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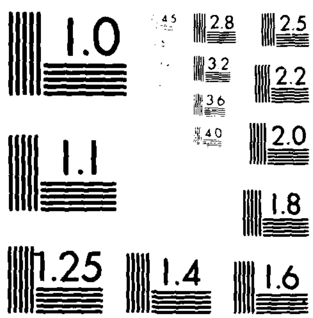

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Improving Training and Performance of Navy Teams: A Design for a Research Program

Perry W. Thorndyke and Milton G. Weiner
with the assistance of Polly Carpenter-Huffman, Theodore Donaldson, R. Stockton Gaines, Barbara Hayes-Roth, Frederick Hayes-Roth, Alain Lewis, Mark Menchik, Shelley Taylor, Keith T. Wescourt

A Report prepared for the

OFFICE OF NAVAL RESEARCH

Rand
SANTA MONICA, CA. 90406

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R-2607-ONR Improving Training and Performance of Navy Teams: A Design for a Research Program.# P. W. Thorndyke, M. G. Weiner, P. Carpenter-Huffman, T. Donaldson, R. S. Gaines, B. Hayes-Roth, A. A. Lewis, M. Menchik, S. Taylor, K. T. Wescourt. July 1980.

A design for a large-scale research program on improving Navy team effectiveness. The report assesses the most critical Navy teams, identifies deficiencies in the performance of these teams, and recommends new research that could lead to significant improvements in team performance. The major conclusions are (1) teams performing time-stressed decisionmaking using symbolic information are most critical to mission effectiveness and ship survivability, (2) several currently available instructional methods could immediately improve training, (3) new interdisciplinary research should study simulated teams in laboratory task environments that provide computer-controlled task scenarios, realistic environmental and enemy models, and intra-team communications networks, and (4) promising approaches to improving teams include improving performance models of team tasks, improving the tools and methods of training, compensating for disruptive effects of turnover in team personnel, improving team organization, and improving human-machine systems to aid task performance. 80 pp. (Author)

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PREFACE

In a 1976 report prepared for the Secretary of Defense, the Defense Science Board Task Force on Training Technology recommended an increase in funds for research and development in training technology. As an indirect result of that study, the Psychological Sciences Division of the Office of Naval Research intends to embark on a program of research in the area of Team Training and Performance. Under ONR Contract N00014-79-C-0753, the Rand Team Performance Project was formed to design this research program between September 1, 1979, and February 28, 1980.

Fourteen Rand staff members and consultants participated in the project. Knowledge of prior and current research on teams and research techniques of potential utility in studying teams were garnered from several sources. These included a review of the literature related to teams (a bibliography of this literature appears at the end of this report), the compilation of a library of books and documents on teams, and the Rand Team Performance Workshop, held November 27-29, 1979. (The proceedings of this workshop are being published as a separate Rand report.) In addition, conversations with representatives of the Military Departments and visits to Navy training and research installations provided insights into the procedures and problems of operational Navy teams. Sites visited by project personnel included the Pacific Fleet Training Command, the Fleet ASW Training Center, the Fleet Combat Training Center, the Fleet Combat Systems Training Unit, and the Naval Ocean Systems Center.

This report presents the project conclusions and recommendations for the design and content of the research program. It describes a large-scale research and development effort focusing on types of teams represented in all Service branches. Thus, the report should interest potential contractors in the research and development communities (including policy analysts, psychologists, computer scientists, and management scientists), program management personnel in the Navy and other Services, and personnel in training and operational commands.

SUMMARY

Many Navy operations depend upon the coordinated actions of a team of individuals. Currently, several obstacles hinder the formation, training, and maintenance of high-quality Navy teams. These obstacles include restrictions on training time, the frequent lack of training objectives and performance criteria, increasing complexity of equipment and jobs, declining basic skills of entering personnel, high rates of personnel turnover, and frequent failures to translate successful research results into improvements in the operational environment.

Against this background, the Office of Naval Research (ONR) charged the Rand Team Performance Project with the task of designing a research program aimed at the improvement of Navy team effectiveness. In particular, ONR requested that this design project address research needs in the areas of team training, development, and evaluation. ONR also sought recommendations on the proper roles of different research disciplines and methodologies in the program.

The major recommendations for the design of the research program are contained in a set of eleven conclusions. These conclusions provide a supporting framework for a set of more specific recommendations for management activities to implement the program and research projects within the program. The major project conclusions follow; each contains a reference to that section of the report presenting supporting arguments for it.

Conclusion 1: The teams for which ONR-supported research is likely to have the greatest impact are those that process large amounts of symbolic information and make tactical decisions under considerable time stress. These teams are the most critical for combat effectiveness and ship survivability and are ubiquitous in the Navy and in the other Services. Moreover, their effectiveness depends on the coordination and organization of the team in addition to the skilled performance of individual team members (see Sections 2.1–2.4).

Conclusion 2: Current personnel problems and Navy policies limit team performance. To improve Navy teams, research should identify organizational policies, technological advances, and changes in team training and procedures that will improve the proficiency of the people staffing Navy teams in the future (see Sections 1, 2.5, and. 2.6).

Conclusion 3: Several techniques currently exist for making immediate improvements in the training of team members. These include providing objective feedback during training, improving the match between training and job requirements, and expanding the use of computer-based instruction. Technology-transfer studies should be undertaken to determine whether and how these improvements should be implemented in operational environments (see Sections 2.5 and 5.1.3).

Conclusion 4: New, longer-term, basic research should include the study of decisionmaking teams in realistic task environments. While this would not necessarily require continual direct contact between researchers and Navy teams, researchers should at least utilize simulated task environments similar to those in the operational Navy. This will require observation of and familiarization with teams in operational settings (see Sections 2.2 and 4.2).

Conclusion 5: The more promising lines of research will require multivariate studies of performance of teams over time. Such studies provide an integrated approach to team research not adequately achieved by more narrow studies of individual dimensions of team performance. The research will include development of methods for simulating operational task performance in the laboratory, controlled experimental studies of team performance, and studies of performance evolution (see Sections 2.2 and 2.5).

Conclusion 6: Several approaches to improving team performance appear to be promising areas for research (see Section 5). These include:

1. Improving understanding of the task by analyzing performance requirements. In particular, research should investigate the criteria for assessing performance, the knowledge required for skilled performance, the variables that influence or limit task performance, and the relationship between individual and team performance.
2. Improving selection of team members by matching individual skills and abilities to task demands.
3. Improving training and exercising of both individuals and teams by developing standard training methodologies, feedback procedures, personalized instruction by computer, and training games.
4. Compensating for disruptive effects of turnover by improving training efficiency, improving socialization and integration of a new member into the team, and reducing attrition.
5. Improving the organization of the team by altering standard operating procedures, communications networks and protocols, or decisionmaking processes.
6. Developing improved human-machine systems and aids for task performance.

Conclusion 7: This multivariate, multidisciplinary research on teams requires one or more Team Performance Research Centers (see Sections 2.5, 5.3, and 6.2). These Centers must have:

1. A laboratory facility for experimental studies of team performance.
2. A system for representing and controlling combat-like situations in which teams perform their tasks. This system must include models of the environment, models of the effects of the team's and enemy actions, mechanisms for dynamic scenario control, an interface between the team and the environmental model, and communications links among team members.
3. Advanced computer hardware and software sufficient to simulate important functional characteristics of operational equipment and communications.

Conclusion 8: Designing a Team Research Center and conducting the research will require an interdisciplinary team of scientists. This team must include experts in cognitive psychology, social psychology, human factors, software and systems design, artificial intelligence, simulation, gaming, and instruction (see Section 6.1).

Conclusion 9: Basic research supported by the program should be complemented by policy studies to determine the potential impact and applicability of research results in the operating environment (see Sections 2.5, 4.1, and 5.1). These studies should include:

1. An analysis of future Navy requirements and personnel resources to determine (a) which teams are most critical to operational effectiveness and which can realize significant performance improvements from research, and (b) how procedures and training will need to be adapted to the abilities of future personnel.
2. An analysis of the barriers to translating research results into changes in policy and procedures in operational environments.

Conclusion 10: To increase the impact and effectiveness of the research program, ONR should include the targeted user and applied research communities in the program (see Sections 4.3 and 4.5), Representatives of these communities might serve several functions, including:

1. Assisting in the identification of critical teams for study and the determination of highly skilled examples of such teams.
2. Suggesting problems or bottlenecks in improving team performance.
3. Facilitating the transition of research results into applied development efforts.
4. Providing researchers with access to facilities and resources in operational or training environments.

Conclusion 11: Implementation of the proposed program should proceed in stages (see Section 6.3). These stages include:

1. Immediate initiation of a study to select the task domain(s) for inclusion in the program and to specify the important task characteristics.
2. Identification of research institutions willing and able to undertake a long-term laboratory development and interdisciplinary research effort.
3. Initiation of activities to coordinate researchers and evaluate research results, including
   a. Formation of a steering committee to monitor the research program.
   b. Sponsorship of a workshop to familiarize contractors with the program structure, task domain, performance specifications, and operational equipment.
   c. Insuring ARPANET access for all contractors.
4. Initial research focused on the development of laboratory facilities, simulations, and games.
5. A program management decision, approximately three years into the program, about how to continue. The decision should be based on contractors' progress in constructing laboratory facilities, the quality of the task representations, initial results of studies using the laboratories, and proposals for future research.
6. Continuation of major research efforts for two to seven years.

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Many individuals contributed to both the project research and the preparation of the final report. The most extensive contributions were made by the research area experts on the project staff: Polly Carpenter-Huffman (instruction), Theodore Donaldson (human factors), R. Stockton Gaines (simulation and gaming), Barbara Hayes-Roth (cognitive psychology), Frederick Hayes-Roth (computer science and artificial intelligence), Alain Lewis (decision theory), Mark Menchik (organization theory), Shelley Taylor (social psychology), and Keith T. Wescourt (instructional technology). These individuals provided valuable ideas and suggestions throughout the project, participated in the Team Performance Workshop, and, to various degrees, authored the research area guidelines in Section 5. Footnotes in each subsection indicate their individual contributions to each research area prescription.

Several project members deserve special recognition for their assistance. R. Stockton Gaines participated in the early stages of workshop planning. Polly Carpenter-Huffman compiled an extensive bibliography of research on teams and investigated the policy and training issues related to operational Navy teams. Barbara Hayes-Roth and Frederick Hayes-Roth played a major role in the formulation and development of potential future research areas. Larry Freeman provided a valuable interface to San Diego Navy personnel and installations and arranged several site visits for various project members. Finally, Frederick Hayes-Roth and Gary Martins provided ideas, advice, suggestions, and management assistance throughout the project.

The ongoing research of several of our colleagues significantly enhanced our understanding and appreciation of the problems faced by information-processing teams. This research includes studies of situation assessment and planning by Frederick Hayes-Roth and Barbara Hayes-Roth, studies of battle management simulations by Monti Callero and Philip Klahr, studies of air traffic control by Robert Wesson and Keith Wescourt, and studies of problem-solving in distributed sensor systems by Frederick Hayes-Roth and Robert Wesson. These research efforts provided a basis for estimating program resource requirements and a continuing source of excellent ideas and research proposals.

This report has benefited from the careful reading and suggestions of many colleagues. For this service we thank Monti Callero, Janet DeLand, Sarah Goldin, Robert Glaser, John Kennedy, Gary Martins, Walter Matyskiela, Joyce Peterson, and Randall Steeb.

Last but not least, several support personnel served essential functions for the project. Joanne Monroe maintained the Team Performance Library and project bibliography. Kay McKenzie prepared the manuscript of the final report. Cathy Jensen, Mary Shannon, and Carole Hillman provided special secretarial services required by the project and, in particular, by the workshop.

CONTENTS

ACRONYMS

AAW	Anti-Air Warfare
AIC	Air Intercept Controller
ARPA	Defense Advanced Research Projects Agency
ASAC	Anti-Submarine Air Controller
ASW	Anti-Submarine Warfare
BIT	Built-In Test
CAI	Computer-Assisted Instruction
CATCC	Carrier Air Traffic Control Center
CATTS	Combined Arms Tactical Training Simulator
CIC	Combat Information Center
DDC	Defense Documentation Center
DEC	Digital Equipment Corporation
ERIC	Educational Resources Information Center
EW	Electronic Warfare
FCSC	Fire Control Systems Coordinator
FPCC	Flag Plot Command Center
ICAI	Intelligent Computer-Assisted Instruction
I/O	Input/Output
ISD	Instructional System Development
NAMMOS	Navy Manpower Mobilization System
NTDS	Naval Tactical Data System
NTEC	Naval Training Equipment Center
NTIS	National Technical Information Service
ONR	Office of Naval Research
R&D	Research and Development
SAGE	Semi-Automatic Ground Environment
SOP	Standard Operating Procedure
SWC	Ship's Weapons Coordinator
TAO	Tactical Action Officer
UBP	Underwater Battery Plot
WES	Warfare Environmental Simulator

1. INTRODUCTION

Many Navy operations depend upon the coordinated actions of a team of individuals. As a result, the quality of the selection, training, equipment, and performance of teams significantly influences the effectiveness of Navy operations. Currently, several obstacles hinder the formation, maintenance, and training of high-quality Navy teams. These obstacles include:

1. Restrictions on available training time,
2. Rapidly increasing training costs,
3. The absence of data on the cost-effectiveness of various current or potential training approaches,
4. The lack of consistent team training methods,
5. The frequent lack of specific training objectives and performance criteria,
6. Declining basic skills of entering Navy personnel,
7. Increasing complexity of equipment and jobs,
8. High rates of personnel turnover on teams as a result of rotation and attrition, and
9. Organizational disincentives to incorporating new training technologies in the operational environment.

Against this background, ONR charged the Rand Team Performance Project with the task of designing of a research program aimed at the improvement of Navy team effectiveness. ONR requested that this design address four specific issues:

1. Research needs in the areas of team training, development, and evaluation.
2. Strategies for assuring the appropriate mix of training, organizational, and human-factors considerations in the research program.
3. The roles of different research methodologies in the program, including theoretical development, modeling, laboratory experimentation, field studies, and simulations.
4. The utility and characteristics of a dedicated facility for research on teams.

To determine where research could most benefit team effectiveness, we first attempted to understand the obstacles to effectiveness faced by the Navy. Among the most serious of the Navy's problems is the difficulty of attracting and retaining people of the caliber needed to operate and maintain the sophisticated equipment vital to the Navy mission. The Office of the Assistant Secretary of Defense for Manpower, Reserve Affairs, and Logistics estimates that by FY 1990 the Navy will acquire between 7 and 24 percent fewer higher-quality[1] males than they obtained in FY 1978 (OASD, MRA&L, 1979). The lower percentage is predicated on a recession civilian economy; the higher, on a vigorous civilian economy. At the same time, technologies and equipment used in military operations are becoming increasingly

[1] Defined to be individuals who have obtained a high-school diploma and are in mental groups *I-III*.

complex and sophisticated. Therefore, a major focus of the proposed team research program is to determine how manipulations in team structure, redefinition of team procedures, advances in training, and the development of human-machine performance aids can best utilize the abilities of future Navy personnel and equipment.

Another problem facing the Navy is the high rate of personnel turnover on teams. Much of this turnover is caused by rotation of personnel assignments. In addition, however, many recruits are lost during the first term of service. OASD has predicted that during FY 1979 the Navy will have experienced a loss of 28 percent of active-duty male enlistees before the end of their first three years of service. Although many of these losses occur among lower-quality recruits, such losses place heavy burdens on Navy training and operating resources.

People familiar with the Navy often attribute these personnel problems to the discomforts of shipboard life and the isolation of persons aboard ship from the rest of society. Yet the acquisition and first-term attrition rates predicted for the Navy are not appreciably different from the corresponding figures for the Army, which does not require sea duty. Nevertheless, we believe that work environment significantly affects morale and job satisfaction. Therefore, another focus for the team research program is the determination of whether and how the formation, training, and exercising of teams can improve morale and job satisfaction aboard ship.

A third problem facing the Navy is the current lack of adequate training time and resources. The declining quality of entering recruits has increased the demand for training in basic skills. This, among other factors, has reduced the time available for job-related training, particularly team training. Further, few facilities exist for team training, and the equipment in those facilities that do exist is often not similar to shipboard equipment. Finally, training curricula often lack systematic approaches to instruction, feedback, and performance evaluation. Thus, another focus of the proposed research program is the enrichment of training for teams.

It is clear that the Navy will need to adopt a variety of measures to alleviate these problems. Some of these measures, such as revised recruiting, training, and rotation policies, may require policy changes in overall Navy personnel management. Others will require the discovery of new knowledge and the development of technology based on research. However, the ultimate goal of improving team effectiveness is obviously too difficult and general to be achieved solely through basic research efforts. Producing a measurable improvement in Navy team performance requires the selection of research problems of concern to the operating Navy, the orchestration of a set of coordinated activities in all 6.1–6.5 research and development categories (research, exploratory development, advanced development, engineering development, management and support), and the acceptance and implementation of R&D products by operational personnel. Consequently, we broadened our task to include the design of a program in which research results will lead directly to changes in equipment or procedures in operational environments.

Such technology transfer will depend both on the success of the research and on the ability of ONR to move results down the R&D pipeline. For the research program to succeed, it must incorporate methods for improving the impact of research results. Thus, this document outlines a broad organizational plan for the management of the research program, in addition to a set of recommended specific topics for research.

In attempting to design a program structure and select a set of research topics, we considered a variety of program objectives that would enhance the prospects for success of the research program. We ultimately selected six objectives—three to be met by the overall design of the program and three to be met by the successful execution of the program research:

Program objectives

1. To limit the scope of the research program to the investigation of a small set of critical Navy teams and research problems.
2. To support research that would attract the highest-quality scientists and that would have early applicability to operational needs.
3. To encourage and facilitate the feed-forward of promising research results to subsequent research efforts (within ONR) and applied development and technology transfer efforts (in 6.2-6.5 programs).

Research objectives

4. To develop analytical and theoretical models of team performance (that is, to answer the question, What does the team do?)
5. To improve the evaluation of team performance (that is, to answer the question, How well is the team performing?)
6. To improve team performance (that is, to answer the question, How might the team perform better?)

These considerations motivated the conclusions about program structure, management policies, and research topics discussed in the following sections. Section 2 provides an overview of the proposed research program and discusses the aspects of current Navy teams and team activities that motivated the conclusions and recommendations of this report. Section 3 presents the project conclusions and general recommendations for the design, management, and content of the research program. Section 4 discusses in detail specific recommendations for ONR management activities to implement the program. Section 5 presents the set of specific research areas that seem most promising and that should be supported within the program. Finally, Section 6 outlines a time-phased plan, budgetary guidelines, and resource requirements for the program.

2. AN OVERVIEW OF THE PROGRAM DESIGN

2.1. THE TEAM CONCEPT

To design a research program on teams, we were forced to consider at the outset how to characterize a "team." Since recent reviews of military teams have discussed the concept of a team in some detail (Hall and Rizzo, 1975; Wagner, Hibbits, Rosenblatt, and Schulz, 1976), we elected not to seek a precise definition or to make fine distinctions between teams and other multi-individual groups (e.g., crews, groups, units). Rather, we use the term "team" generically to refer to a set of individuals working cooperatively to achieve some common objective. We have limited the scope of our consideration to teams with a sufficiently small membership that, in principle, all members of the team could be exercised simultaneously.

This concept of a team embraces such diverse Navy functional groups as air crews, gunnery teams, air traffic control teams, maintenance units, mess crews, combat information center (CIC) teams, underwater battery plot teams (submarine tracking and attacking), ship maneuvering teams, and propulsion and powerplant teams. These teams may vary in any of several critical attributes characterizing team composition, function, and organization. Over the years, researchers have developed taxonomies to capture the important dimensions of variation (Glanzer and Glaser, 1955; Haggard, 1963; Engel, 1970; Meister, 1976). However, Meister (1976) concludes that "a satisfactory taxonomy of team dimensions has not yet been developed". While we did not attempt to develop a definitive taxonomy of teams, we did seek to identify some of the attributes that could describe teams with different functions and structures. These attributes could serve as a basis for loosely clustering teams with similar performance characteristics and research requirements. The following attributes seemed to capture much of the variation among teams:

1. *Team Size.* Variations in team size influence both the complexity in team communications and the feasibility of training teams *in toto.*
2. *Team Function.* Teams vary in the nature of their principal activities. These activities include performing perceptual discriminations (e.g., a radar team), utilizing perceptual-motor skills (e.g., a gun-loading team), and processing symbolic information and making decisions (e.g., a CIC team).
3. *Performance Sequencing.* The synchrony of team member performance influences the requirements for control or supervision of behaviors. Team members may perform simultaneously, sequentially, or asynchronously.
4. *Performance Integration.* Teams vary in the extent to which members cooperate during performance. Tasks may require considerable interaction, little interaction but the sharing of resources, or relatively independent behaviors. These requirements influence the extent to which overall team performance requires coordination skills and the extent to which overall performance is predictable from aggregated individual performance.

5. *Command/Communications Structure.* Teams vary in their command and communications regimes, particularly in the extent to which specific individuals act as central points for receiving messages and making decisions. Alternative structures include hierarchical, linear, star, or modularized organizations.
6. *Role Flexibility.* Teams vary in the extent to which the behaviors of the different team members are rigidly fixed and segregated. The flexibility of team roles will influence the extent to which team tasks can potentially be reorganized to improve efficiency or performance.

Since teams may vary so widely in structure and function, the requirements for selecting team members, organizing and training the team, and measuring team performance will vary as a function of team characteristics. Thus, no research program can address the needs of all Navy teams.

2.2. SELECTION OF TARGET TEAMS

We were next faced with the decision of whether to design a program based on a broad-spectrum approach to teams or on a coordinated, in-depth study of a selected team or team type. The broad-spectrum approach offers the advantage of greater flexibility for contractors to select their own research focus. In addition, this approach would provide better research coverage of the variety of team types within the Navy. On balance, however, the selection of a more narrow research domain seemed more consistent with ONR's goals and seemed to offer a better chance of producing usable results. Several considerations supported this conclusion:

1. A program with a major, focused thrust in a single domain would have higher visibility and, if successful, higher impact than a less focused effort.
2. A single research focus would offer the opportunity for significant cooperation and synergy among contractors.
3. A single research focus would not limit the applicability of successful research results. Rather, successful theories, methods, and technologies developed in the chosen domain could be transferred to new domains.[1]

The selection of a particular focus for the research program required both a review of prior research on teams and a consideration of the types of actual Navy teams. We conducted an extensive search of the literature and compiled a library of documents on teams. Sources of references included Psychological Abstracts, Sociological Abstracts, National Technical Information Service (NTIS), Defense Documentation Center (DDC), Educational Resources Information Center (ERIC), Social Sciences Citation Index, the Rand library, and various documents recommended by the Team Performance Project staff. We did not attempt a comprehensive, formal review of this literature, since several recent reviews have provided excellent digests of this work (Alexander and Copperband, 1965; Hall and Rizzo,

[1] This strategy proved successful in the Defense Advanced Research Projects Agency (ARPA) speech understanding program. Moreover, the system architecture developed for speech understanding in the Carnegie-Mellon HEARSAY-II program has been adapted for use in subsequent efforts to create image understanding systems.

1975; Meister, 1976; Wagner, Hibbits, Rosenblat, and Shulz, 1976). However, we did examine the domains, methodologies, and conclusions of these efforts to determine the current state of knowledge about teams. (A bibliography of these sources appears at the end of this report.)

The Team Performance Project also conducted a three-day workshop on teams at Rand on November 27-29, 1980. The workshop comprised a set of sixteen presented papers that described past, current, and potential future research on teams in a variety of disciplines. In addition, there were wide-ranging discussions among the participants, the Rand project staff, and various Department of Defense personnel.

Several conclusions emerged from the literature and the workshop. First, an enormous body of research has addressed various aspects of team composition, structure, training, and performance. Second, few of the research results appear to be applicable to the solution of real Navy team problems. In general, prior research has investigated teams dissimilar in structure, purpose, and activities to Navy teams. Such research typically focuses on a small set of variables, a narrow range of task and environmental variations, and simplistic laboratory methods. Finally, the tested hypotheses and models are frequently too abstract or discipline-bound to offer prescriptions for teams in the operational environment.

Consequently, we concluded that the research program should focus on the study of a team or type of team similar to one that actually exists in the Navy. Since research using actual operational teams and equipment may be problematic for many potential contractors, the teams actually studied may only simulate critical functional characteristics of the operational teams. Nevertheless, the task environments investigated by contractors should be motivated and constrained by the properties of particular Navy teams.

Three criteria guided the search for an appropriate domain for intensive investigation. First, the program area had to be one in which successful research might lead to significant improvements in the performance of the teams under investigation. This suggested that attractive candidates would be teams with considerable variation in performance, poorly specified performance metrics and criteria, and flexibility in operating procedures and training methods. Such teams might be able and willing to alter their activities based on recommendations from research. Further, teams that perform in a technologically changing environment (e.g., computers, communications, weapons) face changes in procedures as equipment is replaced. These teams offer an excellent opportunity to introduce innovations in training, task allocation, and performance aids.

The second criterion for the selected domain was that team performance must depend on more than simply the aggregated performance of the individuals. Otherwise, little would be gained in team research beyond what might be accomplished in the improved training of individuals. This criterion suggested the desirability of selecting a team or type of team that requires extensive interaction among team members and that uses poorly specified or highly flexible operating procedures.

The third criterion for selecting a research domain was that it be an area in which improvements in team performance would significantly improve overall Navy survivability and combat effectiveness. Thus, research should focus on teams whose performance is vital to the success of the Navy's missions.

These considerations and the program objectives outlined in Section 1 led us to the following conclusion:

The greatest leverage in team performance research can be attained by focusing research on teams that receive and evaluate dynamic information and perform time-stressed decisionmaking.

Such teams deal with the environment largely through symbolic representation for the purpose of threat detection and evaluation, situation assessment, planning, decisionmaking, and control (plan execution and monitoring). These teams tend to have the following attributes:

1. They rely primarily on information-processing activities rather than perceptual-motor skills.
2. They require the coordinated activities of several subteams, such as those that process sensor data, display the data, use the data for decisionmaking, or allocate and direct team resources.
3. They require a high degree of interaction among team members and subteams.
4. They utilize relatively loosely structured standard operating procedures (SOPs) because their data are highly volatile and time-dependent.
5. They are flexible because they must respond to surprises, emergencies, and a variety of external situations.
6. Their activity level varies greatly, from routine operations to critical decisionmaking under conditions of heavy load.

The next section describes some shipboard Navy teams that perform this type of decisionmaking.

2.3. INFORMATION-PROCESSING AND DECISIONMAKING TEAMS IN THE NAVY

Each Navy ship comprises several closely integrated teams that contribute to command decisionmaking. While the details of team organization, procedures, and equipment vary from ship to ship, the general descriptions presented here illustrate the variety of tasks and functions that these teams perform.

The CIC is the focus of each ship's tactical information processing and decisionmaking. CIC teams provide command and control functions for the ship and for shipboard and other aircraft in the immediate area. They detect and track surface ships, submarines, and aircraft; they direct ship maneuvers; they monitor the environment and the progress of the battle; they control the ship's weapons deployment; and they communicate with other CICs to coordinate battle group activities.[2]

While the commanding officer of the ship has ultimate command authority, much of the tactical data evaluation and decisionmaking in the CIC is performed by the Tactical Action Officer (TAO). He must evaluate threats, allocate resources to meet the threats, and make ship maneuvering decisions. Three data sources provide inputs to his decisionmaking process: air radar information, surface and

[2] Navy documents that describe these tactical command and control procedures include Combat Information Center Doctrine (prepared by individual ships), Combat System Operation Design (prepared by Commander, Naval Sea Systems Command, for some classes of ships), and Staff Manuals (such as that prepared by Fleet Combat Direction Systems Support Activity, Dam Neck, Virginia, for the Navy Tactical Data System).

sub-surface radar and sonar information, and electronic warfare information. These three types of information are displayed more or less independently and separately in the CIC.

The ship's weapons coordinator (SWC) coordinates the air and surface war under the direction of the TAO. He views a computer-generated symbolic display of targets and their movements, and he assigns responsibility for some air targets to the air intercept controllers (AICs). The AICs communicate targets, commands, and locations, etc., to the combat air patrol under the ship's control. The SWC assigns responsibility for the tracking and engagement of other air and surface targets to the fire control systems coordinator (FCSC) in the weapons area. The FCSC controls the shipboard missile and gun systems and radars and supervises the activities of the operators of these systems.

On aircraft carriers, the movement of aircraft on and in the vicinity of the carrier is managed by the carrier air traffic control center (CATCC). This team, which is not located in the CIC, provides air approach control and air launch and recovery direction for carrier aircraft. Under the direction of the air squadron leader, the CATCC must coordinate its activities with the CIC and the bridge.

The radar detection and tracking area maintains the updated radar displays for the CIC. Search radar operators view radar repeaters and detect the presence of objects (ships, aircraft, missiles). Track identifiers attempt to determine the identity of these objects and whether they are friendly or hostile "platforms." The track supervisor coordinates these activities and communicates with the SWC and other ships to determine the current status of these platforms.

The electronic warfare (EW) area comprises several individuals who detect electronic emissions from remote air targets. These emissions indicate the bearing and identity of the targets. This information is communicated to a team member in the CIC who maintains current EW information on a Plexiglas status board. The TAO and SWC integrate this information with radar displays to pinpoint the location and identity of enemy targets.

Surface and subsurface information is aggregated and evaluated in the surface area of the CIC. The surface watch officer coordinates the surface war and anti-submarine war (ASW) under the direction of the TAO. The surface area maintains a horizontal, manually operated plotting board to display the locations and movements of surface ships and submarines. Information for maintaining this display is provided by radar and by the sonar area, located outside of the CIC. The sonar area, like the radar area, comprises several individuals who receive low-level sensor data and attempt to determine target identities and locations. Requests for weapons engagements are sent to the anti-submarine air controller and to the underwater battery plot (UBP), also located outside the CIC.

Each ship performs this variety of CIC functions. The flag plot command center (FPCC) is a CIC, commanded by the battle group admiral, that orchestrates the activities of the entire battle group. The FPCC is typically located on the aircraft carrier for the battle group. It formulates the fleet battle plan and monitors its execution through communications with the fleet EW coordinator, the fleet ASW coordinator, the fleet surface warfare coordinator, and the fleet air warfare coordinator. These fleet coordinators, in turn, must coordinate the activities of the various CICs in the battle group.

2.4. THE DEMAND FOR RESEARCH ON DECISIONMAKING TEAMS

Each of the Services has teams that perform similar command decisionmaking functions. Such teams are particularly important to military operations because they make decisions and initiate actions that affect the positioning, the weapons deployment, the combat readiness, and the ultimate survivability of entire operational units. The criticality of these teams is reflected in the heavy investment in studying and training them, both in the research community and in operational environments.

For example, a long history of man-machine studies have investigated the training of such teams (Parsons, 1972), focusing on different aspects of team performance, including operator capacity to process information, evaluations of information displays, decisionmaking processes, communications procedures, and evaluations of computer support options. Such research has primarily investigated individual performance in team settings rather than *team* training or performance per se. Project Cadillac (New York University) and The Rand Corporation's Systems Research Laboratory, among others, pioneered broad-spectrum approaches to team training and performance. Many other efforts, such as the Semi-Automatic Ground Environment (SAGE) system (Systems Development Corporation), focused more narrowly on specific training issues, methodologies, or hardware/software configurations. In general, these efforts have shown that useful research results are most likely to derive from a systems approach to multiple aspects of performance rather than from studies confined to a few team attributes. This suggests that to be successful, new research on teams must emphasize broad, multivariate, interdisciplinary studies of performance.

More recently, numerous facilities have been developed and studies undertaken to investigate complex team decisionmaking, including the Battle Management Laboratory developed at Rand for the Air Force, studies of Air Force battle management decisionmaking at MITRE (Wohl, 1979), the formation of an Air Force Battle Simulation Working Group to improve simulation capabilities (AFBSWG, 1979), the development of various tactical decision aids for the Navy (reviewed in Miller, Rice, and Metcalf, 1979), and the development and evaluation of various Army team training systems (Thurmond and Kribs, 1978; Scott, Meliza, Hardy, Banks, and Word, 1979; Meliza, Scott, and Epstein, 1979). In addition, the Navy maintains several facilities for team training in complex shipboard decisionmaking (Rizzo, 1980).

The importance of research on teams with command and control functions will continue to grow. Sophisticated information-gathering systems will extend the amount, scope, and type of information available from sensors. This will extend and change the demands on individuals to integrate various data and assess the current situation. More sophisticated weapons systems will require increased speed and accuracy of deployment decisions. New hardware and software capabilities will become available to support communications among team members, cooperative problem solving and decisionmaking, and interfaces among sensors, weapons, and humans. Finally, the increasing complexity of systems and procedures will make it increasingly difficult to analyze, assess, and prescribe methods for performance. These trends lead to a growing requirement for research aimed at achieving highly effective performance by such teams. Consequently, we recommend the study of these teams in the team performance program.

2.5. THE FRAMEWORK FOR TEAM PERFORMANCE RESEARCH

As discussed in Section 2.2, the principal shortcomings of prior team research are (1) the lack of similarity between laboratory teams and operational teams and (2) the narrow focus and methodology of most laboratory studies. We sought a framework and design for the research program that would avoid these shortcomings; after considering several designs, we arrived at one that we believed could best meet the program objectives outlined in Section 1. Figure 1 summarizes this framework.

The center of Fig. 1 represents the research and development pyramid that generates new systems, ideas, and procedures for the military Services. The various levels in the pyramid are labeled on the left side of the figure with their R&D category designations. At the top of the pyramid are the operational teams targeted for improvement by the research program. (CIC and CATCC teams are merely illustrative of the information-processing, decisionmaking teams we recommend above as potential research targets.) The next three levels in the pyramid represent the various stages in advancement of the development of systems and ideas for use in operational environments. The bottom of the pyramid represents 6.1 research, the type of scientific studies typically sponsored by ONR.

In this framework, the selection of target teams would constrain the set of potential 6.1 research topics (indicated by the ovals). As in any research program, only some of the research at the bottom of the pyramid will produce successful results and be carried forward into 6.2 development studies. Such selective filtering would occur at each stage in the pyramid. As results move up the pyramid, the objectives of the work become more applied and more specific to particular applications. In addition, however, successful and promising research results at the

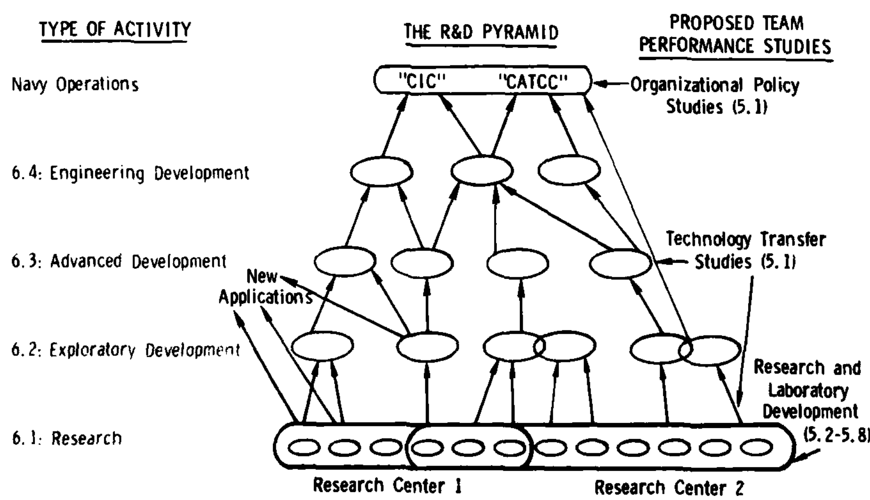

Fig. 1—A framework for team performance research

bottom of the pyramid will presumably suggest new applications both in the Navy and in the other Services. Thus, research will generalize to domains and applications beyond those targeted by the research program.

We believe that successful research on command decisionmaking teams will require the coordination of a variety of research approaches in a simulated task environment. As previous studies of man-machine systems illustrate, the establishment of facilities and capabilities required to simulate a complex task environment is itself a substantial undertaking (Parsons, 1972). Therefore, we concluded that research projects conducted in the program should be clustered in large-budget research centers. The actual number of such centers that ONR could support would depend on the budget available for the program and the proposed size of each center. (Section 6 discusses the anticipated requirements of these centers). Each center would create a task simulation environment and conduct a number of related but distinct interdisciplinary studies of team performance. As shown in Fig. 1, the activities of these centers would overlap to the extent that different centers develop laboratories with similar equipment or for the study of the same teams. However, each site would presumably investigate a unique set of research questions.

We believe that three classes of studies in the research program could lead to significant improvements in team effectiveness. These classes differ in the location in the R&D pyramid at which improvements would occur. They are indicated on the right-hand side of Fig. 1.

Organizational policy studies would focus on current operational teams and Navy policies and plans that may affect their performance and shape the basic research of the next five to ten years. Several studies of Navy operations, discussed in Section 5.1, may produce recommendations for improving team effectiveness. These include assessing the requirements and characteristics of future Navy teams, understanding the organizational factors involved in introducing innovation, and assessing the causes and effects of personnel turnover on teams.

The second class of studies would focus on the translation of current knowledge and technologies into the operational environment. Section 5.1.3 presents several examples of current technologies that could immediately improve the performance of Navy teams. This class of studies would develop plans and specific methods for introducing these improvements into operational environments.

Finally, the bulk of the research activities proposed in Section 5 (5.2-5.8) focus on new studies of team performance. These studies would include laboratory design and development, theoretical development, simulations and games to investigate team interactions and man-machine communications, experiments in manipulating variables of theoretical interest, and research on a variety of software aids for performance modeling, training, and improving task performance. The recommended studies are based on evaluations of the current state of development in psychology, computer science, simulation, and military gaming.

2.6. PRODUCTS OF THE RESEARCH PROGRAM

The ultimate outcomes of the research program will be measured by its products. The quality of these products will be influenced by many as yet undetermined factors, including program budget, program longevity, contractors, the content of the research, and the success of the research. Despite the uncertainties, we anticipate that the research program should support four types of products: scientific knowledge, operational norms, designs for technology transfer, and laboratory facilities. Each of these products and their consumers are discussed below.

The scientists participating in the research will produce and document results for the scientific community in technical reports, journal publications, books, and conference presentations and/or proceedings. The knowledge and theories derived from the research should benefit a scientific community that extends beyond individuals involved in the study of teams, particular teams, or military problems.

Successful research results should also be aggregated into documents for use by the operational community. Thus, contractors might produce a manual for Navy commanders that provides a practical guide on how to train, reward, rotate, evaluate, or organize particular shipboard teams. The recommendations in such a document would be based on behavioral principles derived from the research.

Some research results might take the form of promising technologies for aiding teams, including hardware configurations, design architectures, man-machine interfaces based on human factors studies, computer-assisted training methods or programs, and/or demonstration systems for supplementing or replacing team functions. Thus, researchers might produce hardware or software specifications and designs for technology transfer to further development efforts.

Finally, the research program will support the development of laboratory facilities and capabilities. These laboratories might be used in subsequent research and development by the same or other contractors, or they might be delivered and installed at Navy training sites for use in operational training and training development.

3. GENERAL CONCLUSIONS

Guided by the six goals presented in Section 1 and the considerations discussed in Section 2, we arrived at a set of general conclusions about a program structure offering the best chance of success. These conclusions constrained and suggested the specific recommendations for activities to be undertaken by program management and projects to be sponsored in the research program. We give here our set of general conclusions. In the remainder of the report we elaborate these conclusions as recommendations for specific research and program management activities.

Conclusion 1: The teams for which ONR-supported research is likely to have the greatest impact are those that process large amounts of symbolic information and make tactical decisions under considerable time-stress. Such teams include those in the tactical flag command centers, CICs, nuclear submarine attack centers, ASW attack centers, and carrier and shore-based air traffic control centers. These teams are the most critical for combat effectiveness and ship survivability and are ubiquitous in the Navy and in the other Services. Moreover, their effectiveness depends on the coordination and organization of the team in addition to the skilled performance of individual team members.

Conclusion 2: Current personnel problems and Navy policies limit team performance. Research should identify organizational policies, technological advances, and changes in team training and procedures that will improve the proficiency of the personnel staffing Navy teams.

Conclusion 3: Several techniques exist that could make immediate improvements in the training of team members: providing objective feedback during training, improving the match between training and job requirements, and expanding the use of computer-based instruction. Technology-transfer studies should be undertaken to determine whether and how these improvements should be implemented in operational environments.

Conclusion 4: New, longer-term, basic research should involve the study of decisionmaking teams in realistic task environments. This would not necessarily require continual direct contact between researchers and Navy teams, but researchers should at least utilize simulated task environments similar to those in the operational Navy. This will require observation of and familiarization with teams in operational settings.

Conclusion 5: The more promising lines of research will require multivariate studies of team performance over time. Such studies provide an integrated approach to team research that is not adequately achieved by narrower studies of individual dimensions of team performance. Research should include development of methods for simulating operational task performance in the laboratory, controlled experimental studies of team performance, and studies of performance evolution.

Conclusion 6: Several approaches to improving team performance appear to be promising areas for research:

1. Improving understanding of the task by analyzing performance requirements. In particular, research should investigate the criteria for assessing

performance, the knowledge required for skilled performance, the variables that influence or limit task performance, and the relationship between individual and team performance.

2. Improving selection of team members by matching individual skills and abilities to task demands.
3. Improving training and exercising of both individuals and teams by developing standard training methodologies, feedback procedures, personalized instruction by computer, and training games.
4. Compensating for the disruptive effects of turnover by improving training efficiency, improving socialization and integration of new members into the team, and reducing attrition.
5. Improving the organization of the team by altering standard operating procedures, communications networks and protocols, or decisionmaking processes.
6. Developing improved man-machine systems and aids for task performance.

Conclusion 7: This multivariate, multidisciplinary research requires one or more Team Performance Research Centers that have:

1. A laboratory facility for experimental studies of team performance.
2. A system for representing and controlling combat-like situations in which teams perform their tasks. This system must include models of the environment, models of the effects of the team's and enemy actions, mechanisms for dynamic scenario control, an interface between the team and the environmental model, and communications links among team members.
3. Advanced computer hardware and software that can simulate important functional characteristics of operational equipment and communications. Requisite hardware includes multi-user time-shared processors and/or a network of small processors, and terminals with graphics display capabilities.

Conclusion 8: Designing a Team Research Center and conducting the research will require an interdisciplinary team of scientists. This team must include experts in cognitive psychology, social psychology, human factors, software and systems design, artificial intelligence, simulation, gaming, and instruction.

Conclusion 9: Basic research supported by the program should be complemented by policy studies to determine the potential impact and applicability of research results in the operating environment. These studies should include:

1. An analysis of future Navy requirements and personnel resources to determine (a) which teams are most critical to operational effectiveness and which can realize significant performance improvements from research, and (b) how procedures and training will need to be adapted to the abilities of future personnel. Current team problems and obstacles to improving performance may change rapidly as the character and technology of the Navy changes. Appropriate targets toward which to aim research thrusts must be identified.
2. An analysis of the barriers to translating research results into changes in policy and procedures in operational environments.

Conclusion 10: To increase the impact and effectiveness of the research program, ONR should include the targeted user and applied research communities in the program. Representatives of these communities might serve several functions, including:

1. Assisting in the identification of critical teams for study and in the determination of highly skilled examples of such teams.
2. Suggesting problems or bottlenecks in improving team performance.
3. Facilitating the transition of research results into applied development efforts.
4. Providing researchers with access to facilities and resources in operational or training environments.

Conclusion 11: Implementation of the proposed program should proceed in stages:

1. Immediate initiation of a study to select the task domain(s) for inclusion in the program and to specify the important task characteristics. In addition, the study should identify Navy personnel and facilities willing to cooperate with research contractors in the program. These studies could be carried out in the current fiscal year.
2. Identification of research institutions willing and able to undertake a long-term laboratory development and interdisciplinary research effort.
3. Initiation of activities to coordinate researchers and evaluate research results, including
   a. Formation of a steering committee to monitor the research program.
   b. Sponsorship of a workshop to familiarize contractors with the program structure, task domain, performance specifications, and operational equipment.
   c. Insuring ARPANET access for all contractors.
4. Initial research focused on the development of laboratory facilities, simulations, and games.
5. A program management decision, approximately three years into the program, about how to continue. The decision should be based on contractors' progress in constructing laboratory facilities, the quality of the task representations, initial results of studies using the laboratories, and proposals for future research. Potential decisions include
   a. Continued funding of all contractors to perform additional research.
   b. Continued and possible increased funding of fewer contractors.
   c. Delaying the decision because no contractor has assembled the desired facilities.
   d. Redirecting the program to smaller efforts either more removed from specific applications or focused on a smaller set of research issues, as in current ONR 6.1 programs.
   e. Terminating the program.
6. Continuation of major research efforts for two to seven years.

4. MANAGEMENT POLICIES AND ACTIVITIES

The program proposed in the previous sections is characterized by the close coupling of field research, the development of experimental laboratory facilities, and basic research activities. This reflects a belief that the research environment should functionally resemble a targeted operational environment. Such coupling should also facilitate the transition of 6.1 research results into applied development efforts.

Another important feature of the program is that the recommended domain is represented by critically important teams in all three Services. Thus, the proposed research program could be of significant benefit to the entire defense community. However, the ultimate utility of the research results for improving operational team performance will depend largely on

1. Anticipating the nature and needs of military personnel, teams, and systems 10 to 15 years from now.
2. Communicating to potential contractors the ultimate applied objectives of the research as well as the immediate objectives of the basic research program.
3. Identifying the best research projects and researchers.
4. Attracting these high-quality researchers to the research program.
5. Communicating the benefits of the research enterprise to potential users in the Navy and other Services.
6. Participating in the translation of successful basic research into applied systems and contexts.

These activities represent refinements of the program objectives outlined in Section 2. ONR management should include these activities within the administration of the research program. We suggest below a set of detailed methods for implementing these activities.

4.1. ORGANIZATION OF THE RESEARCH PROGRAM AROUND PROJECTED OPERATIONAL NEEDS OF THE 1990s

Navy teams and their training requirements undergo rapid and continual change. The changes include the composition, skills, and term-expectancies of entering Navy personnel, as well as in the sophistication and complexity of equipment. By the 1990s, significant changes may occur in the relationship between humans and machinery, introducing new training, job-skill, and team-organization requirements. The prominent and critical Navy team activities of the 1990s will very likely be different from those currently central to Navy operations.

If research begun now is to have impact on Navy operations and technologies of the 1980s and 1990s, it must consider the requirements of the future, as well as the present, operational Navy. Thus, one of the first activities of the research program should be a policy study of the types of teams that will be required to make command decisions in the 1990s, what the skills of available personnel are likely to be, and where improvements in team performance would have the greatest impact on Navy operations.

4.2. FOCUSING PROGRAM RESOURCES IN A PARTICULAR TASK DOMAIN

The range of Navy teams and team problems far exceeds the set of issues that the research program could reasonably support. To produce results with the greatest impact on the operational Navy, the program should focus attention on improvement of the operation of information-processing, decisionmaking teams, which are critical to successful Navy functioning.

To guarantee the applicability of research results obtained in the laboratory to the solution of Navy problems, contractors should be required to simulate actual operational teams. This requirement may entail a significant development effort to design and create a team performance laboratory, but such a laboratory will facilitate technology transfer to applied research programs.

4.3. PROMOTION OF COHESIVENESS AND SYNERGY AMONG THE RESEARCH-PROGRAM PROJECTS

To obtain maximum leverage from the research program, progress should derive not only from the accumulation of results from individual projects but from synergy and cross-fertilization of ideas among contractors. To promote close ties among researchers, all projects should be constrained by a common set of target teams, problems, and ultimate operational objectives. Individual researchers or research projects could investigate different but complementary components of a larger problem, while sharing a common task environment and set of research objectives. Cohesion in the research program could be encouraged by the following recommendations:

1. Structure the research program around a small number of large-budget, interdisciplinary projects. Each project should include a number of individual or subproject research activities, such as the design and implementation of laboratory hardware and software, the design and execution of social- and cognitive-psychology experiments, task simulations, games, and the development and testing of training methods. Each project would thus utilize a multipurpose laboratory facility and researchers from several discipline areas. The scale of the individual research efforts and the existence of team observation and experimentation laboratories would give the research program high visibility.

2. Form a steering committee to select, coordinate, and administer the projects in the research program. The committee's functions should include reviewing proposals, determining the relevance of specific proposals and projects to the overall goals of the program, coordinating and promoting communication among the contractors and operational personnel (see 4.4 and 4.5 below), and periodically evaluating the progress of the various research projects. A representative of the research community could organize and manage the activities of the steering committee.

3. Conduct annual workshops at which contractors present research results and representatives of the applied research and operational branches of the Navy discuss their current activities and problems.

4. Establish a clearinghouse for publications produced by contractors to ensure wide distribution and availability of research reports.

5. Provide access to the ARPANET for all contractors in order to facilitate communications and resource-sharing within the program.

4.4. THE DEVELOPMENT OF A NATIONAL COMMUNITY OF TEAM RESEARCHERS

To develop an outstanding national team performance research program, ONR should attempt to promote interest in team problems among researchers in the fields of psychology, computer science, management science, and education. While a considerable body of research on teams has accumulated over the past 20 years, that research has, by and large, been isolated within disciplines, and little of it has had any direct relevance to real Navy team problems. Consequently, ONR should attempt to generate, support, and reward interest in Navy team problems in order to attract researchers to the program.

The problems embraced by the research program must be scientifically tractable, interesting, and intellectually stimulating. To guarantee this, the research problems and the applicability of research results should extend beyond the particular task domains under investigation.

In addition, the research issues must be communicated to and publicized in the research community. Researchers must be attracted to the program and their interest must be sustained. ONR might consider sponsoring an annual conference or workshop, such as the one held at Rand in November 1979, for team performance researchers; awarding an annual prize for the most outstanding publication or other contribution to the field; providing fellowship funds or allowances to support the training of graduate students in research on teams; and providing funds for the establishment of a research institute to operate in conjunction with one or more of the program-supported laboratory facilities. Such an institute might support the post-doctoral or sabbatic research of professionals interested in beginning research on teams and could sponsor symposia, colloquia, or workshops on various aspects of team performance.

4.5. ACTIVE PARTICIPATION IN TRANSFER OF BASIC RESEARCH RESULTS TO APPLIED DEVELOPMENT PROGRAMS

Many useful results from ONR-sponsored research have not been translated into 6.2-6.4 development programs. For results produced in the team performance program to have visibility and impact, they must be transferred to and tested in operational environments. To facilitate this process, ONR should invite key individuals from other R&D areas and from the operational and training commands to participate in the research program. As mentioned above, such individuals might participate in annual contractors' meetings or research conferences, or they might serve on the program steering committee. Such participation would help to ensure the proper research focus and to solidify the investment of these communities in the program. In addition, ONR should attempt to involve basic researchers in the development process to guide the implementation of research results in initial prototype demonstrations.

4.6. CONTINUING EVALUATION OF RESEARCH PROGRESS

The progress of program researchers should be critically evaluated periodically. Contractors should initially develop five-year research plans, but continuation of funding should depend on contractors' abilities to reach research milestones and on their progress in comparison with other contractors. Research teams should, to some extent, be in competition with each other, at least during the early stages of laboratory and simulation development.

The program should also allow flexibility for altering research directions as dictated by the results of early policy studies. For example, if studies uncover a particular type of team or function critical to Navy operations of the 1990s, existing or new projects might be directed toward investigating issues particular to this team or function.

4.7. ESTABLISHMENT OF A TRI-SERVICE RESEARCH PROGRAM

The research issues in the proposed research program transcend the interests of the U.S. Navy. Information-handling teams that assess situations, plan, make decisions, and allocate resources are ubiquitous in the Air Force and the Army as well. The Tactical Air Control Systems of the U.S. Air Force and the Tactical Operations Centers of the U.S. Army resemble Navy combat information centers, so many research results in this program will apply to activities in the other Services. A major tri-Service research program would offer the opportunity for increased leverage in many aspects of the program, including its cohesiveness and synergy, the development of a community of team researchers, the transfer of applicable technology, and the overall cost of facilities. ONR should lead the effort to develop a such a tri-Service program in team performance.

At a minimum, ONR should propose to the other Services a time-phased multi-Service entry and commitment to research activities. The suggested steering committee for the ONR research program should therefore include members of the other military Services with responsibility for establishing interfaces with their respective research offices as a move toward an integrated and jointly funded program.

5. RESEARCH ACTIVITIES

This section outlines the set of R&D activities that should be supported under the Team Performance program. The set comprises 26 distinct but interrelated research activities, which fall into the following eight broad areas:

1. Provide policy recommendations that will maximize the impact of the team performance research (Sections 5.1.1–5.1.4).
2. Develop task specifications and models (Section 5.2).
3. Develop facilities for task simulation and experimentation (Sections 5.3.1–5.3.3).
4. Develop improved performance models and evaluation metrics (Sections 5.4.1–5.4.4).
5. Investigate the effects of team synergy and personnel turnover (Sections 5.5.1–5.5.2).
6. Improve the organization of teams (Sections 5.6.1–5.6.3).
7. Improve the training of teams and team members (Sections 5.7.1–5.7.6).
8. Improve man-machine systems for task performance (Sections 5.8.1–5.8.3).

In each of these areas, we suggest several promising topics for research. For each activity, we describe the problem that motivates our recommendation and the important issues to be addressed.

5.1. POLICY ASSESSMENTS OF NAVY NEEDS

To assess the potential impact of basic research, ONR must undertake a set of policy studies to identify (1) those issues related to team effectiveness that are likely to remain critical over 15 years of strategic and technological change and (2) those approaches to team improvement that, if successful, have some likelihood of being adopted in the operating environment. We recommend four specific projects below.

5.1.1. Navy Teams of the Future[1]

A research program on team training and performance should support long-term Navy requirements in three ways:

1. By determining the types of team activities and functions that will be required to operate threat-evaluation and decisionmaking systems projected for procurement over the next two decades.
2. By directing research toward these anticipated team functions and activities.
3. By providing guidance, based on results of program research, early enough that adequate team training and evaluation capabilities and hu-

[1] Written by Milton Weiner.

man-factors design principles can be incorporated into the design of new equipment.

This proposed effort would focus on the first two items: defining the team functions and activities needed to support advanced systems, and identifying research program requirements to produce relevant results. There are a number of sources of data on anticipated Navy needs for personnel and for particular skills, as well as sources that categorize naval personnel functions and activities, e.g., the Navy Manpower Mobilization System (NAMMOS). Other sources of Navy data on longer-range planning needs for manpower and skills for new systems would also contribute to the investigation of future Navy teams. Procurement decisions may have already generated requirements for team skills several years into the future, but there is no documentation or longer-term projection of anticipated needs for different types of teams or for the skills associated with these teams. Such a projection could assist in determining the types of team activities and functions for which research would have the greatest utility and it could be used to establish policy guidelines for the research program in terms of (1) what team functions or activities seem critical, (2) which research questions have highest priority, (3) what research strategy is indicated, and (4) how the research results are to be used.

This effort would require no more than a 9- to 12-month study by two or three analysts, since a great deal of data may already be available. The major effort would focus on the development of the research guidelines implied by these data. Such a study would assure that the research program is compatible with, and perhaps could contribute to, the design and operation of advanced systems.

5.1.2. Organizational Factors in Introducing Innovation[2]

The frequent rotation of operational command personnel produces disincentives to undertake time- and resource-consuming programs of innovation. Such resistance may discourage the development of more effective technologies for training or the adoption of current technologies. The Task Force on Training Technology recommended in 1976 that the DoD must change management policies to provide greater incentives for the development and adoption of training technologies (Defense Science Board, 1976). In line with this recommendation, the research program should include studies focused on understanding and improving the adoption process. The two principal activities of these studies are described below.

1. *Understanding the Adoption Process.* Several factors inhibit the adoption of new technologies and methods for tactical decisionmaking teams. Since it is difficult to define precisely the activities of such teams, it may not be clear what innovations are necessary or how they should be evaluated (Kaplan and Barber, 1979). Even when requirements for team performance can be established, innovation may be too technically demanding, costly, or inconvenient (Hall and Rizzo, 1975). Finally, the receiving organization may resist some innovations because it fears that they will result in other, unwanted changes. For example, a training unit may be reluctant to urge operating organizations to evaluate the adequacy of its graduates because resulting criticisms may dictate changes in training procedures.

[2] Written by Polly Carpenter-Huffman, with the assistance of Theodore Donaldson, Perry Thorndyke, Milton Weiner, and Keith Wescourt.

Resistance to change is especially strong where tradition is highly valued for its own sake—and some Navy units may be strongly bound by tradition.

Problems of transferring successful research results to operating environments have been studied extensively in several contexts, including education (Carpenter-Huffman, Hall, and Sumner, 1974; Carlson, 1975) and manufacturing (Mansfield, 1961). Using a multivariate analysis of Teacher Corps programs, Corwin (1973) derived a profile of a "social system likely to be highly responsive to deliberate efforts to change it." A number of characteristics of this profile, including as centralization of authority and a clear-cut division of labor, apply to the Navy. Finally, Berman and McLaughlin (1978) proposed that successful innovation in education requires a process of mutual adaptation in which both the innovator and the recipient of the innovation are active partners.

Similar research should investigate these issues in the Navy organization, possibly combining the case study and multivariate analytical approaches adopted by previous analysts. If successful, this work will reinforce the entire research program by articulating constraints on and methods for translating research into improvements in Navy operations.

2. *Establishing the Value of Innovation.* Since innovation can be costly in itself and can levy additional costs on the units that adopt it, a second research effort should develop methodologies for establishing the costs and benefits to the Navy of any proposed innovation. These include procurement and implementation costs, organization disruption, and increments in resulting operating performance. Recent studies of this nature conducted for the Air Force have produced conclusive assessments of alternative training courses for electronic and avionics equipment repairmen (Air Training Command, 1968, 1970; Carpenter-Huffman and Rostker, 1976).

Additional research to develop methodologies for establishing the value of innovations could begin with small-scale demonstrations in the operating environment. Their results could then be used to help determine the Navy-wide applicability of the innovation and its overall cost and value.

The first step will be to choose a promising innovation whose effects may be demonstrated in the near future. Likely candidates include (1) improved feedback in team training and shipboard exercising, (2) improved matching of training in individual skills to team operating requirements, and (3) computer-directed individual drill and practice for potential team members.

Demonstrations of this kind may require a year or more to design, implement, and evaluate. The design phase is the most crucial because it must ensure that the obtained data will permit assessment of the cost of the innovation and its value in operating units. Much of this work should probably be conducted by Navy operations and research personnel, with contractor assistance, in existing Navy facilities.

It will probably not be difficult to demonstrate positive value for the innovation chosen for study. However, development of generalized methodologies for establishing value will be more demanding. Nevertheless, the potential payoff of this study is sufficiently high to warrant the risk of failure.

5.1.3. Current Technologies for Improving Navy Teams[3]

During the past decade, several advances have created opportunities to improve training, most notably the development of systematic techniques to (1) improve feedback to the performer during training and exercising, (2) improve the match between training and requirements for job performance, and (3) improve training through the expanded use of computer-based techniques. The Services, however, have not adopted these advances widely. Therefore, new studies should develop plans and specific methods for introducing the following improvements into operational environments.

1. *Improved Feedback.* As discussed in Section 5.7.6, previous experimental research has established several principles governing the relationship between feedback and performance. Currently, feedback in Navy team training does not adhere to these principles; it is generally haphazard and subjective, varying across team roles, instructors, and training installations (Hall and Rizzo, 1975). With little additional cost or research, it may be possible to improve and systematize feedback in such training situations.

2. *Improved Match Between Training and Job Requirements.* Hall and Rizzo (1975), among others, have pointed out the frequent discrepancies between the content of training and the requirements for job performance. Failure to provide adequate training places added burdens on operating units and can ultimately degrade combat capability.

A systematic procedure, Instructional System Development (ISD), has been developed to deal with the problem, and the Navy has recently established Instructional Program Development Centers to facilitate application of ISD (Vineberg and Joyner, 1980). These centers are attempting to document the skills required for every Navy job rating, but they are currently staffed primarily by training personnel rather than persons with direct experience in team operation.

Studies in this area should focus on strengthening participation of operational personnel in the ISD process. Policy analysts and management specialists should test the efficacy of different approaches to improving cooperation between trainers and operators, ranging from workshops to formal organizational structures. Vehicles for these tests will arise in the normal course of revision of training for selected teams. Researchers could observe the efficacy of a variety of approaches and procedures to select the most promising for implementation.

3. *Application of Existing Computer-Based Techniques.* Two techniques in computer-based instruction could immediately improve team training: drill-and-practice and simulation. (It is not clear that "frame-type" CAI, a third technique now available on many commercial systems, is more effective than conventional programmed texts.)

Drill and Practice. Effective training requires that team members master the factual knowledge required to perform their individual jobs. Adaptive systems for drill-and-practice based on psychological learning theory train learners faster than non-adaptive drill-and-practice systems, result in better long-term retention of knowledge, and enable the instructor to monitor the learners' progress. For some knowledge domains, drill-and-practice can be embedded in games to motivate the

[3] Written by Polly Carpenter-Huffman, with the assistance of Theodore Donaldson, Milton Weiner, and Keith Wescourt.

learner and thus further reduce training time. Team jobs that require memorizing a substantial body of *simple factual relationships* will probably benefit most from this technology.

The Navy Personnel Research and Development Center in San Diego is developing an experimental prototype drill-and-practice system for teaching tactical action officers the characteristics of enemy platforms. Other drill-and-practice systems could be implemented on inexpensive, personal microcomputers, placed at several locations within a training site.

Simulations for Team Practice. Some teams have inadequate opportunities for hands-on practice of routine procedures or have no chance to practice emergency procedures, particularly when the procedures are expensive or dangerous. This problem could be alleviated by combining operational systems and general-purpose digital computers to create the relevant features of the task environment and provide functional simulations.

Simulations have several advantages over operational exercises. They permit creation of situations that are difficult to arrange in the real world, such as emergencies. They allow systematic manipulation of the team functions to enhance trainee perception of critical task features. And they can store performance protocols in the computer for replay during debriefing and critique. Simulations have been used successfully in a number of task domains. The Navy Training Equipment Center at Orlando is developing prototype simulators that rely more heavily on general-purpose computers and input/output (I/O) devices (e.g., graphics) for teaching than have previous simulators. In addition, the Navy Air Traffic Control School at Memphis Naval Air Station trains carrier air traffic control teams using computer-based systems and operational radar displays. The Army Research Institute at Alexandria is developing experimental prototype low-fidelity, functional simulations to teach a range of individual skills. Finally, the Air Force is developing simulators for training maintenance technicians.

More extensive use of simulations could improve training in other domains as well. Past development of simulations for training seems to have proceeded most effectively where computer technology is an accepted part of the operational environment, as in aviation and air traffic control. Expanded application of this technology will require a commitment to computer-based training and a systematic effort to identify individual and team tasks for which such techniques can be used.

5.1.4. Causes and Effects of Personnel Turnover in Navy Teams[4]

Fluctuations in team membership may result from personnel rotation, attrition, illness, rotation of personnel on watch stations, and so on. Turnover in the Navy may well be both a cause and a consequence of low team performance and morale. Organizational studies of turnover and its consequences are needed to determine (1) the impact of turnover on morale and performance, (2) the additional training requirements and costs introduced by turnover, (3) the principal sources and causes of turnover, (4) the feasibility of altering policies producing turnover, and (5) implementable policies and techniques for reducing turnover or its effects.

While a few organizational studies have investigated attrition among military

[4] Written by Shelley Taylor, with the assistance of Polly Carpenter-Huffman, R. Stockton Gaines, Gary Martins, and Perry Thorndyke.

personnel (see review by Hand, Griffeth, and Mobley, 1977) little previous research has attempted such a broad approach to the study of turnover. Experimental studies of teams rarely track performance over time or in cases in which team composition changes. Thus, several new policy studies could be valuable in assessing the influences of turnover on team performance. These studies are outlined below.

1. *Sources of Turnover.* One line of research might investigate the principal sources of turnover and the typical timing of personnel replacements. Is turnover due primarily to personnel rotation and attrition? If so, how much lead time is available to prepare for team member departure? Does most turnover, permanent (attrition, rotation) and temporary (illness), occur while ships are deployed at sea or while stationed in port? The

answers to these questions may suggest methods for better anticipating and compensating for personnel turnover.

2. *Reduction of Turnover.* Another line of research might investigate the extent to which turnover can be reduced. This would require (1) a study of why personnel choose to leave the Navy, and (2) fieldwork to determine the principal sources of dissatisfaction among Navy personnel, how turnover is viewed within the Navy, and what incentives would reduce turnover. Research could assess the effects of the Navy's personnel rotation policy on its team operations and the feasibility of alternative personnel management policies. The consequences of such alternatives for training, team member satisfaction, and overall performance could then be examined.

For example, individuals might be organized into teams fairly early in their duty cycle and then trained, assigned, and housed thereafter as a team. In the event of personnel losses from this team, the entire unit might then be replaced by another similarly trained team. The original team would then receive and integrate new members during a retraining cycle. Where full replacement of the team is not practical, two options remain. A team with only slightly diminished membership could continue to perform short-handed. Since teams would presumably be trained to operate under such circumstances, their performance might be quite good, even if not comparable to that of a well-trained team operating at full capacity. On the other hand, when the membership of the team has been drastically reduced, new assignments could be made as is done today. Such a scheme is only illustrative of the types of alternative policies that might be considered.

3. *Reduction of the Impact of Turnover.* Research should also investigate methods for compensating for the adverse effects of turnover within existing organizational constraints. For example, it may be useful for departing team members to overlap with replacement members to facilitate indoctrination and socialization, or to provide informal training. Section 5.5.2 proposes basic research to examine the efficacy of other compensatory measures. In addition, organizational studies should examine the feasibility and costs of introducing these new procedures into Navy operations. It may also be instructive to identify teams whose performance is not degraded by turnover, in order to determine task characteristics that govern vulnerability to turnover. This might suggest techniques for structuring teams to reduce the negative effects of personnel turnover.

Since turnover is a problem that affects all Navy teams, this research should have a high payoff and wide applicability. It would entail lengthy observation of several different teams undergoing personnel change, studies of organizational policies, and the widespread collection of survey data, and close contact with various Navy personnel and installations would be required. The project staff would have to provide expertise in policy analysis, military operations, social and organizational psychology, and survey research.

5.2. DEVELOPMENT OF A TASK SPECIFICATION FOR TACTICAL DECISIONMAKING[5]

The military Services use many information-processing, decisionmaking teams, comprising many individuals, many diverse and difficult functions, and various types of equipment. In operational environments, the scope of a team is not clearly defined but may vary depending upon the desired degree of functional aggregation. For example, an ASW team comprises the ship's TAO, the anti-submarine air controller (ASAC), the UBP for weapons deployment, several sonar operators and plotters, helicopter crews, and ASW air crews. Similar teams of individuals monitor and control surface warfare and anti-air warfare (AAW). However, the CIC "team" contains individuals from each of these other teams, as well as the AIC and the ship's weapons coordinator (SWC). Thus the partitioning of these individuals into particular teams is somewhat arbitrary.

To identify a critical team or teams for study, research should investigate a variety of teams, perhaps across Services, to assess the similarities and differences among them. This study should produce several results, including:

1. The selection and definition of a domain to be investigated in depth by subsequent research efforts. The selected domain may be either a particular real military team, two or more teams that are highly similar in function and resources, or an artificial team or "game" that closely resembles one or more actual teams.
2. The documentation of the functional specifications and information-processing characteristics of the task and task equipment for use in designing laboratory facilities and subsequent team research. This will require the specification of the inputs (sensor data, environmental conditions, enemy actions, action outcomes, messages) and outputs (console operations, plans, decisions, weapons and equipment deployment, messages) for each team member's task.
3. The characterization of typical scenarios for team performance.
4. The documentation of relevant Navy resources (e.g., trainers, simulators, software, task and/or training experts) that are potentially available and/or training experts) for use the study of the selected team(s).

This work should be undertaken as the first activity of contractors in the research program. Adequate analysis and documentation of such tasks and facilities will require expertise in military operations, engineering, computer science, and cognitive psychology.

[5] Written by Perry Thorndyke.

5.3. DEVELOPMENT OF FACILITIES FOR TASK SIMULATION AND EXPERIMENTATION

Research on the training and performance of decisionmaking teams will require laboratory facilities for the observation of these teams under controlled conditions. Several problems must be addressed in the development of research facilities to support realistic task simulations. This section addresses the major tasks required for that development.

5.3.1. Environmental Simulations for Mock Operational Equipment[6]

The use of simulator-driven exercises would improve much current Navy training and team performance. Training simulators embody two components: an environmental simulator and mock operational equipment. The simulator provides a source of data and stimuli for the decisionmakers and then reacts to their actions in a manner that mimics the actual combat environment. The mock operational equipment permits sensory-motor inputs and outputs similar to those encountered in actual operations. Ordinarily, simulators are designed exclusively for use with special training equipment, but we see an opportunity to separate them so that the simulators can support continuing learning in operational environments. These environmental simulators could then support laboratory studies of team performance.

For many reasons, it would be advantageous for simulated training experience to be distributed more widely than current practices permit. For example, to increase vigilance, motivation, and skills, individual operators of operational equipment could train or practice on the job with simulated team problems during idle or low-stress periods. This would require operational equipment that could accept simulated events or could execute such simulations itself.

Some specific topics for research supporting these objectives follow.

1. *Design of a Hardware/Software Configuration for Laboratory Simulations.* Initial work should focus on the development of experimental facilities for task simulation. Each contractor should choose an advanced set of hardware and software capabilities that can (1) support the environmental simulation tasks of laboratory exercises, (2) provide a basis for simulation archiving and sharing, and (3) exploit favorable economic and computer-science trends in system architecture and languages. These trends favor high-level languages for software implementation (e.g. SIMULA, SMALLTALK, DIRECTOR), large address-space computer mainframes (at least 24-bits), interactive file systems (as in TENEX or UNIX), closely coupled interactive graphics for debugging and monitoring simulations, and local networking to allow environmental simulations and operational equipment emulators to execute on different machines.

2. *Representation of the Environment.* Research should develop models of the peacetime and combat environments of the decisionmaking team under study, using a simulated source of inputs and reactions. This simulation should provide for incremental development and, if possible, variable execution speeds in exchange for variable precision and fidelity. Emulators for operational equipment

[6] Written by Frederick Hayes-Roth, with the assistance of Perry Thorndyke and Milton Weiner.

should also be developed that reflect the principal information processing functions of future equipment (e.g., storage, display, and analysis of intelligence reports and sensor data). Detailed physical characteristics of the equipment emulators, such as function keys, specific visual displays, and keyboard layouts, are less critical and may be ignored for the present.

Most simulators model the uncertainty of the real world poorly. Because teams will be trained to perform against an artificial environment, the simulation should incorporate appropriate kinds of variability and should possess the capability to generate surprising events (i.e., highly unlikely but not impossible situations) spontaneously. These efforts should be coordinated with those addressing the problem of scenario generation described in Section 5.3.2.

3. *Coordination of Multiple Data Sources for Scenario Control.* When a team participates in an exercise, the systems must coordinate and control the simulated scenario and the timings of remote events. Simulations must incorporate a control structure for such multi-event team exercises. The inherent limitations of distributed simulations and exercises (e.g., bandwidth, synchrony, validity) should therefore also be assessed.

4. *Linking of Simulators with Operational Equipment.* Research should investigate a suitable technology to embed simulators directly within operational equipment (such as operator consoles) or a methodology for coupling modularized simulations and operational equipment. Later, a method for standalone training or combined operational/simulated tasks should be developed. Finally, research should develop methods for exploiting the resident simulator as part of a built-in test (BIT) system. The BIT system in each operational equipment unit would continuously contrast simulator-produced data with actual operational I/O to monitor the equipment's behavior and to promote the early detection of unexpected situations.

This research requires modern computing hardware and advanced programming languages. It requires the collaboration of individuals with expertise in the task environments, characteristics of the operational equipment, interactive systems, simulation languages, distributed computing, and computer-controlled multiperson gaming.

This research will help to provide the basis for a team research laboratory, and it could also lead to a much-needed new generation of systems in the Navy (and elsewhere). Such systems could be used either for operational requirements or for simulator-driven on-the-job training. Moreover, improved team training simulations would provide increased access to realistic, challenging, and unpredictable scenarios.

5.3.2. Simulation and Gaming Scenario Development[7]

The simulation of the task environment emphasizes representing that environment in a manner that permits flexible world modeling (e.g., incremental development, variable executive speeds, the introduction of uncertainty and surprise). These qualities ultimately reflect "scenarios," sequences of conditions and events that might occur in combat situations. Because of the almost infinite variety of potential combat scenarios, new research must develop scenarios that are

[7] Written by Milton Weiner.

1. Appropriate (provide useful training on the variety of team tasks),
2. Adequate (challenge the trainees),
3. Realistic (resemble potential combat situations), and
4. Flexible (cover a variety of situations, including surprising and unlikely events).

Virtually every large-scale combat simulation or war game requires considerable preparation of the input events in order to create the task environment. However, there is little sound *theoretical* basis for determining which scenarios will provide effective training. Generally, the emphasis has been on "realism," but the relationship of particular scenarios to training objectives or outcomes is seldom explicit. That is, there is seldom an "experimental design" for the scenario or the simulated events derived from it. Thus it is difficult to relate the results of the simulation (the dependent variables) to the scenario inputs (the independent variables). New research in this area should include a number of tasks:

1. Review of current Navy training simulations to determine the relationships among scenario inputs, training outputs/performance evaluations, and training objectives; these data would be used to construct a preliminary model of these relationships and to assess scenario appropriateness, adequacy, realism, and flexibility.
2. Identification of scenario attributes that are useful in a variety of team experiments and training situations.
3. Testing of scenario attributes in training experiments under the hypothesis that team performance can be predictably improved by efficient scenario control (see Section 5.7.5).
4. Development of computer capabilities for flexible scenario generation according to the team training and experimentation objectives of the research center and the derived principles of scenario utility.

Some of these tasks are likely to form a part of any research using simulation or gaming techniques. But they also represent an attempt to understand the relationship of stimulus material to resulting learning. A machine-based flexible scenario generator would reduce training costs while enhancing training capabilities. The resource requirements for the research are similar to those required for simulating the task environment, but they place greater emphasis on training and experimental-design specialists.

5.3.3. Capabilities for Distributed Exercises[8]

Decisionmaking teams are typically spatially distributed. While the spatial distribution generates requirements for communication, cooperation, and coordination of decisions and actions, these requirements are poorly understood, as demonstrated by the limitations of the Naval Tactical Data System (NTDS), currently the best system supporting distributed decisionmaking. The distribution of team members or subteams makes it generally difficult and expensive to run training exercises, particularly when the exercises include trainees both in land-based

[8] Written by Frederick Hayes-Roth.

simulators and on ships at sea. Thus, there is a need to develop training capabilities that can support distributed exercises.

Significant technology-based advances toward distributed computing, teleconferencing, and group decisionmaking have recently been mediated by various kinds of communication links and conferencing protocols (see review by Scher, 1977). Research sponsored jointly by ARPA and the Navy through the Advanced Command Architecture Testbed (ACCAT) program has, for example, developed graphics teleconferencing, satellite message-handling and data-processing systems—all connected over a secure packet-switched network. However, only a few distributed military exercises have been conducted, and these have not exploited or encouraged the technologies required for improved training or cooperative task performance.

Plans have recently been developed within the Navy to provide some of the tools required for distributed exercises and training. In particular, the Naval Ocean Systems Center in San Diego is developing a Warfare Environmental Simulator (WES) running on a Digital Equipment Corporation (DEC) VAX 11/780 to be placed aboard all carriers. WES provides simulation capabilities for naval engagement exercises and can be expected to support training activities on-board each carrier, if not between two or more carrier task forces.

In addition to a standalone simulator and training system, distributed exercises require facilities to coordinate scenarios involving multiple agents (command-control or force elements) on multiple computers. This requires communications, synchronization, and responsive simulators.

Two major approaches to distributed exercises seem promising. In both approaches, a distributed set of team members or teams participate simultaneously. In one case, all of the participants are humans; in the other case, some of the participants are replaced by computer-based simulations. The primary difference between the two is that simulated team members can reduce some of the problems of synchronization and feedback that arise in all-human exercises.

Existing nets and teleconferencing systems should provide suitable communications media for the research. However, new research must explore cooperative problem-solving techniques using these media. The questions to be addressed include the following: How can distributed problem-solvers divide and conquer shared tasks? How can they minimize communications and response times? How can they manage dynamically changing and locally dissimilar situation assessments? New software aids to support these functions will be required.

Providing simulated training problems to distributed elements will create bandwidth and synchronization problems. If, for example, two carrier task forces are to receive sensor reports that originate simultaneously from one simulated engagement, several problems arise. These will probably require some advances in simulation technology to provide a basis for distributing simulators themselves, so that the overall scenario can be controlled from one processor which in turn synchronizes two local subsimulators at distributed sites. The local subsimulators would then translate the high-level commands of the central simulator into the detailed events that trigger sensor reports and local situation displays. This architecture would avoid the problem of excessive data-communication requirements by moving most of the detailed computing to local processors. Similar multilevel architectures had to be developed for the simpler problem of network graphics communication in the ACCAT program. The present problem will require research on the best way to create multilevel scenario and environment simulators that support distributed computing.

This effort will require simulation software, networked computers, graphics, and teleconferencing software. Cognitive psychologists, computer scientists, and *military personnel familiar with the distributed exercise will be needed to carry out* the proposed research.

5.4. DEVELOPMENT OF IMPROVED PERFORMANCE MODELS AND EVALUATION METRICS

The development of techniques to improve team performance requires an understanding of team functions and techniques for measuring team behavior. This section describes projects aimed at the modeling and evaluation of team performance.

5.4.1. Cognitive Models of Individual Performance[9]

A first step in modeling the performance of teams must be the detailed analysis of the cognitive processes required to perform the tasks of individual team members, e.g., enumeration and characterization of the various kinds of information received by an air intercept controller (AIC) in a CIC. A performance model of the AIC would specify the recognition, classification, transformation, storage, and decision processes he uses to handle enemy air threats. This cognitive modeling approach has proven effective in studies of individual behavior in various problem domains (e.g., Bhaskar and Simon, 1977; Brown and Burton, 1978; Card, Moran, and Newell, 1980; Collins, Brown, and Larkin, 1977; Greeno, 1978; Hayes-Roth and Hayes-Roth, 1979; Newell and Simon, 1972; Resnick, 1976). Thus, an established research technology can be applied to this aspect of team performance.

A well-developed cognitive model would provide a basis for subsequent research on the training and composition of effective teams. Possible applications include (1) selection of individuals and assignment to particular team roles based on their performance of specific information-processing functions; (2) training individuals in the component information-processing functions they will be required to perform (see Section 5.7.1.); (3) diagnosis of faulty information-processing components underlying suboptimal team performance (see Sections 5.4.3, 5.5.1, and 5.6.2); (4) provision of informative feedback to individual team members (see Section 5.7.6); and (5) designing computer-based aids to performance (see Sections 5.8.1 and 5.8.2).

While modeling task performance of team members can utilize many of the methods of earlier studies, it will also require an important conceptual modification. Because the earlier studies focused exclusively on individual performance, they considered only information-processing functions performed by individuals in isolation. In the case of teams, however, interactions among team members constitute a large part of the task. Thus, comprehensive task analyses must also describe information-processing functions that mediate interpersonal communications.

[9] Written by Barbara Hayes-Roth, with the assistance of Shelley Taylor.

Some existing analytic techniques (e.g., Bales, 1950) may be adaptable for studying these coordination and communication functions.

This modeling effort is a low-risk undertaking, since it is largely a new application of existing methodologies. At the same time, it is extremely important, because the results will provide a theoretical basis for many of the other research issues.

5.4.2. Team Members' Mental Models for Task Performance[10]

Many cognitive researchers have emphasized the importance of mental models in problem solving (Brown and Burton, 1975; Stevens and Collins, 1978; Chi and Glaser, 1979; Hayes-Roth, 1980; Larkin, 1979; Schank and Abelson, 1977; Simon and Simon, 1978). A mental model is the problem-solver's internal representation of the problem at hand. It comprises explicit or implicit assumptions regarding the various objects in the problem, the behaviors of these objects, and the interactions among them. Mental models frequently instantiate these objects and behaviors by analogy to some known physical or symbolic system. (For example, one may understand electricity by analogy to a hydraulic flow model.) The model may also entail assumptions about the details of the goal and about knowledge and strategies that would be useful in achieving the goal. Mental models are important because they determine the problem-solver's approach to the problem. This, in turn, determines the ease with which he finds a solution and the quality of the solution.

The concept of mental models relates to team performance in two ways. First, mental models influence the problem-solving performance of individual team members. Team members may perform better if they understand how their task relates to the other members with whom they interact as well as to overall mission goals. Second, the relationships among mental models held by various team members may influence their performance as a team. For example, if team members share the same mental model, this might facilitate overall decisionmaking—they would work under the same assumptions, would have shared expectations about the responsibilities and procedures of various members, and would use similar decision strategies. Their shared conceptualization should facilitate communication, coordination of decisionmaking activities, and cooperation in solving particular subproblems. On the other hand, sharing the same mental model might inhibit team performance if team members became "locked" into an unproductive approach to a problem.

It is also possible that having different mental models might facilitate other aspects of performance. For example, by trying alternative decision strategies entailed by the different mental models of various team members, the team might benefit from synergistic interactions between the products of two or more approaches. Effective exploitation of alternative mental models probably would require an awareness of the characteristics of different models and intelligent decisions about how to coordinate them.

Given this analysis, new research should address the following questions:

1. How can the mental models of team members on information-processing decisionmaking teams be represented? One approach, suggested by Col-

[10] Written by Barbara Hayes-Roth, with the assistance of Alain Lewis.

lins (1980), would model the goal hierarchies of various team members. Alternatively, models might reflect emphases on procedures or information flow rather than on goals.

2. How do team members' mental models differ?
3. What are the advantages and disadvantages of specific mental models?
4. What are the performance consequences of team members using the same or different mental models?
5. How do particular combinations of models interact?

The proposed work would constitute basic research in a relatively unexplored area. As such, it must be considered somewhat risky. If successful, however, the research would have a high payoff, since decisionmaking teams currently work with ill-structured problems, poorly specified problem-solving methods, and loosely defined SOPs.

5.4.3. Investigation of the Relationship between Individual and Team Performance[11]

The necessity for a research program on team training, in addition to individual training, rests on the assumption that team behavior represents more than aggregated individual behavior. Informal simulation experiments have demonstrated that team decisionmaking performance can continue to change after individual member performance has stabilized (Weiner, 1960). However, the relationship between individual and team performance must be systematically investigated to determine the appropriateness and utility of team studies.

New research in this area should address three related issues: (1) the relationship between a team's effectiveness and that of its members, (2) the influence of the leader's skills and behavior on overall performance, and (3) the extent to which training should focus on entire teams (i.e., communication and coordination skills) or on individual members (i.e., individual operator skills).

Two observations should guide the design of experimental studies in this area. First, there is not a strict dichotomy between team and individual training; and second, observations of individual and team performance should be made in the team's working environment or a simulation of that environment. Whether it does so implicitly or explicitly, individual training for later team membership must assume a task structure and, more generally, the team's working environment. Effective transfer of individual training may depend on accurate simulation of the team environment. Moreover, team and individual training may be combined. Individual training of basic, elemental skills may precede team training of communication skills and behavior in unusual situations, which often takes place in shipboard exercises.

Four aspects of the research in this area deserve special attention:

1. *Measurement of Individual and Team Performance.* Two factors interfere with the straightforward assessment of the performance of information-processing decisionmaking teams. First, "true" performance occurs only during actual battle, and thus little data are available from which to assess effectiveness. Second, team performance may be assessed either for its *efficiency* or for its *ffectiveness*. Efficiency

[11] Written by Mark Menchik, with the assistance of Barbara Hayes-Roth, Frederick Hayes-Roth, and Perry Thorndyke.

refers to easily obtained measurements of the process characteristics of team performance, including detection errors, plotting errors, response time to threats, and accuracy of weapons targeting. Effectiveness refers to the ability of the team to achieve the mission objectives, which typically require the team to defuse the enemy threat with minimal loss to its own resources and within the constraints specified by the battle group commander. Thus, performance of both individuals and teams can be measured in a variety of ways and at different levels of abstraction. While team efficiency bears some relationship to effectiveness, this relationship is in practice simply assumed, but in fact it is rarely known. Research will be required to understand this relationship, to devise techniques for aggregating individual performance, and for directly contrasting it with measures of team performance.

Currently available measures of performance in operational training are based on subjective ratings by instructors. Such ratings, however, are prone to various types of systematic and random error (Landy and Farr, 1980). Thus, new, objective performance measures must be developed based on analyses of the task requirements (see Section 5.4.1).

2. *Determination of Individual Contributions to Team Performance.* Research must improve methods for determining how an individual's actions affect overall outcomes in team performance. so that the criticality of the various individual roles can be assessed. One approach to this problem would be to interpret overall outcomes in terms of causal precursor events and then attribute responsibility to appropriate actors. To assist in this analysis, some evaluation should be made of alternative courses of action that were open and what their effects would have been.

3. *Analysis of Task Independence, Concreteness, and Segmentation.* The relationship between the performance of team members and the overall performance of the team may well depend on attributes of the task. Concrete (e.g., requiring motor rather than cognitive skills) or segmented (i.e., separated in time or space) team performance may be simply related to individual performances. In this case, individual training should be sufficient to produce good performance. However, these cass fail to obtain when individual tasks are complex or ill-defined, when coordination among team members' activities is essential, or when the organization of tasks and communications within the team is flexible. In such cases, team performance depends heavily on intrateam interaction and leadership, and team training should especially improve performance.

4. *Analysis of Environmental Predictability and Control.* The relative importance of individual and team skills may also be governed by the predictability of the operating environment. The more the training environment (including enemy weapons and actions, the reliability of equipment and resources, and the behaviors of other team members) resembles the conditions experienced during training exercises, the more team performance may simply relate to individual performances. However, in unpredictable environments (and especially in combat situations that cannot be handled successfully by the team's weapons and SOPs), team performance may depend more heavily on team coordination skills and effective leadership. In such situations, teams cannot successfully follow SOPs. Team members must not only change behaviors, they must coordinate the new behaviors. Effective leadership, experience as a team, and good working relations among team

members (perhaps brought about by team training) should speed adaptation to the new environment and therefore improve performance.

This research is central to the interests of a Team Performance Research Center, since it focuses on the determination of team training requirements. The proposed studies will require the use of a team performance laboratory to provide training, to provide problems on which performance can be measured, and to record performance measures. Expertise will be required in measurement, experimental methodology, instruction, and military simulation and gaming.

5.4.4. Theories of Team Performance[12]

Simply stated, there is no adequate theory of team performance. Such a theory should describe the major factors affecting team performance and should enable interpretation or prediction of the effects of interventions in the team training and performance process.

Many variables and processes interact in determining the performance of a team. These include individual and team morale, retention rates, individual skills, individual and team incentives, individual and team objectives, experience levels, homogeneity or variability of personnel backgrounds, and task difficulty. The development of a theoretical framework requires formulating the key concepts, hypothesizing the causal relations among them, and empirically testing predicted relationships. With a theory in hand, one should be able to identify the crucial factors for Navy intervention. Without such a theory, as is currently the case, one can only guess about the relative impact of alternative programmatic plans.

Prior research on teams in other domains may provide a source of initial ideas for this research. Studies of sports teams and industrial groups have produced informal theories of the influence of training, feedback on performance, motivation, etc. Much previous experimental research on team performance has abstracted tasks from real operating environments to observe how theoretically derived variables influence team behavior (e.g., Steiner, 1972; Ofshe, 1973; Meister, 1976). Studies of this type typically manipulate variables such as stimulus inputs and reinforcement schedules, performance sequencing, team size, and other factors that derive from theories of learning or group behavior. However, how the experimental measures of performance relate to actual team performance and team effectiveness is not known.

Research aimed at developing a theory of team performance should concentrate on two areas:

1. *Development of an Aggregate Theory of Team Performance.* Such a theory might take the form of a causal network expressing dependencies among social, organization, and cognitive variables. A similar approach has been adopted in work on job design for individuals (Hackman, Oldham, Janson, and Purdy, 1975; Barrett, Alexander, and Dambrot, 1979). A causal network for teams might, for example, relate *esprit de corps* and skill level to performance under stress, performance under varying stress conditions to job satisfaction, satisfaction and promotion policies to longevity on the team, and, recursively, longevity to *esprit de corps*. The initial framework should reflect the significant, plausible influences on team perfor-

[12] Written by Frederick Hayes-Roth, with the assistance of Theodore Donaldson and Perry Thorndyke.

mance. These might include, in addition to those cited above, person- and task-specific indices such as measures of the complexity, difficulty, and variability of job roles; personnel intelligence; on-the-job experience; and professional commitment. These initial hypothetical relationships would motivate empirical or experimental assessments, perhaps using covariate structures analysis or longitudinal experimental methods (see Hunt, 1980).

2. *Development of a Micro-Theory of Team Performance.* A micro-theory would elaborate team performance phenomena within the problem-solving framework of cognitive science. Such an analysis of team behavior would articulate the team's goals, its information-processing resources, the hypotheses it must generate and evaluate in the course of working toward its goals, its overall organization, and its control procedures (see Section 5.4.1). In addition, this viewpoint aims at building a theory in finer detail than an aggregate approach would permit.

Two particular problem-solving models seem promising for this approach. This first would model the team as a causal network with input-output dependencies between team members (e.g., between the producers of intermediate decisions and the subsequent consumers). The second would view a team as a loosely coupled collection of problem-solving specialists (see Section 5.6.2). This model raises questions about how decisions are communicated between specialists, how one's actions affect others' concurrent or subsequent responses, and the overall coordination of problem-solving efforts.

Given an initial structural framework, human or machine experiments could test hypotheses about performance determinants. Specifically, particular command structures, communications networks (Section 5.6.3), types of decisionmaking collaboration (Section 5.6.2), or task definitions (Section 5.6.1) of theoretical interest could be empirically tested by evaluating the performance of an experimental team having the appropriate characteristics. The team could consist of several humans following prescribed rules of behavior or, in a completely controlled test, the team could be composed of artificial (computer-based) team members following the same rules. Both types of experiments have been conducted previously in several task domains (e.g., Hayes-Roth and Wesson, 1978; CMU Computer Science Research Group, 1977). Another hypotheses-testing method might contrast the processes and performance of expert teams with those of novice teams. Such comparisons could be made either for real Navy teams or for teams formed and trained in the laboratory.

Such research would require expertise in military decisionmaking, manpower, training, social and cognitive psychology, and computer science, especially the area of cooperative problem-solving. Long-term studies of manpower and personnel data would require access to existing data bases and/or new longitudinal studies. Both human and machine experimental studies should be conducted using interactive computer-based simulation and communication facilities. Computer-based experimental studies could be performed best with a network of powerful midsize computers (e.g., Digital VAX 11/780, Xerox DORADO, or perhaps Three-Rivers PERQ) supporting artificial intelligence programming languages (e.g., LISP).

This research should be considered somewhat long-range, although early results might be obtained in the area of aggregate modeling from existing manpower data. The aggregate effort should, within a few years, influence policy decisions regarding team performance questions. For example, alternative rotation schemes might be found that simultaneously increased assignment durations, *esprit de* *corps*, retention, and individual and team performance. The micro-theoretical effort could, if successful, have a tremendous impact on management science, organizational design, cognitive science, systems engineering, and computer science. This impact would result from the ability to apply the performance theory to practical questions for which no engineering practices or guidelines exist.

5.5. INVESTIGATION OF TEAM SYNERGY AND TURNOVER

It is axiomatic that team performance changes over time and with practice. However, the development of cohesive and efficient teamwork is frequently disrupted by personnel turnover. One approach to improving team performance involves compensation for the disruptive effects of turnover. The following studies based on this approach should be included in the team performance research program.

5.5.1. The Dynamics of Team Evolution[13]

When a team first assembled, the members perform the activities of the team with a great deal of confusion and with rather poor results. With continued practice, however, the team may perform in a highly skilled manner. Little research has systematically investigated the dynamics of team performance evolution. Section 5.4.3 posits circumstances under which a team's performance is not simply predictable from the performance of individual team members. If this hypothesis is correct, the issue of how a collection of individuals evolves into an efficient organization is central to a team performance research program.

The concept of *team* learning, as opposed to an aggregation of the learning of individual team members, has received only limited research attention. The Systems Research Laboratory at The Rand Corporation, the Naval Research Laboratory, and a few other facilities pioneered interest in man-machine systems research, particularly for information-processing teams (Parsons, 1972). The Rand research efforts provided some of the initial conceptual formulations of team evolution or "system growth" (Weiner, 1960). This research identified the importance of having explicit team goals, of providing feedback on the results of team performance, and of allowing teams to change procedures, develop a special language, and alter rules to cope with increasingly difficult tasks. It also provided a framework for viewing team evolution as an interaction among three "environments": the task, the equipment, and the sociocultural environment of the team.

This framework provides a rich source of questions that merit further research:

1. What are the stages or phases through which a decisionmaking team evolves? Do teams always progress through the same stages? How do these stages correspond to the development of individual member skills?
2. What mechanisms or processes in the task, equipment, or sociocultural environments stimulate or underlie change?
3. How do teams modify their standard operating procedures (SOPs) and their decisionmaking processes over time and with practice? How do they

[13] Written by Milton Weiner, with the assistance of R. Stockton Gaines, Mark Menchik, and Shelley Taylor.

develop their own "shared language"? Do these modifications occur continuously or only at certain stages of evolution? Do team-specific SOPs and shared languages in fact increase team efficiency and ease intra-team communication? Do such team idiosyncrasies cause difficulties in communicating outside the team? Does the evolution of team-specific SOPs belie outsiders' understanding of team behavior?

4. How can these mechanisms or processes be incorporated into team training technologies or strategies? Are team members aware of and can they learn to control evolutionary changes?

Early studies of team evolution provided only limited data on these issues, most of which were derived from elaborate simulations of military installations such as Navy CICs and Air Force Air Defense Direction Centers. Simulation still appears to be an appropriate methodology for the research, since an important factor in team performance is the realistic portrayal of consequences of team actions. Thus, a simulation laboratory and the cooperative efforts of specialists in military gaming, computer simulation, graphics, experimental methodology, and protocol analysis will be required. If successful, this research can not only influence team performance, it can also lead to system and equipment designs that enhance overall operational effectiveness.

5.5.2. The Effects of Team Turnover on Performance[14]

The evolution of team performance is frequently disrupted by personnel turnover. While previous studies have investigated some of the factors influencing turnover (Porter and Steers, 1973) and the impact of turnover on system design (Meister, 1976), little or no research has explored the impact of turnover on team performance. Section 5.1.4 outlines proposed policy studies of the impact of turnover on Navy teams. In addition, new research should assess, in the experimental laboratory, the disruptive effects of turnover and the efficacy of various techniques for reducing this disruption.

The high degree of turnover in naval teams must result in considerable cost to overall performance. Team members must frequently learn new jobs and must learn to interact effectively with new teammates. Rapidly changing teams are unable to develop "empathetic models," or models of the goals, skills, and tasks of other team members (see Section 5.7.3). Moreover, they may not have time to evolve specialized interaction protocols or operating procedures, as described in Section 5.5.1. In short, excessive turnover may prevent teams from performing beyond the level predicted by the simple aggregation of individual behaviors. On the other hand, members of completely static teams may become overly dependent upon their particular teammates and the performance protocols and mental models they have developed together (see Section 5.4.2). When unanticipated situations arise, highly structured and integrated teams may be too inflexible.

One major thrust in this research area should be an exploration of the effects of replacing one or more team members during various stages of the team's evolution. Are the old members of the team able to compensate rapidly for the introduction of new members? A second focal area for research would be an investigation

[14] Written by Barbara Hayes-Roth, with the assistance of Milton Weiner.

of techniques for compensating for the disruptive effects of turnover. For example, members of stable teams might benefit from different types of training than are effective for turbulent teams. Members of stable teams might benefit most from training with their own team members (developing empathetic models, interaction protocols, and so on), while members of turbulent teams might benefit from training with a variety of other team personnel, where they would be given experience in cooperating well with a variety of individuals. These people might also benefit from specific training in social and functional adaptability.

Such studies of the costs and benefits of turnover require relatively long-term observation of team performance in the laboratory. Experimental studies manipulating two or three levels of turnover would probably be sufficient to observe significant effects. The research, if successful, will have two payoffs: (1) it will provide knowledge of the consequences of existing team composition policies, and (2) in conjunction with policy decisions about acceptable levels of personnel turnover, it will constrain the set of approaches that are likely to improve performance.

5.6. IMPROVEMENT OF TEAM ORGANIZATION

Most information-processing decisionmaking teams have relatively loose and flexible organizations. Thus, team performance might be improved through the determination of effective organization, communication, and decisionmaking structures.

Several such studies of team organization are described below.

5.6.1. Task Restructuring[15]

Complex information-processing systems are increasing rapidly both in number and in importance for military systems. A basic supposition is that information systems increase weapon effectiveness through increased data acquisition and precision. However, such complex systems also increase the processing demands on teams and the requirements for combining and evaluating knowledge. Thus, it is necessary to develop a methodology for determining task structures that will enhance the use and performance of these systems.

The allocation of operating tasks to team members in military systems is usually determined by system design and by operating procedures developed as part of the design process. Tasks are often allocated according to Service policies and organizational factors. For example, the most important decisionmaking in CICs is performed by members with the highest ranks. Allocation of tasks in terms of system design and institutional constraints may not lead to the most efficient utilization of team resources. Furthermore, the allocation of individuals to tasks within a team varies from ship to ship according to the desires of the commanding officer. Hence, research should consider methods for task structuring that could improve team performance.

The most basic issue regarding task allocation is the determination of the joint requirements for task performance and for information at various system levels.

[15] Written by Theodore Donaldson, with the assistance of Frederick Hayes-Roth, Alain Lewis, and Milton Weiner.

Task allocations are often based on broad policies that do not take into account their effect on system and team performance. For example, the policy to centralize command decisions in CICs results in most decisions being made at high levels, the flooding of information channels, the requirement for rapid and accurate aggregation of information, and delays in response time. Thus, even when low-level sensor data have high fidelity, system response may be poor as a result of failure to rapidly aggregate the data, assess the situation, make decisions, and execute responses. Research is needed to determine how to structure tasks requiring decisionmaking, plan execution, and information transmission to optimize team effectiveness. The success of previous attempts to influence team performance through manipulation of the task structure (e.g., Weiner, 1964; Lawrence and Lorsch, 1967; Shaw, 1971; Hayes-Roth and Wesson, 1978) indicates the promise of this approach.

Another issue is the influence of key personnel on decisionmaking teams without rigid procedures and strict task allocations. A recent Air Force assessment of operating Tactical Command and Control Systems found that actual task structures were often derived from the influence of a single resourceful and energetic person who controlled the system (or a large part of it), rather than from standardized procedures. Teams that depend heavily on particular individuals may degrade dramatically when these key people are lost or overloaded. New research would develop both methods for allocating tasks that exploit such resources effectively and methods for reallocating resources when key personnel are removed.

This research will require the use of laboratory simulations and experiments. While it could have some relatively short-range payoffs, it is most promising as a rather long range (over two years), sequential effort in which earlier studies provide design requirements for later ones.

5.6.2. Investigation of Alternative Decisionmaking Strategies[16]

In the past few years, cognitive scientists have developed team-like models of individual cognitive processing (Newell and Simon, 1972; Lenat, 1975; CMU Computer Science Research Group, 1977; Engelmore and Nii, 1977; Hayes-Roth and Hayes-Roth, 1979; Waterman and Hayes-Roth, 1978). These models assume that individuals possess many functionally independent cognitive "specialists," each of which has its own expertise which it can bring to bear on particular problems. Ordinarily, problem solution requires the combined performance of many such specialists.

The power of these models lies not only in the expertise of the individual specialists, but also in the "executive" strategies that organize their activities. For example, in their work on the Hearsay II speech-understanding system, the CMU group experimented with several different executive strategies. Eventually they decided that the optimal executive strategy for their task was to perform detailed analyses of the speech signal before generating hypotheses about higher-level, more abstract, syntactic or semantic interpretations. In studies of planning behavior, Hayes-Roth (1980) found that similar "bottom-up" strategies worked well for some problems, while "top-down" strategies worked better for others. Thus, individual performance appears to benefit from different strategies, depending upon the task and upon the characteristics of the specific problem at hand.

[16] Written by Barbara Hayes-Roth.

These team-like models of individual behavior provide a promising framework for studying the behavior of decisionmaking teams. The cognitive specialists correspond to the individual members of a team and the executive strategies correspond to the organization of the team's activities. Thus, new research might investigate the effects of executive strategies on team performance.

Extrapolating from the work on individual problem-solvers, one might expect alternative executive strategies to work well for different classes of problems and for specific problems within a class. For example, a top-down, hierarchical executive structure ought to work well for teams that deal with a single, well-structured problem, while a more decentralized, opportunistic, bottom-up approach should work well for teams that deal with ill-structured problems having many alternative actions (March, 1972; Hayes-Roth and Hayes-Roth, 1979; Hunt, 1980).

Given this interaction between problem and strategy, it may be necessary for teams to self-organize, adopting alternative executive strategies as they evolve (see Section 5.5.1). Reorganization might entail changes in individual roles and responsibilities as well as changes in the way individuals' activities are coordinated. Effective self-organization requires that one or more team members understand the relationships between problem characteristics and team organization. It also requires that team members be flexible enough to assume different roles and functions under different circumstances. This in turn may require that individual team members have mental models of task demands and expertise extending well beyond their ordinary responsibilities (see Section 5.4.2).

Another important aspect of team organization is the locus of decisionmaking responsibility. Prior research in social psychology indicates that decisions reached through group deliberation are more risky than those made by individuals (Ofshe, 1973). While some research has investigated the processes of group decisionmaking on real strategic defense problems (Janis, 1977), the case study methodology used in the research prevents the unconfounded comparison of alternative decision methods.

Given this analysis, new research should address the following questions concerning the procedures for organizing team decisionmaking:

1. What alternative executive strategies might be applied to decisionmaking tasks?
2. Are people equally adept at conforming to these strategies?
3. What impact does choice of strategy have on task performance?
4. Overall, which strategies are optimal for which classes of problems?
5. Can teams learn alternative executive strategies and adopt them appropriately for particular problems?
6. What characteristics identify individuals who can operate flexibly under alternative strategies?
7. What side-effects does training in flexibility produce (e.g., higher job satisfaction, better personal relations)?
8. Overall, what is the cost/benefit tradeoff between training flexible versus "fixed-configuration" teams?

These studies could easily be conducted in a simulated task environment by cognitive and social psychologists. The research has high potential payoff in terms of team efficiency and ability to operate under changing conditions. It could easily be conducted on a low-risk schedule, with the major body of research contingent upon promising outcomes for Questions 1 and 3.

5.6.3. Investigation of Alternative Communications Structures[17]

As pointed out in Section 5.6.1, communication is a critical problem in time-stressed team decisionmaking. Messages among cooperating decisionmakers vary in their time criticality, the reactions they demand, and the follow-ups they entail. Messages about most current and future events require time-indexing. Maintaining a coherent picture of the world at any point in time requires the combination and evaluation of time-synchronized messages. A crucial problem in team performance is that of identifying the kinds of information that must be communicated and then increasing the system's efficiency at handling that type of communication.

Most work on communications has been conducted in isolation. Advances in hardware have focused on bandwidths and protocols; advances in software have focused on message systems and teleconferencing; research on group problem-solving has measured the quantity of various types of speech acts within various group communication structures; work on natural language has focused primarily on the meaning of messages between participants. Communications research in the domain of team performance must relate the nature of the decision task to the function of communication within that task environment. Therefore, the overall task must be viewed as an organization of subtasks; communication is the transportation system of such an organization, moving products from producers to consumers. The adequacy of a communication system depends on its capacity for handling expected volumes, the efficiency of its routes, the timeliness of its deliveries, its ability to handle the variety of products involved, and the manner in which it degrades under unfavorable environmental pressures. This functional approach cannot be undertaken by isolating the communications problem from the environmental and problem-solving tasks of the organization. For this reason, the research required will necessarily be more integrative and problem-oriented. Previous studies using such an integrative approach indicate the promise of this research strategy (Chapanis, 1975; Hiltz, 1975; Hiltz, Johnson, and Agle, 1978).

In command and control centers performing tactical decisionmaking, sensor and intelligence reports arrive at variable rates and in different formats, and they must be integrated into a coherent interpretation. Several people cooperate to integrate and process data reports, and they have extremely poor ways to convey, fuse, or contrast their personal world views. The Plexiglas status board and the manual plotting boards of much of today's Navy are inadequate technologies for supporting timely fusion of sensor data, and they raise several crucial communications questions: How can two or more people contribute to a common representation that supports both individual and integrative perspectives? How can hypotheses about events or objects autonomously revise themselves as time progresses? How can tasks be divided among people to promote early attention to the most crucial and perishable data?

Experiments that vary communication structures for such tasks would necessarily also vary task structure and decision strategies (see Sections 5.6.1 and 5.6.2). Hierarchies may prove effective for these tasks, but some previous research sug-

[17] Written by Frederick Hayes-Roth.

gests that flat organizations with direct communications among adjacent spatial sectors are preferable (Hayes-Roth and Wesson, 1978). However, studies need to investigate tasks with realistic data volumes. Stressing a team with a heavy workload will expose the interactions among volume, uncertainty, perishability, ease of communication, and organization. Analyses of communication failures should assist in early theoretical development of communications models for such tasks. Experiments that vary organizational structure by partitioning it to support spatially or temporally defined subtask groups should help elucidate the relationship between communication and sharing of related data. Finally, related research could profitably include studies of special interfaces for manipulating geographic data interactively and cooperatively among two or more co-workers (see Section 5.8.3).

This research requires a laboratory simulation that allows several situation assessors to receive and process simulated sensor reports and to manipulate them geographically, interactively, and cooperatively. Experts in military situation assessment, graphics, teleconferencing, interactive maps, cooperative problem-solving, communication, and experimental methodology should collaborate in this research.

In the future, decisionmaking teams will be crucially dependent on the ability to rapidly integrate combat data from numerous input sources. Current training on these tasks is limited by the lack of a theory of communications that might expedite and facilitate data aggregation. Communication in this environment encompasses what needs to be conveyed, to whom, by what time, and in what format. Improved understanding of these issues will have dramatic effects on systems acquisitions, training, and, most important, force effectiveness.

5.7. IMPROVEMENT OF TRAINING FOR TEAMS AND TEAM MEMBERS

This report has developed a view of decisionmaking teams as groups of cognitive specialists whose efficient, coordinated performance is enhanced by extensive practice and interfered with by personnel turnover. This view suggests several opportunities for training to enhance both the cognitive and cooperative aspects of performance. These promising training approaches are described below.

5.7.1. "Intelligent" Computer-Assisted Instruction for Team Training[18]

In the classroom, in training exercises, and in on-the-job training, an instructor has several important roles. These include monitoring the growth of each trainee's knowledge and skills, providing feedback on performance, and giving advice on how to best use the available resources. Instructor skill varies widely and instruction is considered by many to be more an art than a science. Over the past decade, research has investigated complex learning and instruction using adaptive computer-based instructional systems. This work has made progress in identifying and formalizing the components of the instructor's role as tutor and coach. The result-

[18] Written by Keith Wescourt, with the assistance of Polly Carpenter-Huffman.

ing instructional systems have been called "intelligent" CAI (ICAI), both to indicate their connection to other artificial intelligence research (see Clancey and Bennett, 1979, for the AI perspective) and to differentiate them from "frame-based" CAI, an approach that utilizes prestored, static data structures for all instructional materials and decisions.

Research involving ICAI systems serves three important functions: (1) it permits exploration of performance models, learning models, and instructional strategies and methodologies in general; (2) it supports development of operational ICAI systems that could standardize tutoring and coaching skills; and (3) it offers the promise of constant availability of instruction for trainees despite the incipient shortage of human instructors in the Navy. This shortage is particularly acute in the context of team training, since it would be desirable to have one instructor for each trainee.

Previous ICAI research, supported primarily by ONR, has focused on individual instruction on facts (Collins, 1975) and problem-solving procedures (Brown and Burton, 1975; Carr, 1977; Bates, 1978; Burton and Brown, 1979; Clancey, 1979). These studies have led to the understanding of how to represent explicitly (1) the structure of domain (task) knowledge and skills *for instructional purposes* and (2) general tutoring and coaching strategies. Although ICAI systems have demonstrated the feasibility of the instructional principles and of system design, evaluation of their effectiveness for training has been limited. Exploratory development by the Navy of prototype ICAI training systems has begun at the Naval Personnel Research and Development Center (San Diego) and is being contemplated by the Naval Training Equipment Center (NTEC) in Orlando. However, this technology has not yet been applied to team training.

New research should explore the utility of ICAI for training cognitive skills in team decisionmaking. The focus should be on identifying and representing (1) the knowledge each team member acquires about the task and about the competence and interaction styles of other team members (see Sections 5.7.2 and 5.7.3), (2) the processes that use this knowledge to produce individual performance, and (3) instructional strategies for the development of those performance skills. The system architecture should embody a simulation of a team exercise in which the performance of one or more team members is dynamically simulated in interaction with a trainee. Instructional strategies to be explored would include simulation manipulation (e.g., systematic alteration of simulated team members' behaviors) and scheduling of tutor intervention within the simulation exercises. The research should begin with the analysis and empirical study of team training followed by incremental implementation of the ICAI system based on the results of that study. The theoretical ideas and ICAI system capabilities would be refined through cycles of prototype development and experimental testing.

This approach follows previous examples of ICAI research directly, although none of the prior work has examined team performance and training. Team member simulation is currently being pursued at NTEC, where pilot behavior is simulated in several air control training tasks. However, that research does not address questions of how to manipulate simulated performance for instructional purposes.

The proposed research is relatively expensive in terms of time, equipment, and manpower. The first exploratory development of an ICAI system for individual skill training has just begun, after a decade of research on ICAI. The development effort will probably require five years to produce a prototype suitable for field evaluation, and investigations of ICAI for teams will probably require five years to provide a basis for exploratory prototype development. The project will require systematic observation of operational team training techniques and training experiments involving the experimental ICAI system. Requisite computing capabilities include a high-level artificial intelligence programming language (e.g., LISP, Smalltalk), a dedicated time-sharing research machine (e.g., DEC20 or VAX/UNIX), and/or a network of powerful, single-user systems (e.g., PERQs, Altos). The research staff should include cognitive psychologists, artificial intelligence researchers, and educational psychologists or training specialists.

The long-term payoff of the research would better training for team members with a reduction in demands on human instructors. The proposed research is, however, relatively risky, given its cost. While the theoretical and empirical studies will expand our understanding of team processes, the implementation of the experimental ICAI system to test and refine that understanding will be an ambitious undertaking.

5.7.2. Training Mental Models[19]

Section 5.4.2 discusses the importance of the "mental models" individuals bring to bear on a problem and the potential interactions among different mental models held by team members. To control such interactions, it may be desirable to train prospective team members to use specific mental models. For example, consider the case in which a new individual enters into a previously stable team. The original team members may have evolved a characteristic approach to their task. If the new individual's approach or conception of the task differs, this may degrade both team performance and social interactions among team members. Training the new individual in the team's approach might circumvent some of these difficulties. Conversely, for other tasks it may be desirable for individuals to have different mental models. This could give the team the flexibility of different perspectives in handling novel problems. Again, it may be possible to train individuals to use specific mental models, thus facilitating the composition of effective teams.

There are several possible approaches to the training of mental models. For example, one might formulate a model in operational terms and communicate it directly to students. The formalization might include a statement of acknowledged goals and the relationships among them, preferred strategies and methods, presumed relationships among entities under consideration, and so on. Alternatively, one might attempt to teach models by analogy. Ideally, the analogous problem would be one that was quite familiar to the student and which the student would reliably approach systematically. Given appropriate instructions and the opportunity to work on both kinds of problems in close succession, the student could learn to transfer his or her approach to the familiar problem to the target problem.

Prior research has successfully applied both approaches to the training of simple problem-solving and learning strategies (Hayes-Roth, 1980; Reed, Ernst, and Banerji, 1974; Thorndyke and Stasz, 1980). These and other studies (e.g., Amarel, 1968; Bruner, Goodnow, and Austin, 1956; Greeno and Simon, 1974; Newell and Simon, 1972; Simon, 1976) suggest that human problem-solving is inherently flexi-

[19] Written by Barbara Hayes-Roth.

ble and amenable to modification. However, comprehensive mental models appropriate for complex decisionmaking control tasks would be considerably more complex than the strategies previously studied.

An initial investigation of these problems should address the following research questions:

1. What functional units adequately operationalize people's mental models?
2. How can we communicate these functional units?
3. What familiar problem-solving situations represent useful mental models?
4. How can an individual's mental model be diagnosed?
5. What is the most effective way to present analogical problem-solving experiences to trainees?
6. Under what circumstances do these alternative methods succeed?
7. What other training methods are feasible?
8. What problems arise as the model to be trained becomes more complex?

Formalizing and communicating such complex models will pose formidable challenges for cognitive and instructional psychologists. Therefore, research exploring the training of mental models must be considered a high-risk effort. On the other hand, the potential payoff is also high and extends beyond the immediate consideration of team performance. The basic research questions bear directly on many other important areas including computer simulation of real systems, communication of complex information structures to humans, forecasting, planning, and decisionmaking.

5.7.3. Training Empathetic Models[20]

As team members develop mental models of the team task, they also learn about the roles others play in the team and about those other individuals as people. A promising line of research complementing work on mental models would formalize these social observations for training purposes and would examine their utility in improving performance, reducing the negative effects of turnover, and increasing motivation and morale of team members.

Research in social psychology has indicated that knowledge of the roles of other team members can both increase understanding of the problems seen from others' perspectives and improve overall team performance. New research is needed on the utility of learning the roles of others in the team *training* situation. Specifically, empathetic models might be incorporated into the training environment after individuals have learned their own particular job skills. Team members might practice their skills in teams with other members (real or simulated) who are performing suboptimally. Such manipulations will require an understanding of potential problem situations and errors occurring on particular tasks. This training should teach team members to adapt their own performance based on variability in their cohorts' performance.

Such research may lead to a more general exploration of teamwork skills. Team members may learn not only what functions others perform but also idiosyncratic personal knowledge about others. Can one learn, through this idiosyncratic knowledge, general knowledge applicable to adapting to others? One research approach

[20] Written by Shelley Taylor, with the assistance of Keith Wescourt.

would be to develop flexibility exercises in which individuals are presented with hypothetical problems in team situations involving the need to adapt to the behavior of some other team member (see Section 5.7.4). The kinds of information that can be translated into general adaptation skills can be assessed by measuring performance on new hypothetical problems of a different type.

It may also be possible to develop empathetic exercises to deal with particular chronic team problems. Role-playing techniques and even paper-and-pencil empathy-inducing techniques increase an individual's ability to take the role of another and understand that person's situation. A target problem that might be addressed by such a methodology is the variation in performance demands of different team members. If unstressed team members were to take the role of particularly overloaded cohorts, some of the problems facing other members might become more salient and better understood by all. This, in turn, might improve the interpersonal climate of the teams.

Experimental research on empathetic models could be readily incorporated into the Research Center laboratory. The identification, development, and experimental evaluation of training problems and models would require the collaboration of cognitive and social psychologists. If such models and training methods were automated, additional research would require expertise in artificial intelligence and computer science.

The ability to train empathetic models will serve several functions. First, such training might improve team performance by broadening team members' understanding of the overall task. Second, it might help compensate for disruptive effects of turnover by facilitating the incorporation of new team members (see Section 5.6.2). And finally, it might improve morale by reducing friction and promoting *esprit de corps.*

5.7.4. Training Flexibility in SOP-Based Performance[21]

Typically, team members perform according to well-learned SOPs, which enable individuals and teams to respond to situations rapidly and consistently. Thus, the Navy has sought to institute SOPs for both individuals and teams whenever sufficiently detailed task analyses are available.

A large proportion of training time is spent drilling SOPs in standard exercises. Yet in many situations, such rote performance may be inappropriate or even disastrous. For example, when systems malfunction, team members must quickly decide what to do and must coordinate their unrehearsed actions. As another illustration, wartime incapacity of team members (or simply their impromptu replacement) demands flexibility as the team must cope with changing personnel resources. Finally, enemy tactics may differ from those that training can reasonably anticipate.

Prior research on the development of automaticity in skilled performance may provide insights into the question of how to enable flexible responses despite the existence of highly overlearned procedures. Most of this research, however, has considered rote laboratory learning tasks and motor-skill learning, not complex cognitive procedures. Research has indicated that the inappropriate application of SOPs is responsible for many aircraft emergencies and accidents. incidents. Initial

[21] Written by Mark Menchik, with the assistance of R. Stockton Gaines and Keith Wescourt.

research on how to train aircrews to maintain flexibility has already provided some insights of general value (Lucaccini, 1978).

New research should develop flexible training procedures for decisionmaking teams and should test their effectiveness in standard, unusual, and totally unrehearsed situations. Several questions about the implications of training SOPs need to be investigated:

1. An SOP (or set of SOPs) may be valid for only a subset of the situations that require some response. If the exceptional circumstances are rare, they may not be recognized until the SOP is invoked, leading to undesirable consequences. What training could retain the benefits of SOPs, yet enable the recognition and flexible response to situations for which available SOPs are inappropriate? Do prior experiences with unusual situations and strong cognitive skills assist in this training?
2. Teams may evolve and institute unique SOPs that reflect their specific environment and individual skills. What are the implications of institutionally imposed SOPs for the development of these evolved SOPs? What are the implications of evolved SOPs for integrating new team members trained in institutional SOPs?
3. In decisionmaking teams, the number and specificity of SOPs vary from job to job. How does the more constrained behavior of members who follow detailed SOPs affect the performance of members who must respond flexibly in their roles? Do only high-level decisionmakers require training flexibility, or do low-level operators require such training as well?

New research to investigate these questions would require long-term access to subject teams, because of the time needed to train highly automatic execution of SOPs and to enable teams to evolve their own SOPs. Either comparisons of training techniques or intensive, longitudinal studies of a few teams could be undertaken to draw limited generalizations about the answers to the research questions posed above.

5.7.5. Dynamic Gaming as a Training Aid[22]

Military gaming has a long history as a training, research, and planning technique (Young, 1959; Weiner, 1964; Hansrath, 1971). The simulation of combat interactions between opposing forces offers the potential for exploring a wide variety of team activities such as planning, allocation, decisionmaking, and responding to a spectrum of adversary actions. In recent years, considerable emphasis has been placed on the use of gaming as a research method for examining force structure, hardware, plans, and tactical issues (see Brewer and Shubik, 1979). Similarly, computer-controlled dynamic gaming is being increasingly used to train military personnel in hardware-rich simulators (e.g., the Naval Electronic Warfare Simulation (NEWS), the Battalion Analyzer and Tactical Trainer for Local Engagements (BATTLE), and the Combined Arms Tactical Training Simulator (CATTS) of the Army).

[22] Written by Milton Weiner, with the assistance of Theodore Donaldson, R. Stockton Gaines, and Keith Wescourt.

Despite these applications, there are several major issues in the use of dynamic gaming as a training technique that have received little attention. These include:

1. What do participants actually learn from games?
2. How relevant is the acquired knowledge to actual military operations?
3. Can dynamic gaming provide training on team activities that cannot be carried out effectively by other techniques?

Little is known of the utility of dynamic gaming as a team training technique. Generally, evaluation of the utility of games as training devices rests on subjective estimates by the participants rather than on measures of knowledge transfer to operation settings. Furthermore, such training has generally emphasized individual learning rather than team learning.

Research should investigate the operational situation and the development of principles for the effective use of gaming in team training. New research should undertake two activities:

1. An evaluation of current training methods employing gaming and simulation in terms of such variables as motivation, knowledge acquisition, decisionmaking, and realism.
2. The development of a series of experimental games that highlight specific training objectives such as assimilating complex information structures, handling uncertainty in decisionmaking information, rapid response with incomplete knowledge, and adaptation to new allocation options. These experimental games would initially represent simple dynamic situations involving team participation. They could be used to test hypotheses about goal perception, task models, team structure, option generation, and flexibility of responses. Subsequent efforts could consider more complex situations with more typical operational characteristics.

Research efforts could combine evaluations of current gaming activities (focusing on their specific training objectives and methodology) and development of new experimental training games. A one- to two-year effort should be considered for these efforts. Further effort should be contingent on a review of the utility of gaming techniques for team training research.

The value of this research would lie primarily in the development of effective gaming techniques for training real-time decisionmaking. In particular, it would lead to the development of planning, allocation, and decision aids for decisionmaking teams. The main thrust of the research effort should be to provide a sound conceptual basis for the prescriptive use of gaming for team training, as opposed to the use of "face validity" as a rationale for dynamic gaming techniques.

5.7.6. Enriching Feedback in Training and Operational Environments[23]

Feedback is a critical component of training. Without it, individuals cannot learn their responsibilities as individual performers and as team members. Periodic evaluation and feedback in the operating environment is also required for mainte-

[23] Written by Shelley Taylor, with the assistance of Polly Carpenter-Huffman and Keith Wescourt.

nance of skilled performance and high motivation. At present, feedback in team training and in the operating environment tends to be infrequent, irregular, and often subjective. Training practices should include rapid, useful feedback as an integral part of each practice session. Hence, research aimed at enriching feedback has the potential for improving team performance and motivation.

Previous experimental research has established several principles governing the relationship between feedback and performance (see reviews by Klaus and Glaser, 1970; Nadler, 1979). These principles include the following:

1. Feedback should be as temporally proximal to performance as possible.
2. Positive feedback benefits performance and satisfaction, except when individuals' errors are obscured by the positive feedback.
3. Individual and team feedback are both important, since they serve different functions. Positive group feedback enhances team spirit and group morale. Individual feedback enhances motivation and provides clues as to how to correct performance.
4. Negative feedback to either the group or the individual has mixed effects. Under some circumstances, motivation and performance decrease and defensiveness increases.
5. "Process-oriented" feedback (i.e., generalized feedback about the group environment rather than the group product) may reduce defensiveness but may not improve performance.

These considerations generate the requirement for new research on feedback. Such research includes field studies and experimental studies, as summarized below.

Field studies should assess Navy team members' desires and requirements for feedback. Where do they feel they need feedback? At what points during performance do they want feedback? Do they desire additional group feedback or individual feedback? How do they feel it can best be integrated into the task environment without obstructing ongoing performance? Research in this area should focus on whether the perceived need for feedback stems from uncertainty about one's own performance or a need for approval and support.

Experimental work should address the following high-priority issues:

1. In most, if not all, previous studies, an experimenter or another agent outside the team provides feedback. However, several interesting questions arise in the consideration of who provides the feedback. Should feedback be centralized or decentralized? If it should be centralized, should it come from outside the team or from the team leader? Can team members reinforce each other? Can machines provide individual and team feedback? If so, under what circumstances is such feedback reinforcing?

2. In team situations, there are multiple options for supplying feedback during performance. Research should investigate the conditions under which individual versus overall team feedback is most effective. When the team is performing, it may be difficult to provide feedback to either individuals or teams without interrupting the time-course of the scenario. Research should explore options for overcoming these timing problems. Such options may include switching simulated team members into the system while feedback is given, multiplexing feedback with continuing performance, or videotaping performance for post-training review and evaluation.

Finally, research should investigate whether feedback should optimally be provided in public or privately.

3. Negative feedback is problematic but is essential to improving performance. What is the best way to provide negative feedback? Should negative feedback be provided only on a private basis and only to individuals? Can it be provided by a machine? Who should provide negative feedback—the leaders or other group members? Is negative feedback to the overall team desirable if performance deficits stem from poor coordination?

4. To be effective, feedback must include a usage component. That is, the recipient must be able to convert the feedback into the appropriate task behaviors. One approach would be to study how feedback is used when it is provided in the naturally occurring environment, and how its use can be increased. Experimental studies that systematically manipulate message characteristics of the feedback would also seem well suited to addressing this problem.

5. Experimental studies should also focus on the role of feedback over time to assess the impact of feedback both on teams that are performing very well and on those that are functioning poorly. The ability to alter a teams' performance and *esprit de corps* over time may depend on the complex interaction between baseline performance and the type of feedback it receives.

This research would require the collaboration of social psychologists, experimental psychologists, instructional or educational psychologists, and perhaps computer scientists. Studies could be conducted both in the research laboratory and at Navy training sites. Because of the importance of feedback in training and the current deficiencies in the operational administration of feedback, this research could have tremendous benefits for team performance.

5.8. MAN-MACHINE SYSTEMS FOR TASK PERFORMANCE

Traditionally, systems involved in team performance have been supported by two kinds of interaction between humans and machines: In the first, humans use of the computer as a data-processing medium (Hiltz and Turoff, 1978). In the second, they monitor and control a complex, usually monolithic computer system. However, team decisionmaking requires a more integrative approach to man-machine cooperation. Each member of the interaction brings unique capabilities to the task, but little is known, theoretically or practically, about how to decompose team tasks or how to allocate subtasks to humans and machines. Furthermore, we know very little about conveying what a human knows or believes to a machine or, conversely, transforming a machine representation of a complex situation into a form readily accessible to a human. Several approaches to the design of man-machine systems could improve both the efficiency and quality of team performance.

5.8.1. Use of Automated Specialists to Supplement or Replace Team Members[24]

Team performance is currently limited by the difficulty of arranging training exercises. The magnitude of the operation required for training exercises could be

[24] Written by Frederick Hayes-Roth.

reduced by creating environments in which a single team member could interact with intelligent simulations of other team members. Furthermore, requirements for human participation in actual operations might be substantially altered by increasing reliance on such automated simulations of team members. Both of these goals require research to transfer human capabilities to machine-based specialists.

Prior research has succeeded in automating human expertise in limited applications. This work has focused chiefly on electric circuit diagnosis (Brown and Burton, 1975), medical diagnosis (Shortliffe, 1976) air traffic control (Klass, 1979), and speech and image processing (Mostow and Hayes-Roth, 1978). Such research typically begins with a cognitive analysis of task performance (see Section 5.4.1). This analysis ordinarily requires thinking-aloud protocols produced during actual task performance, the construction of a model that accounts for the protocols, the implementation of a computer simulation of the model, and finally, the refinement of the knowledge and strategies in the simulation.

Problem-solving in decisionmaking teams seems ideally suited to this research approach. The performance of team members should be observed, modeled, simulated, and refined in a laboratory or training setting. Then, the derived machine-based team members may be used in a variety of experimental ways to determine their benefits and costs. First, the performance of the models can be compared to that of their human counterparts. Second, the models can provide surrogates for missing human members in training contexts, as suggested in Section 5.3.3. Simulated team members might include either individuals on the team or individuals outside the team who interact with team members. These simulations, if successful, may also provide standalone alternatives to humans for certain tasks. Finally, the models may be used by human team members as computational aids for task performance (see Section 5.8.2).

Beyond the normal difficulties associated with building heuristic models, this area of application will require careful attention to the cooperative and adaptive aspects of team behavior. The computer models will need to be able to accept questions and tasks from others, to convey tasks and information to others, and to explain and rationalize their behavior. Further, these specialists may need to demonstrate flexibility in responses to unexpected situations (see Section 5.7.4).

This research will require the combined efforts of psychologists, who will perform task analysis and initial model building, and computer scientists, who will build and refine the machine implementations. Initial performance should be monitored in team problem-solving experiments in the research laboratory.

This research offers significant promise for improving team performance by creating new training opportunities. Currently, team training requires simultaneous participation of numerous human team members. By creating machine-based members, training will be more accessible, less expensive, and more controllable. This in turn will increase the quality and quantity of team training each member receives. It may, in addition, obviate the need for special training facilities, since the space requirements for training can be reduced to that required to support the number of humans who will be trained simultaneously. Furthermore, the research may lead to the improvement of team skills through the automation of both mundane and highly complex team activities.

5.8.2. Automated Planning Aids for Decisionmaking[25]

Section 5.8.1 discusses the development of automated specialists to supplement team members. One such aid deserving special attention would assist individuals in the difficult and imprecise task of tactical planning. Automated planning aids could serve a number of useful purposes, including the following:

1. *Performance of Standard Computational Functions* (such as table lookup, mathematical calculations, and information retrieval). This kind of assistance would presumably improve both the accuracy and the speed of computations underlying plan development.
2. *Bookkeeping Assistance.* When several people cooperate on a single problem, managing their interactions can become a problem in itself. A computer aid could greatly facilitate these interactions by (a) providing an efficient communication medium for team members, regardless of their respective locations; (b) maintaining a well-structured, perspicuous record of the current solution, incorporating the contributions of all team members; and (c) maintaining an historical record of the development and rationale behind solution elements and their alternatives.
3. *Evaluation of Tentative Plans.* There are two general methods for evaluating tentative plans. The first is simply to calculate a plan's "score" against each of several established criteria and aggregate component scores. While people can perform this kind of evaluation, a computer aid could provide greater speed and reliability, thereby permitting comparative evaluation of many more alternative plans. The second method is to simulate the execution of a plan and assess its effectiveness, shortcomings, side effects, etc. This method has much greater potential utility than the first because (a) most planning problems lack a satisfactory set of well-defined, mutually consistent evaluation criteria, and (b) scoring/aggregation procedures may not reliably discriminate good plans from poor plans. The second method is also much more difficult for people to apply for themselves. Therefore, computer aids can make enormous potential contributions in this area.
4. *Participation in the Planning Process.* An intelligent computer aid might participate in plan development in two ways. It could oversee individual contributions, coordinating them into a comprehensive plan, detecting and resolving conflicts, etc. This is an important function because independently generated plan components frequently produce interactions that are both unforeseen and difficult to detect. As discussed in the previous section, the aid could also be endowed with planning skills and knowledge about the problem domain and could effectively act as another team member. These skills and knowledge might well simulate those of a human being.

Items 1–4 show a progression toward increasingly sophisticated aids playing increasingly central roles in the planning process. Item 1 is quite feasible, given existing technology. While items 2–4 represent state-of-the-art computer science research, preliminary research in all three areas is very promising (Goldstein, 1980; Hayes-Roth, Hayes-Roth, Rosenschein, and Cammarata, 1979; Hayes-Roth and Wesson, 1978; Hiltz and Turoff, 1978; Klahr, Faught, and Martins, 1980; Wesson, 1977). Therefore, we view this research as low-risk, with a high potential payoff.

The success of such planning aids depends not only upon their efficacy in performing the appropriate functions, but also upon several other factors govern-

[25] Written by Barbara Hayes-Roth, with the assistance of Mark Menchik.

ing the readiness of humans to rely on them. First, aids must be easy for people to learn and to use. Second, they must be reliable and accurate. More importantly, the users must have confidence in their reliability and accuracy. Third, they must not threaten people's sense of autonomy or the structure of authority. Accordingly, research on the development of planning aids should be accompanied by related research on human factors and the cognitive and social factors influencing people's use of them.

5.8.3. Machine Aids for Cooperative Problem-Solving[26]

Humans and machines are best suited to different types of tasks. Information-processing decisionmaking tasks requiring both situation assessment and planning can benefit from the relative advantages of both. Humans, for example, are superb visual pattern perceivers; machines are notoriously weak in this area. Humans are the best sources of heuristics about how to treat uncertain information and how to draw inferences. However, machines, once instructed, can perform such inferences faster and more systematically than humans. How then can these two kinds of processors cooperate when several people and several machines must work together? The problem faced in man-machine teams is to identify the crucial kinds of information-processing responsibilities, to allocate responsibilities to the most appropriate resources, and to design communications media that facilitate their interactions.

In the situation-assessment portion of a command and control task, sensor and intelligence reports about past, current, and potential future events arrive at variable rates. Maintaining a coherent and current picture of the world requires time-indexing and the fusion of these time-synchronized messages into a comprehensible interpretation. Where and how sensor data should be aggregated and processed is a central problem. Because timeliness of processing is essential, communication delays are serious (see Sections 5.6.1 and 5.6.3). On the other hand, passing raw sensor data directly to central facilities requires high bandwidths and can easily lead to a glut that may delay the processing of perishable information. Moreover, several people must often cooperate to integrate and process data reports, and they may have extremely poor methods for conveying, fusing, or contrasting their personal world views. Messages among cooperating decisionmakers vary in their time criticality and in the responses they demand. New research should therefore investigate the utility of alternative modes of communication among humans and between humans and machines. Furthermore, the distribution of tasks—including signal processing, signature analysis, hypothesis formation, and team scheduling responsibilities—among people and machines is a wide-open issue of considerable long-term import.

Several additional problems arise in the planning component of the task. Forecasting probable outcomes of current situations requires a combination of causal reasoning, simulation, and non-deterministic reasoning. People are essential in the assessment of dangers and opportunities in forecasted situations, yet they seem to perform poorly both at look-ahead calculations and at maintaining numerous alternatives. Machines excel at both types of calculations, but the products of their calculations comprise many alternative outcomes, each with numerous assump-

[26] Written by Frederick Hayes-Roth.

tions and details (see Section 5.8.2). Experimental research should explore methods for translating this volume of data to a form intended for human planners. Furthermore, new efforts are warranted on the related problem of incremental replanning. How can complex plans be changed marginally to respond to specific problems detected during plan execution? Can a human suggest incremental fixes? Can the shared representation of a plan in progress be graphical? And can a computer compute possible outcomes rapidly and display them visually?

The research laboratory for these studies should allow several situation assessors to receive and process reports and to manipulate them geographically, interactively, and cooperatively. Experts in military situation assessment and planning tasks, graphics, teleconferencing, interactive maps, cooperative problem-solving, communication, and experimental methodology should collaborate in this research.

6. PROGRAM IMPLEMENTATION

The research program described in this report emphasizes a broad, integrated, and multivariate approach to the study of information-processing decisionmaking teams. We believe that this research can best be carried out in a small number of large-budget, resource-rich, Team Performance Research Centers. Such centers will be better equipped to address the range of important problems in team performance than would small, more narrowly focused contract efforts. To carry out the range of studies critical to the improvement of team performance, each Research Center will require an interdisciplinary staff of researchers engaged in a variety of related project activities. These activities will include policy studies focused on the operational Navy (as described in Section 5.1), the development of laboratory and experimentation capabilities (as described in Sections 5.2 and 5.3), and scientific research, including theoretical development and empirical studies, on a subset of the research problems described in Sections 5.4-5.8.

Based on our analysis of the requirements for research in the team performance program and our observation of facilities with similar goals and methods, we have derived a tentative set of specifications for these Research Centers. These specifications are rough guidelines for the capabilities, facilities, and costs required to successfully carry out the research we have recommended.

6.1. INSTITUTIONAL REQUIREMENTS

A research institution capable of undertaking the long-term program we have described must have the following characteristics:

1. The capability to assemble and manage a large interdisciplinary team of researchers with expertise in military operations research, simulation, gaming, cognitive modeling, social psychology, policy analysis, systems design, computer hardware, artificial intelligence, human factors, and instruction.
2. Researchers who are available to commit significant amounts of time to the research.
3. The space, knowledge, and administrative support to create and manage a large computer-based laboratory that has state-of-the-art hardware and software, a pool of subjects who are available over a long period of time, and facilities for observing experiments within the laboratory (laboratory requirements and costs are discussed below).
4. The expertise to conduct research on combat operations and defense-related command, control, and communications.
5. In-house or readily available liaison with military personnel and sites.
6. Reasonable proximity to major Navy installations.
7. A history of excellence in program-related research.

These considerations suggest that the most appropriate research sites would be existing research organizations or independently managed, interdisciplinary research organizations within universities. Most universities are not designed to undertake large-scale development efforts on military team performance. However, a few have successfully undertaken applied efforts either alone (e.g., Carnegie-Mellon University's ARPA-sponsored speech understanding work) or in conjunction with other research institutes (e.g., University of Illinois with Bolt, Beranek, & Newman, Inc. in reading research; Carnegie-Mellon University with the American Institutes for Research in document design research).

6.2. LABORATORY FACILITIES

The precise specifications and costs for the laboratory facilities depend on the domain to be investigated. However, we can make some general assumptions about the required laboratory capabilities.

If the task domain is an information-processing decisionmaking task such as that performed in Navy CICs, the laboratory must be able to accommodate between ten and twenty team members, including receivers, users, and integrators of information, decisionmakers, and communicators. Each of these team members will require some form of display device, a keyboard, and a method of communicating with other team members. Communications will probably require both telephone and computer network links.

A central laboratory processor will be required to perform several functions during team experiments: maintaining a representation of the combat situations, providing a source of enemy activities, generating appropriate inputs, controlling the simulations, and maintaining an event memory for data collection and subsequent analysis. In addition, this processor must support high-level programming languages, word processing, ARPANET interfaces, and message-handling.

Finally, additional equipment will be required to support the observation of team performance by researchers. Typical equipment might include a large graphics display for all scenario activities and assorted recording equipment (e.g., a videotape recorder and camera).

At least three areas would be required to house this facility: a laboratory that contains the display stations and in which the teams perform, a hardware area to house the processors and storage devices, and a conference area with large projection equipment to accommodate experimenters and observers. This entire facility would require about 1,500 to 2,000 square feet of floor space.

In computing approximate costs for this laboratory, we assumed that the central processor would have computing power equivalent to that of a Digital Equipment Corporation VAX 11/780 and that the power of each display station would be equivalent to that of a 3-Rivers PERQ. On this basis, the combined costs for hardware acquisition, software acquisition, and systems support software for the laboratory would be approximately $ 1 million. This cost could be amortized over the duration of the research contract, and of course, it would be lower for institutions with some or all of the requisite equipment already operational.

6.3. THE RESEARCH PLAN

This section suggests a set of time-phased activities by ONR management and potential contractors for executing the proposed research plan. A number of unknown factors prevented us from estimating the level of effort that could be committed to each contractor. These unknowns included the number of contractors in the program, the current laboratory capabilities of the contractors, the number of research projects undertaken by each contractor, and the precise amount of money available in the research program. Thus, rather than proposing expected levels of effort, we restricted ourselves to categories of activities to be undertaken at each stage of the program. We base our plan on a projected six-year program, including the current fiscal year (FY80).

ONR should immediately undertake several activities to initiate the research program:

1. Establish the budgetary guidelines for the entire program.
2. Form the steering committee to monitor the research (see Section 4.3).
3. Enlist tri-Service and other agency support for the program (see Section 4.7).
4. Identify and select the long-term contractor(s).
5. Fund start-up efforts for the contractor(s) (see below).
6. Organize a workshop for the contractor(s) and relevant operational and training personnel.

The scope of the research activities recommended in Section 5 is sufficiently broad that we assume only a subset can be undertaken simultaneously (unless there were very substantial funding and multiple Research Centers). Therefore, once the individual contractors have been selected, they must develop a detailed research agenda. While the particular interests and capabilities of the individual contractors will determine the specific proposals, we suggest the following research strategy.

In the current year, ONR should focus on the selection and analysis of target teams, the identification of research requirements, and the design of a research laboratory. The following specific research activities (described in Section 5) should be undertaken because they have immediate utility for the operational Navy and/or because they provide the laboratory requirements and design:

1. Navy teams of the future (Section 5.1.1)
2. Development of a task specification for tactical decisionmaking (Section 5.2)
3. Cognitive models of individual performance (Section 5.4.1)

The completion of these research efforts will depend on the capabilities and funding level of the individual contractors and the date on which research is begun.

The second year should continue first-year research and expand into a larger set of activities. The goal of the second year would be to order and install available laboratory equipment and use the results of first-year research to design one or more pilot experiments. The pilot experiments would provide a shakedown of the available laboratory facilities, assist in the development of task scenarios, and provide some initial results of team experiments. The candidates for second-year research include the following activities:

1. Current technologies for improving Navy teams (Section 5.1.3).
2. Environmental simulations for mock operational equipment (Section 5.3.1)

3. Simulation and gaming scenario development (Section 5.3.2)
4. Investigation of the relationship between individual and team performance (Section 5.4.3)
5. The dynamics of team evolution (Section 5.5.1)
6. Enriching feedback in training and operational environments (Section 5.7.6).

The outcome of these research activities should lead to the design of larger-scale experimentation and the selection of subsequent high-priority research topics.

The third year would see the completion of the laboratory installation and debugging. During this year, the research program would focus on producing the first major research results. It would also expand to include additional research activities as dictated by laboratory availability and early research results. The promising candidates for this stage of the research include the following:

1. Organizational factors in introducing innovation (Section 5.1.2)
2. Capabilities for distributed exercises (Section 5.3.3)
3. Theories of team performance (Section 5.4.4)
4. Investigation of alternative decisionmaking strategies (Section 5.6.2)
5. "Intelligent" computer-assisted instruction for team training (Section 5.7.1)
6. Training flexibility in SOP-based performance (Section 5.7.4)
7. Automated planning aids for decisionmaking (Section 5.8.2)
8. Machine aids for cooperative problem-solving (Section 5.8.3)

At the end of the third year or during the following year, ONR should decide how to continue the research program. In particular, it should determine whether to continue with the same or an altered number of contractors, what research areas seem the most promising (based on the results of policy studies and laboratory development, and initial research), and how successful the contractors have been at meeting research objectives. Possible decisions include:

1. Continue funding of all contractors to perform additional research.
2. Continue and possibly increase funding of fewer contractors.
3. Delay the decision because no contractor has assembled the desired facilities.
4. Redirect the program to smaller efforts either more removed from specific applications or focused on a smaller set of research issues, as in current ONR 6.1 programs.
5. Terminate the program.

Assuming a positive decision, research would then continue for three to seven years (to a total of ten years), subject to negotiations between the contractors and ONR. Candidate areas for new research initiatives include:

1. Causes and effects of Navy team turnover (Section 5.1.4)
2. Team members' mental models for task performance (Section 5.4.2)
3. The effects of team turnover on performance (Section 5.5.2)
4. Task restructuring (Section 5.6.1)
5. Investigation of alternative communications structures (Section 5.6.3)
6. Training mental models (Section 5.7.2)

7. Training empathetic models (Section 5.7.3)
8. Dynamic gaming as a training aid (Section 5.7.5)
9. Automated specialists to supplement or replace team members (Section 5.8.1)

The suggested time scale and research priorities listed above are intended *only* as guides. As indicated earlier, the funding level and capabilities of the individual contractor(s) will be significant determiners of the extent of the program and the order in which research activities are undertaken. The recommended development sequence should lay the foundation for subsequent and more extensive research on the specific team improvement research efforts suggested for the third year and beyond. The establishment of several Research Centers with particular capabilities may lead to an overlap of effort on some research activities, and to a division of effort on others. *Some duplication of effort* should be anticipated and, in some cases, encouraged, particularly for experiments in which the generality of the research results is important. As research results become available, ONR and the contractors should work with the applied development and operational communities to create Navy testbeds for these results. At the conclusion of the research program, the contractors should deliver the products discussed in Section 2.6.

TEAM TRAINING BIBLIOGRAPHY

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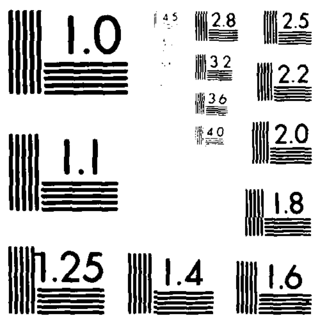

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