits him to simplify and adapt training to the level of the student. It permits the creation of conditions where danger or risk preempt exposure of the student on-the-job. In addition, it permits creation of conditions that occur rarely such as actual combat against a real, armed, intelligent adversary. The US Army has been having success with engagement simulation for this purpose.

Still, the fidelity of these training situations is less than complete. However realistic they seem, the threat, enemy, and danger are not real; the trainee's vulnerability is safeguarded by the instructor. Some stimuli, particularly contextual ones, are attenuated or absent. There are no algorithms for estimating the degree of fidelity needed and the amount of transfer that will be obtained. They are probably interactive with the type of tasks.

At the present state of technology it is desirable to have as high a degree of fidelity as possible, even though the increments of transfer decrease in the upper ranges. Cost considerations create a force to reduce fidelity as low as possible since costs and level of fidelity are positively related. The growth of cost is possibly exponential in the upper ranges of fidelity.

Therefore, the specification of fidelity requirements affects both sides of the cost-effectiveness ratio for training. We cannot afford to neglect it.

SIMULATION FOR C^2T^2

The use of simulation for C^2T^2 will require technological development in three areas: 1) methods for development of simulated exercises, 2) improved techniques for the management of simulated exercises for training and research, and 3) specific issues needed in C^2T^2 simulation.

There are many impressive, existing simulations which were designed and built during the past 20 years. The US Navy's Tactical Advanced Combat Direction and Electronic Warfare (TACDEW) facility is one of these. Generally, these simulations are costly; their capability is more limited than desirable; they lack adequate support functions for instructors/controllers; they are inflexible and difficult to modify; and they were developed on an *ad hoc*, one-of-a-kind basis.

The routine use of simulation for training requires removing these limitations. Recent advances in computing machinery, software design, modeling, war gaming, and training make it possible to make significant advances in the capability and use of simulation.

This discussion of simulation has two aspects. One is its use as a research tool; the second is its use for training of command teams. It has become increasingly necessary to rely on simulation for training because rising costs and shortages of equipment have produced a shortage of live flying events and activities for training. Furthermore, simulation is the only way in which trainees can be exposed to tactical conditions and force ratios characteristic of combat in the period of 1980 to 2000. Some of the issues to be discussed are common to both applications of training and research. For example, the procedures for determining requirements for and designing simulated exercises are basically the same for both applications. The purpose of the exercise is a training objective in one case and a research objective in the other.

Current practice in the use of simulation and development of training does not provide systematic procedures for deriving simulation requirements from training objectives. Such procedures are possible, but the available technology from other disciplines has not been used. Current practice in simulation tends to reproduction of the operational environment and equipment in as much detail as possible. If all capabilities and events of the situation can be generated, then all system-related behaviors can potentially be elicited. Consequently, minimal task and training analyses are needed because the potential for all system-related behaviors is inherent in the simulation.

The approach is costly and inefficient. Fidelity of the simulation exceeds what is needed for training. It becomes excessively costly since the costs of simulation increase exponentially with increasing fidelity. It is also inefficient to use since it is usually not possible to isolate parts of the simulation selectively to meet the limited needs of a given training objective.

Large-scale, war-gaming simulation for individual and team training has become necessary, while the advances in computers through solid state electronics are making their use feasible and affordable. They are providing larger memories and revolutionizing software. However, we need better techniques for the design, use, and management of simulated exercises and the information they can generate.

The use of simulation for behaviorally related issues in man-machine operating systems has had its largest application in flight simulation. There have been applications to ships, submarines, nuclear power plants, and other complex or dangerous situations. However, flight simulators have been the most extensive and sophisticated developmental programs. The aerodynamic equations for the aircraft did much toward determining or fixing the driver scenario, operating procedures, and constraints on the simulated system. It was feasible to build a device that looks and "flies" realistically; consequently, aircraft simulators have been used successfully for training in flying and navigation.

Simulation has been less adequate, however, in representing air combat against simulated, intelligent adversaries. The operational conditions are more complex and less structured; therefore, more analytical effort must be put forth to determine what should and can be simulated. Simulation for team training is at an analogous level of development. We need ways of representing and managing this greater complexity in order to increase the cost-effectiveness of training.

The Navy has built some large facilities for training in anti-submarine warfare (for example, 14A2 Team Trainer) and sonar operation. They are stimulator/emulators rather than simulators. Some C^2 test bed simulators have recently been developed at the Naval Ocean System Center (for example, Advanced Command and Control Architectural Testbed--ACCAT). They are computer systems designed for development and test of software. They were not intended for man-in-the-loop simulation and have limited capability for it. However, Poock at the Naval Postgraduate School has made some use of it for human factors studies in C^2 (Reference 21).

Methods for Development of Simulated Exercises

Systematic procedures for defining training objectives and simulation requirements for simulated combat exercises should be developed. They should be applicable to exercises for individual, subteam, team, and superteam training. The procedures would provide techniques to extract data from operational requirements of systems, tactical scenarios, and mission requirements, establish performance objectives, and analyze the performance objectives into:

1. Training objectives
2. Instructional strategy

3. Simulation objectives (consisting of the events and conditions necessary to elicit and provide adequate exercise of the skills in a training objective)

4. Performance measures, diagnostic analysis, and feedback techniques

Simulation and training are two distinct methodologies or disciplines that must be integrated in order to provide effective use of simulation for training. The procedure in designing and developing a simulation is to produce a symbolic or graphic replica of the operational situation which is driven by a computer and responds in a realistic manner to events in the simulated world. If used in training, it may also accept or sense input from the trainee.

The procedure in established methods of developing training courses is to develop measurable behavioral objectives. The methodology of training development must be extended to incorporate simulation requirements. Training objectives must be translated into simulation requirements for exercise of each training objective.

Similarly, there is a standard methodology for developing simulation. It must be extended to incorporate sets of exercises nested within a larger scenario. The simulation must be capable of flexibility in the rapid configuration of modules into exercises that meet the requirements of specific training objectives. The simulation software should be treated as a library of modules which can be called up to compile the exercises needed for each training objective. The procedures for compiling simulation exercises should be within the capability of a casual computer user.

As the complexity and scope of simulation and its use in training increase, instructor support becomes increasingly important. Definition of the instructor's role is needed to identify actions he takes and tasks he performs in setting up and initializing exercises, feedback, real-time control, modification of the scenario, collection of performance data, processing of performance data to identify competencies and deficiencies in skills, and conducting critique sessions. The instructor functions should be differentiated into roles of instructor, controller, programmers, and computer system operator. Identification of instructor functions and some support can be done within the current state of technology. However, the functions can be only minimally incorporated into existing simulations. Therefore, progress in instructor support is largely dependent on the research-oriented development of simulators suitable for C^2T^2.

The driver scenario must provide a representation of the threat and tactics at a level of fidelity needed to support the training objectives. These attributes are derived from analysis of mission and operational requirements. The information needed is functional for the purposes of training and descriptive of what the operational personnel do and how they do it. Existing methods of analysis for this application are rudimentary at best.

There is also a need for techniques of planning and analysis to define fidelity and functional requirements of simulation and simulators. This issue involves knowing what and how to simulate and translating these requirements into features of scenarios, fidelity in representation, instructional strategies, software architecture, and functional capabilities of hardware. This information must be generated by analysis of performance objectives. It is integrated into functional capabilities of a simulation facility which can in turn be translated into design concepts and engineering specifications from which a simulator or simulation facility can be built.

Establishing fidelity requirements begins with identifying cues and behaviors which are necessary or beneficial in the performance and learning of operational team tasks. This information should be integrated into the specifications for simulated exercises. These requirements should specify the attributes of the operational situation which must be representative or functional and the level of realism needed to support specific training and performance objectives.

The simulation requirements should be interpreted, decomposed, and extrapolated into the definition of the model bases, data bases, and algorithms necessary to support the exercise, performance measurement, and training analysis. The model bases will include representations of the weapons and platforms employed in the exercises, terrain, and atmospheric conditions and the events of behavior and system operation which must be sampled, monitored, and controlled. This type of analysis may require the integration of concepts, data, and techniques from mission analysis and instructional technology to identify the data needed and the level of resolution and detail.

Management of Simulated Exercises

There are also problems in the management of simulation exercises and facilities. Functions, duties, and tasks performed by instructors, controllers, players, role players, and support personnel must be defined. Further, the man-machine interfaces and computer support needed for each individual must be determined. Techniques are required to extract simulation requirements needed to support the instructional strategy for each training objective or family of training objectives. It is assumed that the simulation personnel will be given the training needed and develop the instructional strategy in collaboration with the training user.

Modification and update of the simulation facility in accordance with changes in simulated systems or feedback from evaluation of the training program will be necessary. Analytical aids will be needed to assist simulation personnel in determining the impact of the changes and making the necessary modifications.

Training, briefing, and design for support personnel are very important factors in successful operation of simulation. It is especially important for support personnel who role-play components in the scenario. Simulated aircraft, for example, are manually controlled by operators at consoles. Their actions generate simulated radar returns for the interceptor aircraft. The operators are typically enlisted personnel who are not flight rates; they have little knowledge of the aerodynamics of aircraft and limitations such as maximum turn rates and tactics.

Designing for these personnel, as integral to the simulation, will enhance the effectiveness of the simulator for training. There are two available approaches: training for the role player and reallocating some functions in the simulation. Software can be designed, for example, to impose limits on the movements of platforms and even to execute some maneuvers on command. Automation of aspects of aircraft maneuverability will require aircraft models and data bases for simulating platform motions and atmospheric conditions that affect flying. This level of automation would require design of a new operator-simulator interactive interface. It would reduce training requirements in the control of the simulated aircraft. However, the total effect of a redesign is uncertain since added capability and operator-computer interaction may increase the scope of the operator's responsibility.

Research studies will also require changes in standard experimental practices. Participants as subjects would have to be sophisticated in the operational activities to be able to generalize the studies to operational problems. Therefore, a core of long-term, semi-professional subjects would be required. They could be supplemented by military subjects on short-term assignment. The "standard" college sophomore might be used occasionally to test hypotheses about basic psychological processes if the hypotheses become significant or critical issues. Extended scenarios spanning hours and days of operations will be necessary to provide adequate, realistic baseline data. Multiple, equivalent, or parallel exercises and scenarios will be required.

Better methods for the conceptualization, management, and analysis of studies must be developed. The costliness of extended periods of data collection makes it necessary to:

- Test several hypotheses concurrently.
- Conceptualize behavioral processes so that analysis of the protocols of behavior and system events will provide multiple data points that are equivalent for testing hypothesis.

- Provide management tools for the study director, controllers, and support personnel to enhance their capacity to use the behavioral data base generated in a study to provide answers to the questions and hypotheses for the study.

- Provide management tools for the director and controllers to keep track of the state of the experiment in real time and make decisions in accordance with the objectives of the study.

Specific Needs in C^2T^2 Simulation

The increasing costs of live exercises have generated a need for simulated training approaching the realism of live events. However, the scarcity of suitable equipment and the low priority of both C^2 and T^2 in budgeting indicates the need for research to provide data on comparative benefits and costs of live and simulated events. The use of simulation would also entail significant expenditures to provide enough devices of adequate capability. Further, the comparative evaluation would be expensive in the requirement of live flying which is not now a part of the operating budget.

The studies can be both analytic and experimental. Cost data on live events can be obtained analytically. The idealized approach would be to determine the gains in proficiency for numbers of live and simulated events for given tasks or families of tasks. The numbers of events can also be translated into costs. The data generated would permit determination of the comparative value of the two kinds of events and the strengths and weaknesses of each method for given tasks.

There are also some significant deficiencies in current simulation in the areas of interactive ECM and sensor management. Realistic simulation of ECM and its incorporation into man-in-the-loop simulation has been a chronically unsatisfactory situation. The shortcomings have been in representation of the output characteristics of interference, complexity of concurrent use of multiple types of ECM, realism of counter-countermeasures which operators can employ, and the software intensiveness of the simulations.

Analysis should be initiated to determine the requirements for adequate simulation of ECM, performance objectives needed to provide operators competent in operations under ECM conditions, and training objectives. Cost-benefit analysis can then be performed to evaluate alternative approaches.

Development of training objectives for sensor management also entails establishing performance and training objectives from which the training requirements can be established and evaluated. Sensor management involves team coordination consisting of development of a deployment plan for sensors by the battle staff, its implementation by the console and sensor operators, and maintenance of system quality.

Performance in ECM and sensor management must be evaluated by an expert, instructor, or controller against some criterion of adequacy. They cannot be evaluated against criteria of an adversary's response, increased attrition, or changes in probability of kill, $p_{(k)}$.

These areas must be provided for in the design of a simulation so that adequate provision can be made for models, algorithms, performance measures, and interaction with the driver scenario.

Research Strategy

Given the broad scope and complexity of the issues that must be addressed in designing a simulation facility, it is recommended that a study be undertaken to define in detail the needed and desired functional capabilities for simulation facilities devoted to C^2T^2. The objective should be to develop a Type A System Specification in accordance with MIL-STD-490 (Reference 22). The study should define the uses to which the facility will be put, the functions which must be performed to satisfy these uses, support functions and personnel needed to operate and manage the facility, and a system concept and configuration of the system.

The approach consists of the following major steps:

1. Identify the types of training exercises to be conducted. Description of the exercises should include the numbers and types of players, C^2 functions and tasks to be performed, performance measures and other data collection, functions of operational equipment which must be simulated, and the tactical operating procedures involved.
2. Identify the experimental issues and questions to be addressed, the types of experimental designs to be employed, and the kinds of data analysis to be performed. Description of the experiments

should include the numbers and kinds of people involved, variables to be included, functions and tasks to be performed, performance measures and other data collection, and the types of operation equipment which must be simulated.

3. Develop tactical scenarios representative of the kind to be used in training and research studies. The scenarios should include temporal course of events, permissible tactics and maneuvers, types and numbers of platforms involved, parameters and functional characteristics for weapons and sensors, tactical constraints, geopolitical conditions, and environmental conditions.

4. Identify support personnel who will operate the simulation facility including computer operators, maintenance staff, role players, simulation controllers, and director. Define role, functions, and tasks for each type of individual. Identify man-machine interfaces needed, types of information required, and control actions needed.

5. Identify major categories of software needed including models of systems and platforms, supporting data bases and algorithms required to perform computations necessary to run the scenarios, exercises, and experiments. These software requirements should be translated into a preliminary software architecture.

6. Develop a preliminary functional network for the simulation facility including a system concept, configuration of major components, required supporting utilities, and functions to be implemented. This statement is the Type A System Specification. It is the design objective for subsequent development leading to detailed hardware and software specifications from which procurement can be done.

The approach was used for development of the Naval War Gaming System at the Naval Air College, Newport, R.I. Relevant documents are the Statement of Work (Reference 23), Representative Scenarios for NWC War Gaming (Reference 24), and Program Performance Specification (Reference 25). The last document takes the design beyond the Type A level, but it is useful in illustrating the categories and kind of information needed.

Similar kinds of analyses were done in procuring the Combined Arms Tactical Training Simulator (CATTS) which has been in operation at Combined-Arms Training Development Activity (CATRADA), Fort Leavenworth, Kansas. A basic document for that system is the Specification for Trainer (Reference 26).

This study will not require special facilities, but it will require an appropriate mix of skills among the personnel. Systems analysts, software designers, computer engineers, human factors engineers, operational specialists representing the user community, and training specialists should all be represented.

The work should be done jointly in-house and on-contract. Some steps, such as defining the types of training exercises and experimental studies, require heavy involvement of military personnel and integration of their requirements. Therefore, it should be an in-house effort with some support from consultants, perhaps. Other steps can be formulated so that major parts of them can be done on-contract.

A second study is recommended in the area of determining simulation requirements for ECM and sensor management. The approach consists of:

1. Determine the effects of ECM and sensor management on job tasks. The tasks affected and the changes in operating procedure should be identified.

2. Prepare performance and training objectives for operations under ECM conditions and sensor management.

3. Identify adequate simulation capability and fidelity requirements to support training objectives.

4. Identify means of incorporating the simulation for ECM and sensor management into standard exercises.

5. Conduct cost-benefit analysis of the simulation.

6. Recommend a simulation approach.

This work can be done either on-contract or in-house depending on the availability of competence in ECM and sensor management. No specialized facilities are needed.

PERSONNEL REQUIREMENTS

The most significant research issue encountered involving personnel is the selection of weapons controllers. There are currently no entry-level aptitude requirements. Determining and setting minimal aptitude requirements could reduce training time and increase the ability of controllers.

At this time, we do not know the behavioral processes of weapons control well enough to begin to identify abilities and aptitudes as candidate variables for selection. Expert judgment of peer nomination would be necessary even to identify good and poor controllers given the status of performance measurement and evaluation. The differentiating factors could lie in either the operational tasks or the team behaviors.

Setting selection criteria presumes that there are attributes of ability and life history that are related to success or competence in job performance. Adequate measures of job performance must also be available to serve as criteria for determining the validity of predictor variables.

This issue is confounded with the problem of the availability of manpower with given qualifications in sufficient number to satisfy the manning requirements of Air Force systems. The system designer or manager might have to choose between a larger, more heterogeneous supply of manpower with lesser competences and a smaller, more homogeneous supply with greater competence. If the choice is equivalent to selecting between overmanning with incompetents and undermanning with competents, then the choice may well be a lose-lose situation.

Establishing criteria for selection of the weapons controller is within the current state of psychometric technology. However, it is a time-consuming, labor-intensive undertaking which cannot be completed quickly. The initial step to be taken consists of assessing the difficulty of the problem. A survey of the weapons controller job and personnel should be undertaken to identify potentially relevant attributes and job tasks, skills, and knowledge which might differentiate among levels of performers. The existence and availability of suitable measuring instruments for predictor and criteria variables and the need for additional instruments to be constructed should be determined. Finally, a cost-benefit analysis for development and use of a selection battery should be performed. If the effort is judged worthwhile, a development plan would then be instituted.

Research on command team behaviors would, of course, yield information on the behavioral processes in C^2 activities which can contribute to identifying potential selection variables. This point can be illustrated by a possible research topic of spatial perceptual organization in C^2 behaviors.

A critical capability of weapons controllers and perhaps all C^2 personnel is the ability to form a dynamic spatial construct of the dispersion of forces, their movement, relationship to each other, and the observer's orientation to the C^2 graphic plot. This organization is basic to giving direction such as range or bearing from the perspective of the operator of a platform rather than the C^2 operator. This construct is a three-dimensional geometric one extended through time. The C^2 operator must use this spatial structure to select paths, anticipate conflicts, and extrapolate intercept points.

This capability was identified, during a discussion with a respondent to the interviews, as one that differentiates among good and poor controllers; its acquisition is a critical point in training. Observation of weapons directors provided additional information indicating that good controllers can operate from orientations both outside and inside the cockpit of an aircraft.

A similar capability is required of civilian air traffic controllers. There is some related information from the Ohio State simulation project on air traffic control. For example, a board game was developed as a training aid for teaching this skill. There are similar problems of spatial orientation for operators of remote manipulators. The capability might be a basis for selection of weapons controllers.

Skill level may also be an important variable affecting the use of simulation. This relationship is suggested by the findings of a study of performance measurement in high-skill specialties (Reference 27). Job sample performance tests were used to assess performance in a highly skilled electronics maintenance specialty. Valid and reliable tests were constructed. However, the requirements in equipment, facilities, and standardization limits its use to an ideal location such as a school.

If the finding is applicable to operator as well as maintenance jobs and to training as well as performance evaluation, then the study has serious implications for C^2T^2. Training for highly skilled personnel takes place predominantly in their units and through on-the-job training (OJT). That training is not sufficiently controlled to be beneficial. Alternative approaches may be prohibitively costly and disruptive of unit operations.

The recommended personnel research is a feasibility study of setting selection criteria for weapons directors. The approach consists of surveying the weapons director career field for potential attributes and the criteria selection, assessing the impact on the career field in terms of changes in performance and availability of qualified personnel, and determining the costs of developing and implementing a selection battery.

Standard data processing facilities for psychometric research are needed. The key factor is the availability of qualified military psychometrists. Therefore, the study can be done best in-house.

SUMMARY OF RESEARCH RECOMMENDATIONS

The issues and problem areas identified during this study have been discussed and 16 specific research projects have been recommended. These projects are listed in the right-hand column of Table 7 and are cross-referenced by parenthetical numbers to the Issue and Problem Areas listed in the left-hand column.

Each project has been described in terms of objective, approach, and resources required. These descriptions may be found in Chapter IV, where the topic emerges in the discussion.

The projects are listed below with a brief statement of the objective and intent and are also cross-referenced by parenthetical numbers to the Issue and Problem Areas in Table 7.

Field Study for Further Definition of Deficiencies in C^2 Team Performance and Training (All issues and problem areas)

The objective is to obtain more precise definition of the deficiencies found during this study by using more objective and focused evaluation of each issue. Better estimation of the impact on effectiveness and cost-benefit data could be obtained.

TABLE 7. RECOMMENDATIONS FOR LONG-TERM RESEARCH

Issue or Problem Area	Long-term Research Objectives	Recommended Research Projects
Definition and Development	Determination of deficiencies in performance and training for C^2T^2	Field study for further definition of deficiencies in C^2 team performance and training. (all)
1. Lack of a definitive framework for analyzing team skills and designing team structure and function.	Develop a conceptual model and framework for the descriptions and analysis of C^2 team functions and behaviors. (1*)	Construct a model for C^2 team performance in CRC, AWACS, or TACC type of organization. (1)
2. Lack of objective criteria and standards for evaluating team-oriented skills, individual and team readiness, and system effectiveness.	Develop comprehensive performance objectives for C^2T^2 at the level of preteam, team, and superteam exercises. (2)	Develop procedures for system and task analyses, compatible with MIL H 46855 and ISD, to be used in design of man machine components for C^2 teams. (3, 4)
3. Lack of analytic techniques and empirical data for determining institutional and operational T^2 requirements and objectives.	Develop and evaluate a set of performance measures that will assess competence of C^2 teams and battle staffs and relate team competence to system effectiveness and individual proficiency. (2)	Develop a performance measurement system for C^2 teams which assesses team competence effect in system effectiveness and needs for remedial traing. (2)
4. Lack of comprehensive, systematic procedures for defining training objectives for simulated combat missions.	Develop a set of standardized C^2 team exercises which are graded in difficulty and cover the range of C^2T^2 operational activities. (2)	Compare soft vs hard C^2 teams in performance of representative C^2 tasks. (17)
5. Inadequate planning and analytic techniques for defining T^2 simulation/simulator fidelity and functional requirements.	Develop analytical techniques for deriving T^2 requirements and compile supporting data. (3)	Develop standardized, representative tasks for C^2 teams to be used in experimental studies. (1)
6. Failure to define and develop formal training for C^2 system supervisors.	Develop and evaluate systematic procedures for determining the skill and knowledge requirements for simulated combat missions for C^2 teams and partition them over the categories of indidual, preteam, team, and superteam exercises as most appropriate vehicle for training. (4)	Develop a problem space of calibrated exercises for C^2T^2. (9, 4)
Implementation	Develop data for simulation of operational situations for C^2 teams and battle staffs which identify the a) independently controllable features of the simulation; b) necessary and sufficient conditions of fidelity to reproduce the desired behaviors; c) cost-benefit relationships for inclusion of each feature in a simulation. (5)	Develop decision aids for C^2 teams. (1)
7. Deficient simulator capabilities including a lack of facilities for combined systems training.	Develop and evaluate techniques for defining the required components, functional capabilities, and level of fidelity for simulation of C^2 teams in a weapons system. (7)	Assess applicability of existing taxonomies for learning types and instructional strategies to design of C^2T^2. (9)
8. Mismatch between entry-level requirements and Air Weapons Controller Fundamentals Course syllabus.	Develop and assess feasibility of a psychometric research plan to identify selection criteria for entry into a career field of air weapons controller. (8)	Assess usefulness of available techniques for sequencing instructional content for C^2T^2. (9)
9. Lack of empirical data regarding the optimal instructional methods and sequencing for subteam, team, and superteam skill training.	Identify and evaluate in a controlled fashion existing instructional strategies. (9)	Compare C^2 job context vs neutral context for training team skills. (5)
10. Lack of training for personnel who simulate interceptor pilots.	Identify new topics and data for research when existing technology does not provide appropriate or adequate instructional strategies. (9)	Compare cost-effectiveness of live and simulated events for C^2T^2 exercises. (15)
11. Lack of AWACS-oriented block of instruction in Air Weapons Controller Fundamentals or Automatic Positionally Qualified (APQ) courses.	Develop techniques for interpreting measures of team performance to identify deficiencies in skill and knowledge and to select appropriate remedial action. (13)	Develop simulation and training requirements for ECM in C^2T^2. (7)
12. Lack of instruction for supervisors, battle staff, and decision makers.	Develop techniques for analysis and interpretation of team performance measures in terms of the combat readiness of teams and systems. (13)	Develop simulation and training requirements for sensor management in C^2T^2 exercises. (7)
Program Evaluation and Modification	Conduct research studies on the comparative cost-cost-effectiveness of live and simulated combat exercises--and mixes of these events. (16)	Develop Type A System Specification for a C^2T^2 simulation facility. (7)
13. Lack of valid evaluation measures.	Conduct research to evaluate the comparative strengths and weaknesses of hard and soft C^2 teams on performance of critical C^2T^2 tasks. (18)	Determine feasibility of developing selection criteria for weapons directors. (8)
14. Incomplete use of existing evaluative data.	*Numbers in parentheses indicate the related issue or problem area.	
Personnel Policy and Resource Constraints		
15. Low retention rate of experienced C^2 system personnel.		
16. Shortage of live flying events/activities for T^2.		
17. Inadequate instructor training and evaluation in operations training programs.		
18. Difficulties posed in training and evaluating "soft" as opposed to "hard" teams.		
19. Lack of T^2 guidance for C^2 training program managers.		

Construct a Model for C^2 Team Performance in CRC, AWACS, or TACC Type of Organization (1)

The objective is to take the first step in developing C^2 team performance models. The purpose of the model is to provide a conceptual framework and terminology for describing and analyzing the behaviors of C^2 teams. The approach consists of observation of team operations and analysis of the technical literature on teams and C^2 to develop and test a limited model based on a selected system.

Develop Procedures for System and Task Analysis, Compatible with MIL-H-46855 and ISD, to be Used in Design of Man-Machine Components for C^2 Teams (3, 4)

The objective is to develop tools for generating and analyzing behavioral data to design man-machine interfaces, personnel subsystems, and training during system development and maintenance of system readiness. These tools will be adaptations or extensions of existing methods to the less structured situations of command and control systems and team performance.

Develop a Performance Measurement System for C^2 Teams which Assesses Team Competence Effect in System Effectiveness and Needs for Remedial Training (2)

The objective is to provide more objective and systematic measure of performance of C^2 teams. These measures are intended to provide an index of team competence, to be able to interpret in terms of impact on system effectiveness, and provide diagnosis of team and individual training needs.

Compare "Soft" vs "Hard" C^2 Teams in Performance of Representative C^2 Tasks (1, 2)

Soft teams do not have a stable membership, but team members change between exercises. The objective of this project is to assess the impact of this instability on team performance.

Develop Standardized, Representative Tasks for C^2 Teams to be Used in Experimental Studies (1)

The objective is to develop standardized tasks for representative C^2 team functions to be used in experimental studies of team processes.

Develop Decision Aids for C^2 Teams (1)

The objective is to provide improved, interactive decision support systems in man-machine interfaces to facilitate team performance. This project is aimed at effective utilization of the increasing levels of automation in system design.

Assess Applicability of Existing Taxonomies for Learning Types and Instructional Strategies to Design of C^2T^2 (9)

Assess Usefulness of Available Techniques for Sequencing Instructional Content for C^2T^2 (9)

The overall objective of these projects is to develop an instructional methodology for C^2T^2. Existing methods were developed in the context of individual training and may be applicable to C^2T^2 if the job tasks in C^2 teams can be analyzed to the necessary level.

Develop a Problem Space of Calibrated Exercises for C^2T^2 (9, 4)

This project has two objectives: 1) provide link between training content and job tasks by means of a sequence of training objectives that progressively approach job tasks; and 2) provide sequences of training exercises increasing in complexity and difficulty and progressing through higher levels of skill and knowledge.

Compare C^2 Job Context vs Neutral Context for Training Team Skills (5)

The objective is to compare two approaches to training team skills. One approach consists of training them in the context of the job tasks where they occur; the other approach consists of training them in a context free of job context, such as multi-person research games, so that the team skills can be more clearly highlighted. The approaches may differ in ease of learning and amount of transfer of training.

Compare Cost-Effectiveness of Live and Simulated Events for C^2T^2 Exercises (15)

The objective is to develop tradeoff data for cost-effectiveness evaluation of simulated events in C^2T^2 exercises. The evaluation can be used to develop a strategy for using simulation to reduce costs and increase the training effectiveness of exercises.

Develop Type A System Specification for a C^2T^2 Simulation Facility (7)

The purpose of this project is to develop the functional requirements and system concept for a simulation facility for training and research in C^2T^2. The requirements are derived from an analysis of the intended application and the capabilities needed to operate and support the facility.

Develop Simulation and Training Requirements for ECM in C^2T^2 (7)

Develop Simulation and Training Requirements for Sensor Management in C^2T^2 Exercises (7)

These two projects are aimed at determining the requirements to add these capabilities to training exercises to improve the realism, fidelity, and effectiveness. These areas are significant deficiences in current operational training.

Determine Feasibility of Developing Selection Criteria for Weapons Directors (8)

There are no selection criteria for weapons director at the present time, and the lack of appropriate aptitudes may be a source of inadequate performance in weapons directors. The objective of this effort is to evaluate the feasibility of identifying and setting entry standards for the career field and thereby improving operational performance.

These recommended projects must now be evaluated and assigned a rank or priority for implementation. Criteria will be defined and applied to these recommendations in Chapter IV.

CHAPTER IV

EVALUATION OF THE RECOMMENDED RESEARCH PROJECTS

The 16 recommended research projects were evaluated for priority. The priority is expressed as a rank.

THE EVALUATION PROCEDURE

Five criteria were defined against which to evaluate the projects. They are:

- Feasibility of accomplishment
- Utility
- Usability
- Probability of success
- Practical payoff

The attributes defining each of the criteria are summarized in Table 8. The criteria are not independent. However, they were used primarily as a guideline to the factors to consider.

The evaluations were done by one evaluator and reviewed by two human factors specialists. The ratings are summarized in Table 9.

TABLE 8. CRITERIA FOR EVALUATION OF RECOMMENDED RESEARCH PROJECTS

Technical Feasibility of Accomplishment:

- --Availability of methods and data used for the effort
- --Time to accomplish with nearer-term accomplishment being more feasible than longer-term accomplishment
- --Difficulty and complexity of the problem
- --Availability of specialized resources or facilities required
- --Availability of special or highly skilled personnel required
- --Cost

Utility:

- --Criticality of C^2 team functions affected by the deficiency
- --Frequency of the C^2 team functions affected by the deficiency
- --Technical leverage acquired

Usability:

- --Ease of use by personnel in training or operating command and research community
- --Specialized or not commonly available skill and knowledge required for use
- --Ease of implementation
- --Cost to implement and support
- --Ease of transferring technology to the user

Probability of Success:

- --Subjective estimate of achieving the objective

Practical Payoff:

- --Value of the expected outcome
- --Expected improvement in team performance and effectiveness
- --Expected improvement in training effectiveness
- --Cost reduction

TABLE 9. SUMMARY OF EVALUATION AND RANKING OF RECOMMENDED RESEARCH PROJECTS

Recommended Research Projects	Technical Feasibility	Utility		Usability		Probability of Success	Practical Payoff		Rank
		Research	Training	Research	Training		Research	Training	
Field study for further definition of deficiencies in C^2 performance and training.	H	H	H			M	H	H-M	2
Construct a model for C^2 team performance in CRC, AWACS, or TACC type of organization.	M	H	H	M		M	H	H	4
Develop procedures for system and task analysis, compatible with MIL-H-46855 and ISD, to be used in design of man-machine components for C^2 teams.	M-L	M	H		M	M		H	9
Develop a performance measurement system for C^2 teams which assesses team competence effect in system effectiveness and needs for remedial training.	M-L	H	H	H	H	M	H	H	5
Compare "soft" vs "hard" C^2 teams in performance of representative C^2 tasks.	H-M		H			H-M		M	6
Develop standardized, representative tasks for C^2 teams to be used in experimental studies.	H	H		H		H	H		1
Develop a problem space of calibrated exercises for C^2T^2.	L-M	H	H	H	M-L	M	H	H	6
Develop decision aids for C^2 teams.	L-M	H	H		M	M	H	M	7
Assess applicability of existing taxonomies for learning types and instructional strategies to design of C^2T^2.	H	M	H		H-M	H		M	3
Assess usefulness of available techniques for sequencing instructional content for C^2T^2.	H	M	H		H-M	H		H	3
Compare C^2 job context vs neutral context for training team skills.	M	M	M			H-M		M	11
Compare cost-effectiveness of live and simulated events for C^2T^2 exercises.	M	M	H	H		M		H	6
Develop simulation and training requirements for ECM in C^2T^2.	L	M	H		M	L-M	H	H	10
Develop simulation and training requirements for sensor management in C^2T2 exercises.	L-M	M	H		M	L-M	H	H	8
Develop Type A System Specification for a C^2T^2 simulation facility.	H	H		H		H	H		1
Determine feasibility of developing selection criteria for weapons directors.	H		H		H	H		H	1

The procedure for evaluation consisted of rating each project as high, medium, or low on each criterion. Separate ratings for research and training were made on utility, usability, and practical payoff.

Some of the projects were grouped into the categories of information generation, application tools, and research tools which follow.

Information Generation

- Field study for further definition of deficiencies in C^2 team performance and training.
- Compare "soft" vs "hard" C^2 teams in performance of representative C^2 tasks.
- Compare C^2 job context vs neutral context for training team skills.
- Compare cost-effectiveness of live and simulated events for C^2T^2 exercises.

Application Tools

- Develop procedures for system and task analysis, compatible with MIL-H-46855 and ISD, to be used in design of man-machine components for C^2 teams.
- Develop decision aids for C^2 teams.
- Assess applicability of existing taxonomies for learning types and instructional strategies to design of C^2T^2.
- Assess usefulness of available techniques for sequencing instructional content for C^2T^2.
- Develop simulation and training requirements for ECM in C^2T^2.

- Develop simulation and training requirements for sensor management in C^2T^2 exercises.
- Determine feasibility of developing selection criteria for weapons directors.

Research Tools

- Develop standardized, representative tasks for C^2 teams to be used in experimental studies.
- Develop Type A System Specification for a C^2T^2 simulation facility.

The procedure for evaluation in these categories was:

	Evaluation Rules	Rationale
Information generation	Not evaluated on usability	Usability deals with implementation of tool or solution and does not differentiate in this category.
	Not evaluated on practical payoff for research	Cannot differentiate since all information gives research leverage.
Application tools	Not evaluated for research, except on utility	Primary relevance for research is technical leverage from knowledge gained.
Research tools	Not evaluated for training	Primary benefit is for research capability; only incidental direct benefit to application.

When each project was evaluated on the relevant criteria, a rank score was derived for each project. Points were assigned to the H, M, and L ratings, and a mean of unweighed values was computed. All ties were assigned the same rank, and the project with the next highest score was assigned the next rank number. For example, three projects tied with the highest mean rating, and each was assigned rank 1; the project with the next highest mean rating was assigned rank 2. The 16 research projects were assigned 11 ranks.

RESULTS OF THE EVALUATION

The highest ranked projects were:

- Develop standardized, representative tasks for C^2 teams to be used in experimental studies.
- Develop Type A System Specification for a C^2T^2 simulation facility.
- Determine feasibility of developing selection criteria for weapons directors.

Two are research tools which are basic to providing facilities to support a research program in C^2T^2. The third project deals with selection criteria for weapons directors. The feasibility study is well within the state of the art and has a high potential payoff for training in the sense of increasing the match between job requirements and performed qualifications.

4. Field study for further definition of deficiencies in C^2 team performance and training.

5. Assess applicability of existing taxonomies for learning types and instructional strategies to design of C^2T^2.

6. Assess usefulness of available techniques for sequencing instructional content for C^2T^2.

Two additional projects were recommended. They are projects with some technical risk but their pervasiveness in all research areas warrants their pursuit. They are:

- Construct a model for C^2 team performance in a CRC, AWACS, or TACC type of organization and develop procedures for system and task analysis.
- Develop a performance measurement system for C^2 teams which assesses team competence effect in system effectiveness and needs for remedial training.

The three lowest ranked projects were:

- Develop procedures for system and task analysis, compatible with MIL-H-46855 and ISD, to be used in design of man-machine components for C^2 teams.
- Develop simulation and training requirements for ECM in C^2T^2.
- Compare C^2 job context vs neutral context for training team skills.

Develop Procedures for System and Task Analysis

This project was ranked M or lower on technical feasibility and probability of success because the research problem is complex and unstructured in the areas of C^2 team behaviors. Thus, the nature and availability of needed data are uncertain.

Develop Simulation and Training Requirements for ECM in C^2T^2

This project was disabled primarily by the L rating on technical feasibility compared with the companion project on simulation of sensor management; the latter project was judged to be somewhat more tractable a problem. Simulating ECM will require an engineering/human factors analysis to derive functional implications for individual and team performance, identification of the fidelity requirements, and task analysis of the counter-countermeasures. The state of this knowledge is immature and therefore a very risky, key element in the analysis.

Compare C^2 Job Context vs Neutral Context for Training Team Skills

This project was basically a moderately complex experimental problem that was more basic than applied research, and thus, the ratings fall short across the criteria.

Construct a Model for C^2 Team Performance

This project received a rank of 4 because it was judged M in technical feasibility and probability of success. The probability was influenced largely by the feasibility and is redundant. It is a difficult and complex problem area, especially since its present state is still at the level of formulating the research problem. It is basic research in many ways. However, it is well within the state of the art in modeling. A potential difficulty is that the C^2T^2 application may be large enough to approach the limits of computing power. However, this difficulty can be circumvented by partitioning the model into more computable segments and reducing the size by establishing priorities for features to be modeled.

The modeling project is basic to the research program since it provides the conceptual framework and terminology for C^2T^2. It will also produce useful products continuously through the research program, and parts of it will be incorporated into other projects in research and application.

Therefore, it is recommended that C^2 team modeling be given a higher priority on the grounds that the evaluation was not an adequate assessment of its worth. It will have highly significant benefit to the research program even if it falls short of success against the criteria of the technology of modeling.

Develop a Measurement System for C^2 Teams

This was also a significant project whose ranking (5) was lowered because its complexity and difficulty resulted in M ratings on technical feasibility and probability of success. Even if the total objective is not attainable, significant improvements in C^2T^2 can be achieved from partial products and methods produced.

The two projects for assessing the applicability and usefulness of existing knowledge and techniques for instructional strategies and sequencing of instructional content received moderately high ratings. They are relatively easy to do and inexpensive, however, and will contribute to the C^2 team model. They should be considered for implementation.

RECOMMENDED CANDIDATES FOR IMPLEMENTATION

The 16 projects were divided into thirds as an aid in selecting candidates for implementation. The top third (six projects) are recommended as candidates. They are:

1. Develop standardized, representative tasks for C^2 teams to be used in experimental studies.
2. Develop Type A System Specification for C^2T^2 simulation facility.
3. Determine feasibility of developing selection criteria for weapons directors.
4. Field study for further definition of deficiencies in C^2 team performance and training.

5. Assess applicability of existing taxonomies for learning types and instructional strategies to design of C^2T^2.

6. Assess usefulness of available techniques for sequencing instructional content for C^2T^2.

In addition, the following should be candidates for the reasons discussed above:

- Construct a model for C^2 team performance in a CRC, AWACS, or TACC type of organization and develop procedures for system and task analysis.
- Develop a performance measurement system for C^2 teams which assesses team competence effect in system effectiveness and needs for remedial training.

A final comment is that one should consider modifying the criteria for evaluation when making one's own ratings. For example, the criteria might be weighed differentially rather than equally. Further, some improvements can be made in the criteria. The interdependence among them can be reduced. Probability of success, for example, is heavily influenced by technical feasibility ana thus highly redundant. Practical payoff should be better defined so that degrees of payoff are more readily differentiated.

One approach to be considered is to conceptualize the evaluation in terms of probability of success and value. Probability of success would be a function of factors such as complexity, present state of formulation of the problem, maturity of the needed technology, availability of resources, time period for accomplishment, and cost. Value might be defined in terms of utility, usability, and anticipated improvement in the cost-effectiveness of C^2 teams or C^2 systems.

This approach can easily become more complicated and expensive than the input data warrants. However, the criteria for evaluation are important for planning. The criteria used in this analysis were an approximation that was attainable within the time and resources available. Possible improvements are apparent in the hindsight following an attempt to apply them.

SUMMARY

The 16 recommended research projects were evaluated against the criteria of technical feasibility, utility, usability, probability of success, and practical payoff. The projects were ranked on the basis of ratings on these criteria.

The top-ranked third of the projects were recommended as candidates for evaluation. They are:

1. Develop standardized, representative tasks for C^2 teams to be used in experimental studies.
2. Develop Type A System Specification for C^2T^2 simulation facility.
3. Determine feasibility of developing selection criteria for weapons directors.

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