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Research Report 1812

Human Performance Essential to Battle Command: Report on Four Future Combat Systems Command and Control (FCS C^2) Experiments

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14. ABSTRACT *(Maximum 200 words)* The Army's ongoing transformation to Future Combat Systems (FCS) requires an unprecedented alliance of humans and machines. Creating an alliance that actually improves, and does not impede, battle command is a human systems integration challenge for FCS and particularly the area of command and control (C^2). To address that challenge, the FCS C^2 program is investigating future battle command concepts at the small unit level. The FCS C^2 effort, led by Defense Advanced Research Projects Agency (DARPA) and Communications Electronics and Engineering Command (CECOM) with a focus on human performance by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), included a series of command-in-the-loop experiments from October 2001 to March 2003. This report summarizes research methods and findings on human performance across four iterative and exploratory FCS C^2 experiments. The human performance findings reported are based on subjective measures and highly detailed objective measures of the command group's verbal and human-computer interactions. Overall, the results provide an emerging empirical database on the C^2 functions and tasks required by an FCS command group in collaboration with prototype C^2 systems. More problematic conclusions on workload and training are followed by more promising conclusions on user-based involvement and proactive research, and particularly their potential for solving workload and training problems.

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FOREWORD

Historically, Army acquisition research has had difficulty conducting an adequate early assessment of the human dimension in system performance. Human performance research is critical to Future Combat Systems (FCS) because enhanced battle command through advanced command and control (C^2) systems is at the heart of the FCS concept. The FCS C^2 program reflects the proactive research on human performance needed to build the force of the future. Attention to the human dimension underscores the role performed by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) as the Army's primary research organization for Personnel, Training, and Leader Development.

This report describes and documents ARI's work and products, particularly measurement methods and results, as a key member of the Human Performance Team for the FCS C^2 program. The work reported here focused on measuring human performance to understand and address task and training requirements for command groups in future FCS organizations. This report provides summary results and conclusions from the FCS C^2 experiments that attend to the human dimension of battle command in the future force.

The research reported here reflects ongoing work to address human performance issues by ARI, and especially the Future Battlefield Conditions (FBC) Team of the Armored Forces Research Unit (AFRU). This report supports work package (211) FUTURETRAIN: Techniques and Tools for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C^4ISR) Training of Future Brigade Combat Team Commanders and Staffs, and supports the Science and Technology Objective (STO) "Methods and Measures of Commander-Centric Training."

Findings from this effort were briefed to the Deputy Chief of Staff for Operations and Training (DCSOPS&T) from the Training and Doctrine Command (TRADOC). Methods and findings from each of the four experiments were provided to the Program Manager (PM) for FCS C^2 as part of ARI's ongoing support to FCS and Army research and development efforts. Human performance findings by ARI helped shape the C^2 prototype showcased in the FCS Capstone Demonstration of C^2 systems prior to the FCS Milestone B decision.

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HUMAN PERFORMANCE ESSENTIAL TO BATTLE COMMAND: REPORT ON FOUR FUTURE COMBAT SYSTEMS COMMAND AND CONTROL (FCS C^2) EXPERIMENTS

EXECUTIVE SUMMARY

Research Requirement:

The U.S. Army's challenging transformation to Future Combat Systems (FCS) entails an unprecedented amalgam of humans and machines, a truly hybrid future force. A pivotal example of the FCS transformation challenge is the requirement that a relatively small command group must be able to command and control (C^2) an interdependent mix of manned and autonomous systems. An ongoing research program called FCS C^2 exemplifies the Army's effort to proactively meet this requirement. This report describes and documents research by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) for the FCS C^2 program that focuses on the human performance essential to battle command.

Procedure:

A series of four command-in-the-loop exploratory experiments were conducted by the FCS C^2 research program at Fort Monmouth, NJ, from October 2001 to March 2003. Primary participants were four Active Duty Lieutenant Colonels who formed a notional FCS command group to more fully explore and develop new command and control paradigms. Each experiment lasted two weeks with the first three days dedicated to training and the remaining days to experimental exercises referred to as "runs."

Efforts by ARI in support of training and evaluation resulted in the respective use of *deliberate practice* and run *complexity* levels. Design for deliberate practice stressed the repetition of similar runs with feedback to ensure results were based on proficient performance. Run complexity was varied (Medium, High, and Too High) to assess how changes in operational conditions might impact command group performance, and to gauge the performance limits of the proposed Unit Cell organization.

Measurement methods for assessing human performance were developed and iteratively refined by ARI across the four experiments to better understand command group performance and to identify training requirements. Subjective measures obtained participant feedback on multiple research issues including: training, skill proficiency, workload, performance success, teamwork skills, decision making, function and task allocations, prototype effectiveness, and human-system integration.

Objective measures obtained detailed and comprehensive data on the verbal and human-computer interactions performed by the command group participants during run planning and execution phases. Analyses related the relatively micro objective behaviors measured to more meaningful C^2 functions including Plan, See, Move, and Strike.

Findings:

Summary description and documentation on the human performance findings obtained by ARI across four FCS C^2 experiments is provided in this report. Overall, the body of subjective and particularly objective results obtained on human performance is an emerging empirical database on command group task and training requirements in small FCS units. Measurement methods and the evaluation framework developed by ARI resulted in reliable and meaningful data on humans performing command and control in a notional FCS organization. Such human performance data is needed to understand and improve command group performance, and particularly to address training issues including: task analysis, task allocation, workload, performance assessment, and training requirements.

Results and discussion are followed by a status report on ARI's human performance objectives in support of the FCS C^2 research program to: initiate an empirical database on future command group performance for FCS; measure performance to iteratively improve the FCS C2 research environment; develop and transfer human performance measurement methods to future efforts; and identify training requirements and develop innovative training approaches based on empirical measures of command group performance.

Conclusions stress that workload and training requirements for future command groups represent an imposing and still emerging mix of technical and tactical skills. To adequately achieve these skills and meet the FCS requirements for simulation-based and embedded training, more exacting measurement methods will be required to provide the feedback needed to enable learning and improve performance. Conclusions also stress the potential of user-based involvement and proactive research, as demonstrated by the FCS C^2 effort, to address future battle command issues particularly workload and training problems.

Utilization of Findings:

Methods and findings on human performance from each experiment were provided to the Program Manager (PM) FCS C^2 as part of ARI's ongoing support of FCS and Army research and development efforts. Findings by ARI were briefed to the Deputy Chief of Staff for Operations and Training (DCSOPS&T) from the Training and Doctrine Command (TRADOC). The FCS C^2 program was demonstrated to and favorably reviewed by the U.S. Army Chief of Staff and the Secretary of the Army during Experiment 4. The human performance findings by ARI helped shape the C^2 prototype showcased in the FCS Capstone Demonstration of C^2 systems prior to the FCS Milestone B decision.

The measurement methods developed by ARI to measure, analyze, and report human performance were documented to facilitate their transfer to future efforts, particularly research on battle command. Training issues identified will guide training development efforts for FCS including ARI's Science and Technology Objective (STO) titled "Methods and Measures of Commander-Centric Training."

HUMAN PERFORMANCE ESSENTIAL TO BATTLE COMMAND: REPORT ON FOUR FUTURE COMBAT SYSTEMS COMMAND AND CONTROL (FCS C^2) EXPERIMENTS

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Introduction

The Army's ongoing transformation to Future Combat Systems (FCS[1]) poses an unprecedented alliance of humans and machines. Examples of the alliance include humans working with intelligent agents or "bots" for information processing and decision aiding, and with robotic entities for moving, seeing, and shooting. Creating an alliance that actually improves, and does not impede, battle command is a human systems integration challenge for FCS.

A paradox of technology is that advances intended to ease our life and work often add complexity, difficulty, and frustration (Norman, 1988; 1997). Humans as analog systems are compliant, flexible, and tolerant; in contrast, digital systems all too often require us to be rigid, fixed, and intolerant. This paradox is of particular concern to the design and development of FCS that entails an extraordinary mix of humans and machines, a truly hybrid future force.

Currently, FCS is essentially a conceptual design featuring an interdependent system-of-systems (Unit of Action Maneuver Battle Laboratory, 2003). Interdependence is reflected in the concept of a network-centric force composed of modular manned and progressively autonomous platforms with netted communication, sensor, and fire capabilities.

How to best allocate human-machine tasks and functions for command groups is a growing concern for FCS force transformation. A fundamental lesson from modern warfare is that the insertion of technology burdens and stresses the force (Cordesman & Wagner, 1996). Notably, the burden on humans associated with advances in military technology is attributed less to technology per se than to inflated expectations *about* technology.

Cordesman and Wagner (1996) stressed that the impact of heightened expectations on humans is pervasive to include: technology enables faster maneuver, more sorties, extended fires, just-in-time logistics, and continuous operations. Moreover, expectations about technology include a "more with fewer personnel" premise, including command group personnel.

Although automated systems are beginning to relieve commanders and staffs of some repetitive and computational tasks, the human tasks that remain are the most challenging and critical (Taylor, Charlton & Canham, 1996, p.301). Many command and control tasks are too complicated and too important to assign to machines. For battle command, for example, advanced technologies should help commanders visualize the operation, describe it within their intent, and direct subordinates toward accomplishing the mission. However, the "science" of technology, severely lags the "art" of battle command.

A pivotal example of the human-system integration challenge in FCS is the requirement that a relatively small command group will be able to command and control an expansive mix of manned and autonomous systems. This command group requirement for a notional, small

[1] A list of acronyms is provided in Appendix A.

combined arms echelon in future FCS organizations, called the Unit Cell for the FCS C^2 program, is the immediate focus of the research discussed here. This challenge is compounded by the command group's extraordinary reliance on technology, and by the expectation that technology will enable new paradigms in command and control (Unit of Action Maneuver Battle Laboratory, 2003). In sum, for FCS the integration of humans and automated systems is integral to both re-conceptualizing and performing command and control.

The Army learns by doing. The research reported here is a pioneering effort in support of the Army's learning requirement for new approaches to battle command. Transforming complex concepts into viable solutions requires sustained empirical exploration, assessment and feedback. Forging a forceful human-machine alliance requires shaping technology to complement human performance.

Human Performance Perspective

This report provides summary description and documentation on the human performance measurement methods developed and the findings obtained in the Army's FCS C^2 program. The FCS C^2 program reflects the Army's proactive effort to understand and improve performance in emerging FCS organizations, particularly command group performance in small units with a challenging array of manned and unmanned systems.

This report examines how three basic principles of human performance apply to the new challenges raised by future battle command requirements:

- Human performance is essential to battle command.
- Measurement is essential to understanding human performance.
- Training is essential to improving human performance.

First and foremost, human performance is regarded as essential to battle command. The critical role of the human dimension in military operations and particularly battle command is a core Army value and a doctrinal precept (Department of the Army, 2001). Attention to the human dimension also underscores the role performed by the U. S. Army Research Institute as the Army's primary research organization for Personnel, Training, and Leader Development. The unprecedented alliance of humans and machines by FCS reinforces the need to focus on human performance, as many battle command tasks remain too complex and too important to assign to machines (Taylor, Charlton & Canham, 1996, p. 301).

Second, measurement is essential to understanding human performance. Given that battle command is fundamentally a human endeavor, then measurement methods are needed to understand battle command. Human performance data can address the question "How well did the command group perform?" versus simply asking, "Who won the battle?" For command-centered research, such as FCS C^2, human performance data are more relevant and valuable than loss-exchange ratios and other battle outcome measures for assessing the new approaches to command and control required by FCS.

A more fundamental and tractable question than "How well?" is "How?" The FCS C^2 efforts by ARI focused on understanding battle command by objectively measuring: "*How* did the command group perform the basic C^2 functions including Plan, See, Move, and Strike in a futuristic FCS organization?

Third, training is essential to improving human performance. A critical training fallacy identified by Schneider (1985) is: "Practice makes perfect." A poorly structured regimen of practice, practice, practice often results in little or no improvement in learning or performance. A more structured training approach improves knowledge, skills, and abilities (Campbell, Quinkert, & Burnside, 2000). Structured training also makes more automatic the performance of lower-level skills such as map reading and terrain visualization (Fisk & Eboch, 1989) needed for higher-level battle command skills such as battlefield visualization.

A form of structured training called "deliberate practice" was used during the FCS C^2 experiments to stress that the training and experimental design should require specific objectives and ensure repeated practice opportunities with feedback. Accordingly, ARI's analysis of verbal and human-computer interaction focused on latter, more deliberately practiced, exercises or runs from each experiment to better ensure findings were based on more proficient performance.

The need to measure the *outcome* of learning to determine if, or ensure that, learning has occurred is a widely accepted practice in traditional training and educational settings. Purposes for outcome measures include adjudicating grades, classes, and ranks (pass/fail/percentile), determining retention rates, detecting remediation needs, and prescribing refresher training.

The need to measure the *process* of learning is not so widely appreciated or practiced. Process measures of learning are needed to provide the feedback instrumental to learning. Feedback to learners, both during and after performing, is essential to learning (Campbell, Quinkert, & Burnside, 2000; Schneider, 1985).

In many real world settings, the consequences of performance often provide feedback automatically and clearly. The "measured" comparison between actual and desired performance may be so obvious, so intuitive, that it belies any measurement requirement.

However, the more artificial and complex the performance setting, the less feedback is an automatic affordance and the more difficult its interpretation. For example, in the simulation-based runs conducted for FCS C^2 with interdependent and highly automated technologies, performance feedback was too often missing and inadequate. At times, automation failed to perform as expected. At other times, automation performed in unexpected and detrimental ways. The causes of the automation problems experienced were often unclear. Was it a shortcoming in the technology, in the training, or in the performers' tactics, techniques and procedures (TTPs)?

This report stresses that the training requirements for command group performance represent an imposing and still emerging mix of technical and tactical skills. To adequately achieve these skills and the new FCS training requirements, including simulation-based training and embedded training, more exacting measurement methods will be required to provide the feedback needed to enable learning and improve performance.

Human Performance Research Objectives

The major research objectives that directed ARI's involvement in the FCS C^2 research program are bulleted below and briefly described:

- Initiate an empirical database on future command group performance for FCS.
- Measure performance to iteratively improve the FCS C^2 research environment.
- Develop and transfer human performance measurement methods to future efforts.
- Identify training requirements and develop innovative training approaches based on empirical measures of command group performance.

A primary objective of ARI's efforts to measure human performance was to initiate the development of an empirical database on command group performance for future FCS organizations. The command-in-the-loop focus of FCS C^2 research supported the requirement to focus on the measures of human performance needed to begin to understand the determinants and consequences of command group behavior. The findings from this exploratory research program were expected to provide empirical groundwork, if not benchmarks, for future research on battle command and new approaches to command and control.

Another more immediate objective was to capture and document the performance of the command group during each experiment in order to iteratively improve the overall research environment for latter experiments. Shortcomings in human-human interaction and human-computer interaction were routinely identified in each experiment. Refinements to redress shortcomings were then made to improve system design, experimental design, and training in subsequent experiments.

A more general objective was to *transfer* ARI's human performance measurement methods to future efforts. For FCS C^2 efforts, the goal was to document and refine the measurement methods in a manner that other researchers could apply to subsequent FCS C^2 experiments. To facilitate transfer, ARI's documentation included methods for analyzing and reporting the results obtained from the human performance measures. For example, the Interim Report for Experiment 3 provided by ARI to the PM FCS C^2 was also published as an ARI Research Report (Lickteig, Sanders, Durlach, & Carnahan, in preparation) to ensure more detailed documentation on human performance measurement methods for command groups is readily available. A related goal was to provide a set of human performance measurement methods that would transfer to a broad range of future research efforts on command and control, particularly battle command and command group research issues.

A final objective was to identify training requirements and develop innovative training approaches based on empirical measures of command group performance. This goal emphasizes the crucial role of performance measurement in developing, providing and evaluating training. It also directly supports the ARI STO Objective "Methods and Measures of Commander-Centric Training." The evaluative framework for measurement developed by ARI was based on a functional analysis of performance that related relatively micro behaviors, particularly verbal and human-computer interaction, to relatively macro level command and control functions. This C^2 function approach provided a meaningful framework to compile human performance data that could be used to address training related issues including: task analysis, task allocation, workload, performance assessment, and training requirements.

Overview of the Evaluation Framework

An overview of the evaluation framework used by ARI to measure and assess human performance in the FCS C^2 research program is provided here, followed by a more detailed description in the Method section.

The functional analysis by ARI was designed to identify and describe the command and control behaviors of the command group for a small, notional FCS unit in the emerging Objective Force structure, the Unit Cell. Overall, measurement and analysis methods for human performance developed detailed descriptions of critical command group functions and supporting behaviors, including operational definitions and behavioral anchors, that applied to both the planning and execution phases of the FCS C^2 experimental runs.

The framework for measurement was based on a functional analysis of the command group's performance that related objective behaviors to basic C^2 functions adapted from the experimental design that included Plan, See, Move, and Strike. The evaluative approach for assessing human performance was based on the following measurement methods:

- Subjective Measures. Responses obtained from command group participants in after action reviews and surveys on multiple research issues including: workload, human performance, system performance and training.
- Verbal Interactions. Verbal analysis of communications included transcription from audio recordings of all spoken exchanges by members of the command group with one another, with higher headquarters, and with subordinate personnel. A verbal communications taxonomy was developed as a structural framework for the verbal communications analysis.
- Human-Computer Interactions (HCI). The HCI analysis of participant interactions with the C^2 prototype included comprehensive analysis of all interactions across the command group for selected runs. An HCI taxonomy was developed as a structural framework for HCI analysis.
- Automated Measures. An ARI measurement goal was to promote the development of automated measures of C^2 performance. The ARI validated the available subset of automated measures developed by comparing them with manual measures obtained from HCI analysis.

The FCS C^2 Research Environment

The FCS C^2 program provides a working example of the Army's ongoing effort to explore command and control concepts and address human system integration issues with future command group performance. From October 2001 to March 2003, the program conducted a series of four command-in-the-loop experiments at Fort Monmouth, NJ. The program leads are the Defense Advanced Research Projects Agency (DARPA) and the U.S. Army Communications Electronics and Engineering Command (CECOM) Research and Development and Engineering

Center (RDEC). As a partner in the FCS C^2 program, ARI focused on measuring human performance to better understand and address performance and training requirements for small command groups in FCS organizations.

Purpose of FCS C^2 Program

The stated purpose of the FCS C2 program is to explore the hypothesis that digitization of current battlefield operating systems enables a new approach to command and control:

> If digitization of current battlefield operating systems can substantially enhance command and control by providing better, more accurate, and timely battlefield data to today's commander and staff for decision making; then a 'new' approach to Battle Command and Control, implemented in the form of synthesized/ analyzed information presented to the future Unit Cell Commander, will enable him to leverage opportunities by focusing on fewer unknowns, clearly visualizing current and future end states, and dictating the tempo within a variety of environments, while being supported by a significantly reduced staff (Pronti, Molnar, & Wilson, 2002, p. ES-3).

To investigate this hypothesis, the FCS C^2 program created a transformation environment for empirical assessment of command group performance at the small unit level, the notional Unit Cell. During Experiments 1-4, the Unit Cell served as the smallest combined arms echelon within FCS organizations. Figure 1 depicts the manned and robotic elements of the Unit Cell examined in Experiments 1-4, including the surrogate C^2 vehicle occupied by the command group. As indicated in Figure 1, the command group directly controlled 16 air and ground vehicle platforms, 13 of which were unmanned, and a set of unmanned ground sensors (UGSs).

Building the FCS C^2 Transformation Environment

The resources and products of three interdependent teams—Operational, Technical, and Human Performance—were required to create the FCS C^2 environment for transforming command and control. The Technical Team developed the Commander's Support Environment (CSE), the hardware and software system located in the surrogate C^2 vehicle. The CSE's prototype C^2 workstations for the four command group participants allowed them to command and control their Unit Cell elements.

The Technical Team also developed supporting technologies such as the Collaborative Server so the command group could share information via a common operational picture, and the Collective Intelligence module to ensure the Unit Cell's elements worked together in a network centric environment. Through the CSE's links to Distributed Interactive Simulation (DIS), the command group interacted with simulated elements of the Unit Cell, the threat force, and civilian entities.

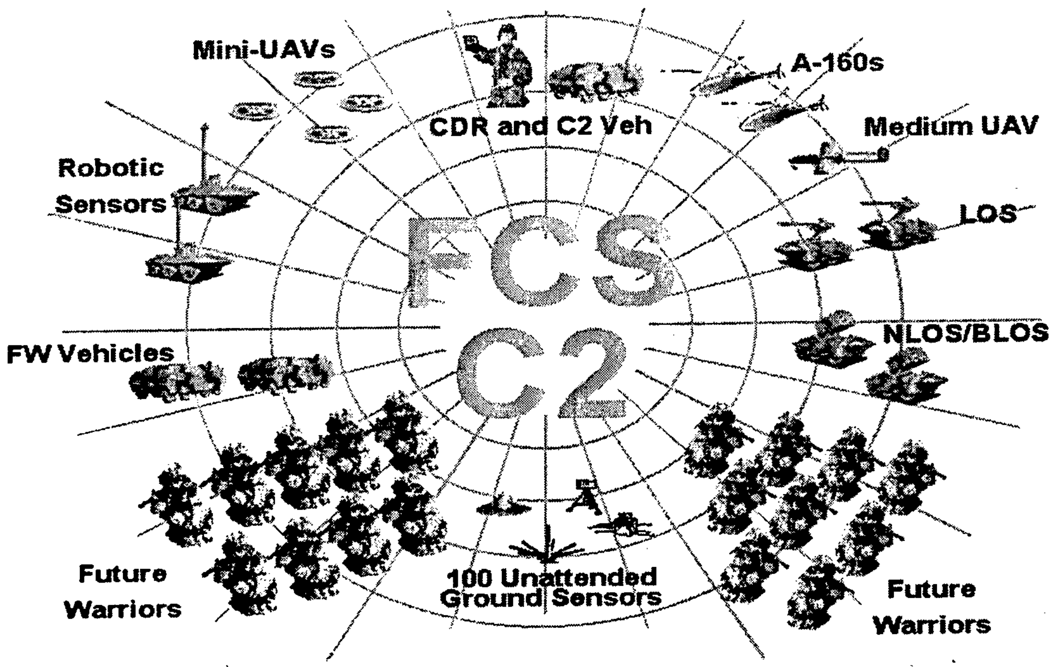

Figure 1. Organization of the Unit Cell.

The Operational Team collaborated on C^2 prototype design, developed mission requirements and scenarios for Unit Cell operations, and provided participants and support personnel. The command group participants were four active duty U.S. Army Lieutenant Colonels in the duty positions of: Commander, Battle Space Manager, Information Manager, and Effects Manager. The Operational Team included an experienced and capable group of subject matter experts (SMEs) who served as higher Friendly and Enemy commanders, and the Observer/Controller (O/C) team for After Action Reviews (AARs).

The Human Performance Team devised and implemented training and evaluation methods compatible with an incremental series of experiments designed to explore and document lessons learned for Army transformation and acquisition objectives. As a lead member of this team, ARI efforts focused on the human-human and human-machine interactions required by FCS concepts for small unit command and control. A core tenet stressed by ARI was that building a forceful human-machine alliance required shaping technology to complement human performance.

Formation and *sustainment* of a proactive research environment is required to effectively integrate human and system performance. Iterative refinement of the environment and research program is reflected in the bulleted schedule for Experiments 1-4 provided below. Experiment 1 only assessed the ability of the Unit Cell to move its elements in order to see and not be seen (i.e., See/Move). By Experiment 4, Unit Cell missions and C^2 prototype capabilities progressed to Improved See/Move/Strike and Sustain operations.

- Exp 1 — Dec 2001 — See/Move (with limited Strike).
- Exp 2 — May 2002 — Improved See/Move and Strike.
- Exp 3 — Sep 2002 — Improved See/Move/Strike.
- Exp 4 — Mar 2003 — Improved See/Move/Strike and Sustain.

In addition, a fifth experiment with Army Cadets called the Summer Experiment was conducted in August 2002, between Experiment 2 and 3. This experiment was used to compare novice versus expert command groups based on the Cadet performance during the Summer Experiment versus the Lieutenant Colonels performance during Experiments 2 and 3. Results from that comparison are reported in an ARI Research Report by Carnahan, Lickteig, Sanders, and Durlach (in preparation).

Method

The basic experimental schedule for FCS C^2 Experiments 1-4 is depicted in Table 1. Variations in schedule were relatively moderate for an exploratory research program and primarily due to technical problems during Experiments 1-2. This summary description of research methods identifies more notable variations in method within and across experiments. However, the program's deliberate focus on new approaches to battle command stressed exploration and iterative refinement of system and human parameters across experiments to meet emerging operational and doctrinal requirements for FCS.

Table 1

Basic Experimental Schedule for FCS C^2 Experiments 1-4

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
AM	Training			Run 1	Run 3	Run 5	Run 7	Run 9	Run 11	Final AAR
PM	Training			Run 2 AAR	Run 4 AAR	Run 6 AAR	Run 8 AAR	Run 10 AAR	Run 12 AAR	

Training and Experimental Design

Each experiment lasted two weeks with the first three days dedicated to training, and the remaining days to experimental exercises referred to as "runs." Training on days 1-2 of each experiment focused on developing the participants' individual skills with the C^2 prototype system. This training was intentionally not duty position specific, but rather designed to provide cross-duty skills required to operate the C^2 prototype from any of the four command group duty positions. Training on the third day typically addressed collective command group skills and took place in the surrogate C^2 vehicle linked by virtual simulation to friendly and enemy entities to support run rehearsal.

Experimental runs required approximately 2-3 hours to complete the planning and execution phases, resulting in two runs per day as shown in Table 1. At the end of each run day, the O/C team led an AAR of that day's runs that reviewed operational, technical, and human performance issues. More complete account of the research methods is provided in the Interim Reports on each experiment provided to the Program Manager (PM) FCS C^2 and in Lickteig, Sanders, Durlach, and Carnahan, in preparation.

Efforts by ARI in support of training and evaluation resulted in the respective use of *deliberate practice* and run *complexity* levels. Design for deliberate practice stressed the repetition of similar runs with feedback to ensure results were based on proficient performance. The execution phase for each run was structured, therefore, and limited to approximately 60-90 minutes to help maintain focus on research objectives. Consequently, the operational setting and basic mission of the Unit Cell was relatively constant across experiments, except for controlled variations in run complexity.

The setting was simulated desert terrain from the National Training Center (NTC) in which the Unit Cell conducted deliberate attack missions against a battalion (minus/plus) to clear passage lanes for a follow-on force. The performance feedback essential to deliberate practice included end-of-day AARs. Design goals were to help participants learn, assess, and refine the new technical skills required to operate their C^2 prototypes and the new tactical skills required to exploit the Unit Cell's progressively automated assets.

Experimental design varied run complexity levels as a function of METT-TC (Mission, Enemy, Terrain, Troops, Time, and Civilians) for Experiments 1-3. Three complexity levels (Medium, High, and Too High) were varied by increasing enemy force activity and size, eliminating a key friendly asset, and inserting civilians on the battlefield.

Run complexity was introduced to identify how changes in operational conditions impact FCS units, particularly command group performance, and to gauge the performance limits of the proposed Unit Cell organization. It was hypothesized that run complexity would change workload, performance, and human-system integration requirements. To establish baseline performance indicators for future efforts, however, all runs for Experiment 4 were conducted at the "High" level of complexity.

Participants

Four Active Duty Lieutenant Colonels were selected as command group participants to more fully explore and develop new command and control paradigms. Alternate participants were used occasionally, however, due to schedule conflicts. Notably, the Information Manager for the latter half of the runs in Experiment 3 and all Experiment 4 runs was a Major with less operational and command experience. However, the Major had extensive experience with the FCS C^2 prototype as he was assigned to Fort Monmouth and the FCS C^2 research program.

Across experiments, the participants became relatively expert members in an FCS command group. This assessment of expertise is based, in part, on an assumption that command group expertise entails an incremental progression of skill development from tactical skills, to technical skills, and then to the integration of tactical and technical skills. Clearly, more basic or generic technical skills such as familiarity with commercial software applications may support and precede tactical skill development. However, more applied technical skills on how to use a C^2 system to effectively command and control manned and unmanned systems are only tools to support the "art" of battle command. Technical C^2 tools cannot be effectively applied without underlying tactical skills.

The tactical expertise of the primary participants included exceptional educational, professional development, and operational experience. For example, their selection as participants was based in part on graduation from the School of Advanced Military Studies (SAMS). Participants' tactical expertise provided a solid base for developing and applying the technical skills required to command and control the assets of the Unit Cell by means of the FCS C^2 prototype interface.

Technical skills were developed in individual and collective training sessions prior to each experiment's runs, as described below in the Training section. Participant feedback to system developers during each experiment was routinely used to develop and revise the C^2 system and interface, including the addition of new features and tools. Many of the technical skill requirements, therefore, were precisely tailored to participants' expectations about how features and tools should be designed and applied. Skill integration opportunities included over 40 + experimental runs across Experiments 1-4. Notably, these runs were followed by After Action Reviews that provided tactical and technical feedback to the participants.

The integral role performed by key support personnel suggests they be regarded as background participants essential to the effort. Three (3) support personnel roles performed by highly experienced SMEs were: higher Friendly commander, Enemy commander, and senior member of the O/C team. The expertise and vision of these background participants in preparing, supporting, and particularly in leading the reviews of experimental runs in AARs was invaluable in helping the participants develop, assess, and refine new approaches to command and control.

C^2 Prototype Functions and Features

Figure 2 depicts a sample view of a C^2 prototype interface used in FCS C^2 experiments. Dual C^2 interfaces were located at each of the four participant workstations in the surrogate C^2 vehicle. These interfaces provided a near real-time common operational picture of the Unit Cell's battlefield situation, such as the Deliberate Attack mission against an enemy battalion shown in Figure 2. The C^2 interfaces were the primary means by which the command group performed basic C^2 functions such as Plan, See, Move, and Strike. Participants relied on their C^2 systems to command and control the Unit Cell assets depicted in Figure 1, particularly to task ground and air robotic platforms and receive information from a mix of ground and air sensors.

As portrayed in Figure 2, the C^2 display was based on a relatively standard interface design of windows, icons, menus, and pull downs (WIMP). The set of windows opened in the Figure 2 indicate some of the C^2 system's functionality. More precisely, the interface shown in Figure 2 reflects the level of functionality and a sample of the new features available to the

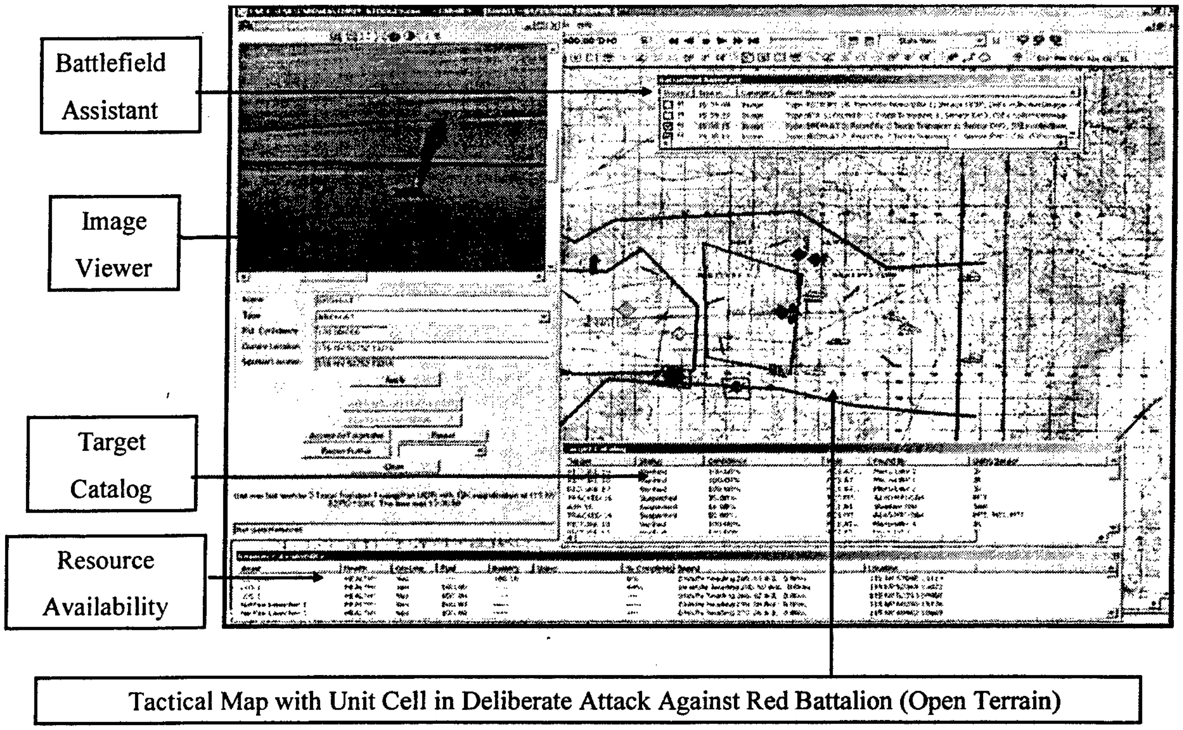

Figure 2. Sample view of a C^2 prototype interface.

command group by Experiment 3. Overall, these and numerous other tools and features could be opened, configured, and used by each participant during the course of a run or mission. The four windowed features opened in Figure 2 are briefly described below:

- Battlefield Assistant provided information regarding various alerts that participants could tailor to their information requirements and activate. For example, alerts could signal the participants when a previously identified and tracked friendly, enemy, or neutral vehicle had crossed a phase line or entered a named area of interest (NAI).
- Image Viewer displayed target images for human target recognition (HTR) and battle damage assessment (BDA). Image Viewer allowed participants to input or revise the information associated with icons on the map including affiliation (e.g., friendly, enemy, neutral), type (e.g., tank, artillery), and status (e.g., suspected target, dead target).
- Target Catalog allowed participants to input or revise information associated with enemy targets including what friendly sensor(s) had identified the target, when the target was identified, and the location and route of the enemy target.
- Resource Availability was used to access and revise information on friendly Unit Cell assets including operational status, available fuel, and current speed and location.

Instrumentation

An adequate assessment of human performance requires a balance between subjective measures about performance and objective measures of performance. The ARI's measurement methods used to assess human performance included a battery of subjective measures and detailed, comprehensive objective measures of verbal and human-computer interaction.

Subjective Measures

The set of subjective measures used to assess human performance expanded from two to ten questionnaires across experiments. Overall, these measures were designed and developed to obtain participant feedback on multiple research issues including: training, skill proficiency, workload, performance success, teamwork skills, decision making, function and task allocations, prototype effectiveness, and human-system integration.

A brief summary of the basic administration schedule is provided before describing some of the subjective measures used. Most questionnaires were administered only once during each experiment. However, several questionnaires such as skill proficiency and training adequacy were administered more often to detect changes across an experiment. For example, during Experiment 4 the training questionnaire was administered before and after the participants completed the set of experimental runs. Only the questionnaires on workload and performance success were routinely administered after each run. By Experiment 4, subjective measures were administered electronically rather than in paper-and-pencil format.

Descriptions of selected subjective measures are provided below to help clarify their corresponding findings reported in the Results section. An overview list and description of all the questionnaires used by ARI during the experiments is provided in Table 2. A complete set of all subjective measures and sample results from each measure obtained during Experiment 3 is provided in an ARI Research Report (Lickteig, Sanders, Durlach, & Carnahan, in preparation).

Workload and performance success. After an In-Place AAR as depicted in Figure 3, participants exited the C^2 Vehicle and completed a brief survey on Workload and Performance Success. Participants rated their perceived workload across five dimensions: Mental, Physical, Temporal, Effort, and Frustration (1 = Low to 100 = High). The workload questions and dimensions were adapted from the relatively standard Task Load Index (TLX) from the National Aeronautics and Space Administration (NASA-Ames Research Center, 1986). Performance success by duty position was rated on the TLX questionnaire in an item worded "How successful were you in accomplishing what you were asked to do? (1 = Failure to 100 = Perfect).

New C^2 prototype features effectiveness. This questionnaire was developed to more precisely assess the value of the new C^2 prototype features added for Experiment 3. It asked the participants to rate the effectiveness of 13 new prototype features on a 5-point scale (1 = Very Ineffective to 5 = Very Effective). The questionnaire was administered after earlier and later runs to determine if perceived effectiveness of the new features changed with experience. This questionnaire was adapted and administered by a supporting contractor during Experiment 4.

Table 2

Description of Subjective Measures by Item Content and Response Format

Subjective Measure	Item Content	Response Format
*Workload Task Load Index (TLX) (NASA-Ames, 1986)	Mental, physical, temporal, effort, and frustration scales.	(1 = Low to 100 = High)
*Performance Success	How successful were you...?	(1 = Low to 100 = High)
*C^2 Prototype New Features Effectiveness	How effective were the new C^2 prototype features listed...?	(1 = Very Ineffective to 5 = Very Effective)
C^2 Prototype New Features Workload	How did the new C^2 prototype features impact workload?	(1 = Increased Greatly to 5 = Decreased Greatly)
C^2 Prototype Support of Human-Computer Interactions	How effective was the C^2 prototype in support of the C^2 interactions listed ...?	(1 = Very Ineffective to 5 = Very Effective)
C^2 Prototype Effectiveness for C^2 Functions and Mission, Enemy, Terrain, Troops, Time and Civilians (METT-TC) Factors	How effective was the C^2 prototype for C^2 Functions and METT-TC Factors listed below...?	(1 = Very Ineffective to 5 = Very Effective)
C^2 Teamwork Skills	Provide examples of effective and ineffective teamwork skills for the C^2 tasks listed below ...	Open-ended comments
C^2 Decision making	Describe important decisions you made how C^2 features supported each decision...	Open-ended comments
Skills Proficiency	Rate your individual and the group's collective proficiency.	(1 = Extremely Low to 9 = Extremely High)
*Training Adequacy	How adequate was training content and time for individual and collective skills?	Open-ended comments
Human Systems Integration (Durbin, 2002)	HCI workload and difficulty. Usability of the C^2 prototype.	Rating/checklist formats Open-ended for problems and recommendations.
*In-Place AAR (After Action Review) Interview	What went right and what went wrong?	Open-ended comments

Note. * Indicates sample measures described and sample findings provided in this report. All subjective measures and sample results from Experiment 3 are provided in Lickteig, Sanders, Durlach, & Carnahan, in preparation.

Training. A training adequacy questionnaire was routinely administered after the participants had completed all individual and collective training and before their first experimental run. Hence, it was called a Pre-Run survey. For Experiment 4, the same training adequacy questionnaire was also administered after the participants had completed all of the experimental runs, called a Post-Run survey. Four open-ended items asked participants to assess the adequacy of the individual and collective training in terms of content and time allotted.

Objective Measures

Instrumentation for objective measures of human performance primarily included video/ audio recordings of all experimental runs from multiple perspectives. Recordings included a separate wide-angle view of each participant taken from across the interior of the C^2 vehicle. The wide-angle perspectives were combined into a quadraplex recording of the participants that greatly assisted verbal analysts in transcribing and coding verbalizations into pre-defined categories, such as the source and function of each communication.

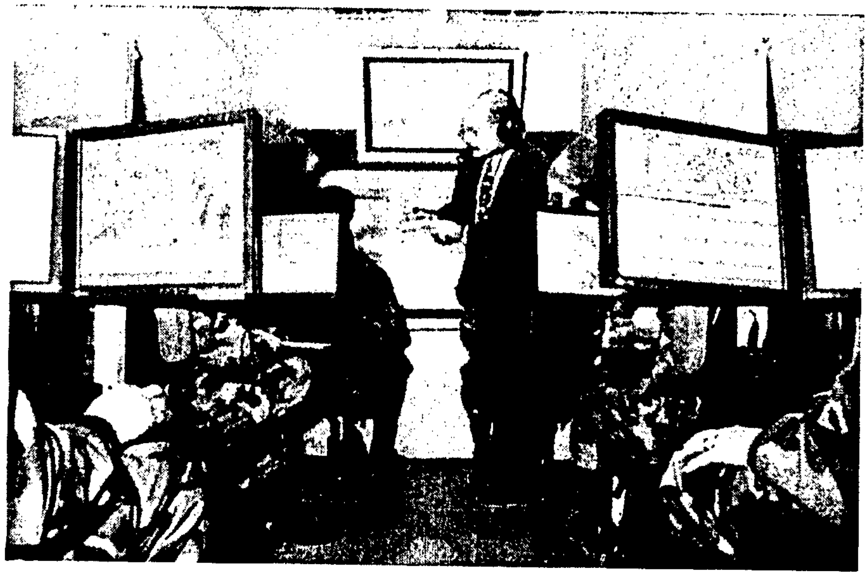

Figure 3. In-Place AAR conducted in surrogate C^2 vehicle.

In addition, eight separate recordings provided a dedicated view for each of the two C^2 interfaces at each of the four participant workstations in the C^2 vehicle. These recordings of each C^2 interface were reviewed extensively by the human-computer interaction analysts to code and tabulate all participant interactions with their C^2 prototypes. Unfortunately, low-resolution video prevented HCI analysis for Experiment 1. Therefore, instrumentation upgrades were made to digital format for the eight C^2 interface recordings for Experiments 2-4.

During each experimental run, these and additional recordings were streamed to multiple locations throughout the FCS C^2 testbed to support observation by members of the Operational, Technical, and Human Performance teams, as well as to a Visitors Observation room.

By Experiment 4, refinement of objective measurement methods added a dedicated suite of observer workstations that allowed four observer teams to more closely monitor the four participant workstations. The four displays available at each observer workstation provided on-call access to any of five different perspectives: the two participant C^2 interfaces for the duty position they were assigned to observe, the Heads-Up Display near the front of the C^2 vehicle, the "ground truth" battlefield situation from the One Semi-Automated Forces Testbed Baseline (OneSAF OTB), and the quadraplex overview of the four command group participants. Data loggers also captured the performance of simulated friendly and threat entities during exercises and a small subset of automated measures on participant interactions with their C^2 prototypes.

This overall suite of instrumentation for objective measures resulted in the two types of objective human performance data, verbal and human-computer interactions, described in the subsequent section "Evaluation Framework." For Experiments 3 and 4, ARI's analysis of these objective measures during the execution phase was extended to include the planning phase for selected experimental runs.

Automated Measures

Automated measures of C^2performance are required to support training, evaluation, and C^2 system design (Unit of Action Maneuver Battle Laboratory, 2003). Notably, this new FCS requirement for automated measures, particularly measures of human-computer interaction, applies to FCS prototype and fielded C^2 systems.

An ARI measurement goal was to promote the development of automated measures of C^2 performance. Only minimal progress toward that goal was made during the FCS C^2 experiments. However, the approach taken and lessons learned are documented here to underscore the work required and payoff available by automating many of the human-machine performance measures integral to future command and control.

Automated measures of human-computer interaction can provide efficient and effective measures of command and control performance. The efficiency of automated measures equates to quick and inexpensive. It includes the ability to adjust the range and selection of data to include the performance of any or all C^2 users at any or all times during an operational exercise. The effectiveness of automated measures equates to increased scope and precision in the collection of C^2 performance data. It includes more meaningful measures by automatically correlating C^2 performance with the battlefield situation in which it occurred.

In contrast, manual data capture and reduction of command and control performance can only examine a fraction of the data available from any training, testing or evaluation effort. The burden in labor and time to provide objective and direct measures of command and control performance is practically unbearable (Brown, Nordyke, Gerlock, Begley, & Meliza, 1998; Lickteig & Quinkert, 2001). Manual measures are unresponsive to pressing timelines, including training feedback and performance support requirements. The manual measurement methods reported here to obtain objective data on C^2 performance attest to that burden, and limited the analysis of all verbal and human-computer interactions by the command group to selected runs.

After Experiment 2 and ARI's first analysis of HCI performance, ARI requested that a set of key automated measures be developed to support human performance assessment. Table 3 lists and describes the 23 automated measures requested to capture command group interactions with their C^2 prototypes. Validation methods compared the automated data from Experiment 3 with ARI's manually derived data on corresponding HCI measures.

Evaluation Framework

The human performance issues for future battle command were based on a functional analysis of the Unit Cell's command group performance. The set of C^2 functions adapted from the experimental design for analyzing verbal and human-computer interactions is bulleted below:

- Plan: Develop, assess, and modify plans including tasking for unmanned air/ground assets in response to changing events.
- See: Control/interpret input from set of manned/unmanned networked sensors to maintain accurate battlefield "picture."
- Move: Control movement/activity manned/unmanned assets.
- Strike: Control manual/automated networked fires.
- BDA: Control/interpret input from set of manned/unmanned networked sensors for battle damage assessment (BDA).

A method inconsistency noted is that BDA was categorized as separate function for verbal analysis, but as a sub-function under the See function for analysis of human-computer interactions.

Table 3

Automated Measures Requested by ARI for Experiment 3

Measurement Category Automated Measure
See
Number of pictures/images available.
Number of pictures/images with actual enemy image of those available.
Number of pictures/images opened.
Amount of time manipulating pictures (zoom, contrast, pan) to improve image.
Number of times *same* picture opened by *same* individual.
Number of times *same* picture opened by *different* individuals.
Alerts
Number and type of alerts set by duty position.
Number and type of alerts triggered/activated by duty position.
Time to respond to alerts by turning it off.
Number of times robotic vehicles auto halt (red line under the vehicle).
Time to respond to auto halt to re-tasking the entity.
Number of fratricide warnings (identify shooter/target pair).
Move Assets
Number of times and task duration for Create a Route (ground platform).
Number of times and task duration for Create a Route (air platform).
Strike
Number of times weapon fired and task duration (Netfire, Line of Sight (LOS), Infantry Fighting Vehicle [IFV]).
Number of times "Reassign" menu option selected for Loitering Attack Missile (LAM).
Number of times target Type changed by selecting "Apply" button in Recon Window.
Number of times Target Status modified by selecting "Suspected," "Targeted," "Dead," etc.
Number of times sensors tasked to recon targets by selecting "OK" from Recon Target menu.
Assess Icon and Map Information
Number of times cursor moved over a platform to bring up information window.
Number of times "Templated" targets toggled off in status toolbar.
Number of times Zoom Map options selected (box and/or arrows menu option).
Number of times scroll arrows used for map manipulation.

Verbal Analysis

Verbal interactions from selected runs were analyzed based on transcribed voice communications among the command group participants, and the participants' communications with the higher and lower elements role played by supporting personnel. The verbal transcripts were first "chunked" into more meaningful blocks of communication for subsequent coding. Chunking required researchers to evaluate the communications and then group a cluster of dialog together that appeared to be unitary and consistent. The goal of chunking was to create coherent blocks of dialog that were specific enough in they did not fall under multiple rating categories.

Chunking and classifying communications into meaningful categories often requires a consideration of context and a degree of interpretation that broadens disagreement between raters independently assigning codes to each verbal chunk. If raters fail to agree in their coding, then one must question the reliability of the method and validity of the results. One way to increase inter-rater agreement is to identify smaller chunks or samples of verbal data in order to narrow the range of interpretation. To improve the low inter-rater agreement levels obtained with larger chunks from Experiment 1, communications from Experiments 2-4 were classified into smaller chunks. By Experiment 2, refinements in analysis methods including smaller verbal chunks resulted in more acceptable inter-rater values ranging from .86 for Factor to .99 for Source.

The primary categories that were used to code each block or chunk of verbal interaction by the command group participants included:

- Function: Plan, See, Move, Strike, and BDA.
- Source: Within Cell, Cell-Lower, Cell-Higher, Higher-Higher.
- Factor: Mission, Enemy, Terrain, Troops, Time, and Civilians.
- Type: Share, Act, Direct, Ask, Process, and Decide.
- System: Platform break-out of air/ground assets.
- Valence: Positive versus negative status information.
- Command Considerations: Cognitive requirements of battle command.

The latter categories of Valence and Command Considerations were method refinements introduced for Experiments 3 and 4. Valence codes were added to distinguish communications conveying positive versus negative status on accomplishing basic C^2 functions and tasks. Command Considerations codes and classifications, such as situational awareness, were added to relate battle command verbalizations to cognitions.

Human-Computer Interaction Analysis

Human-computer interactions (HCI) were analyzed based on manual review and tabulation of all command group participant interactions with their C^2 prototypes based on the digital recordings of their C^2 interfaces. Eight HCI logs were developed for each run analyzed; one for each of the dual displays at the four participant workstations. In addition, a Heads-Up Display (HUD) ceiling-mounted in the forward area of the C^2 vehicle (see Figure 2) provided a shared display to which participants could toggle any of their screen displays at any time. While HCI logs captured participant use of the HUD, no recording of the information on the HUD was available to ARI researchers. As noted, HCI analysis was not performed for Experiment 1 due to low-resolution video. In addition, HCI analysis was limited to selected runs from Experiments 2-4 due to the high analyst workload required in reviewing and tabulating video data from the eight C^2 interfaces used by the participants.

HCI coding categories were based on the C^2 functions of Plan, See, Move, and Strike. More detailed analysis identified supporting sub-functions and interactions, shown in Figure 4. HCI coding was refined across experiments as new features were added to the C^2 prototype, such as automated fires and route generation routines. For Experiments 2-4 respectively, the HCI codes were expanded from 53 to 83 to 95 different types of interaction. By Experiment 3, refinements in HCI methods resulted in inter-rater agreement of 96%.

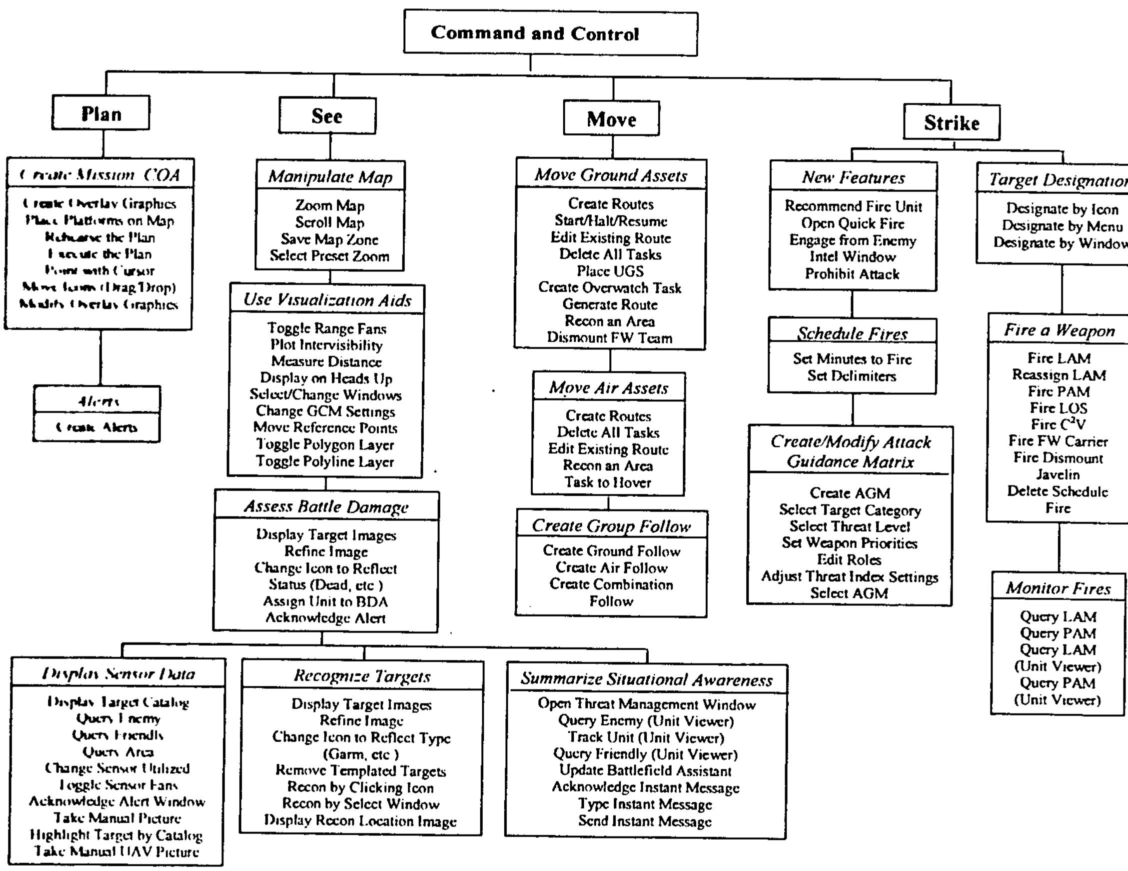

Figure 4. Evaluative framework for HCI analysis, Experiment 4.

Analysis

Analytic methods and descriptive statistics were chosen to complement the exploratory versus controlled nature of the FCS C^2 experiments. Comparisons within experiments were often complicated by technical issues, particularly for Experiments 1 and 2. Between runs, technical changes were sometimes required to reduce system crashes and to revise inadequate sensor models and user-identified shortcomings in prototype features.

Comparisons across experiments were complicated by the program's deliberate focus on new approaches to battle command that stressed exploration and iterative refinement of system and human parameters to meet emerging operational and doctrinal requirements for FCS (Unit of Action Maneuver Battle Laboratory, 2003). For example, the C^2 prototype used during Experiment 1 was estimated as providing only about 20% of the full functionality envisioned by FCS.

As experiments progressed, new technologies were added, and older technologies were refined or abandoned based on lessons learned. System refinements and changes in the command group's Standing Operating Procedures (SOPs) resulted in repeated and progressive changes in the allocation and performance of command group functions and tasks. Similarly, Unit Cell performance requirements expanded from See/Move functions in Experiment 1 to Improved See/Move/Strike and Sustain functions by Experiment 4.

As noted, more formal consideration of the Plan function was stressed by ARI during Experiments 3 and 4. Accordingly, the results reported below will include the verbal and human-computer interactions of the participants during the planning and execution phases of selected runs. By Experiment 4, this emphasis on planning resulted in more controlled experimental procedures during the planning phase, including the requirement for a brief of the plan by the participant Unit Cell Commander to Higher prior to the execution phase.

Results and Discussion

A small and representative sample of the human performance results from FCS C^2 Experiments 1-4 is provided in this section. The sample includes subjective and objective measures of performance to help understand and improve command group performance in future FCS organizations.

A more complete account of the human performance results from each experiment is provided in ARI's Interim Reports to PM FCS C^2. For Experiment 3, more complete results on human performance are also provided in Lickteig, Sanders, Durlach, and Carnahan, in preparation. Operational results, including measures of performance and effectiveness, were documented by other researchers and are also available from PM FCS C^2.

Subjective Results

A select set of subjective results from the FCS C^2 experiments is provided in this section under the topics of workload, human performance, system performance, and training. A sample of participant comments from the In-Place AARs is included to present an "in their own words" account of participant feedback, and to indicate the range of subjective information on human performance provided to and available from PM FCS C^2.

Workload

Workload was targeted as a key human performance concern given the FCS goal of reducing the command group personnel assigned to a small unit with manned and predominantly robotic elements. Therefore, the Too High level of run complexity was designed to test human-system limitations and more precisely identify workload and performance thresholds of the proposed command group structure and Unit Cell organization.

Figure 5 depicts exemplar results on subjective ratings of workload from Experiment 3 by duty position and run complexity. Mean workload values were calculated by averaging participant ratings across the scale items on the mental, physical, temporal, effort, and frustration dimensions of work.

Figure 5 indicates an increase in command group workload particularly during the Too High runs. The increase was most pronounced for the duty positions of Battlespace Manager and Information Manager during more complex runs. Workload ratings by complexity from Experiments 1 and 2 showed a similar pattern. Recall, complexity was not varied during Experiment 4.

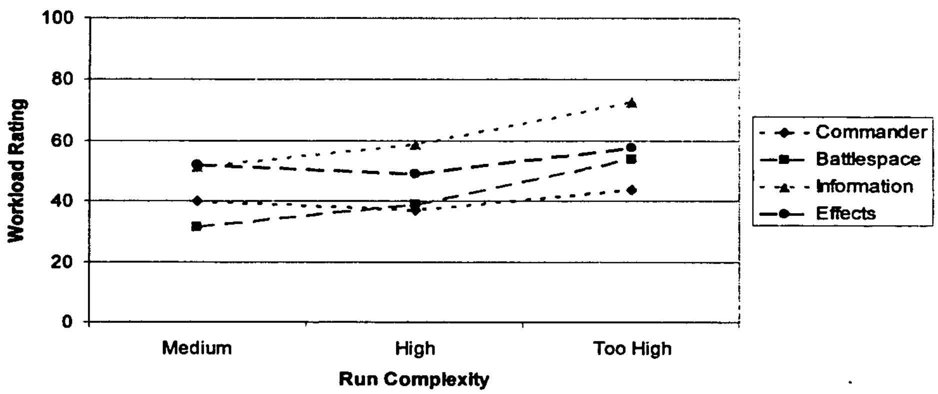

Figure 5. Mean workload ratings by duty position and run complexity, Experiment 3. (Scale: 0 = Very Low, 100 = Very High)

Across the four experiments, a comparison of workload ratings by duty position is shown in Figure 6. When averaged across duty positions and run complexity for Experiments 1-3, the overall mean workload ratings were: 58, 61, 49, and 69 for Experiments 1-4, respectively. However, caution is exercised and urged in efforts to explain apparent differences in workload ratings between experiments.

In sum, the subjective results suggest that the participants experienced moderate to high levels of workload in the FCS command group and the Unit Cell organization as examined. Subjective workload was not uniform across duty positions. The Battlespace Manager and particularly the Information Manager generally reported higher workload across experiments. Overall, the results suggest that during more complex runs the participants were relatively busy, if not stressed, by the workload required to command and control Unit Cell, particularly the array of unmanned ground and air assets proposed for smaller FCS units.

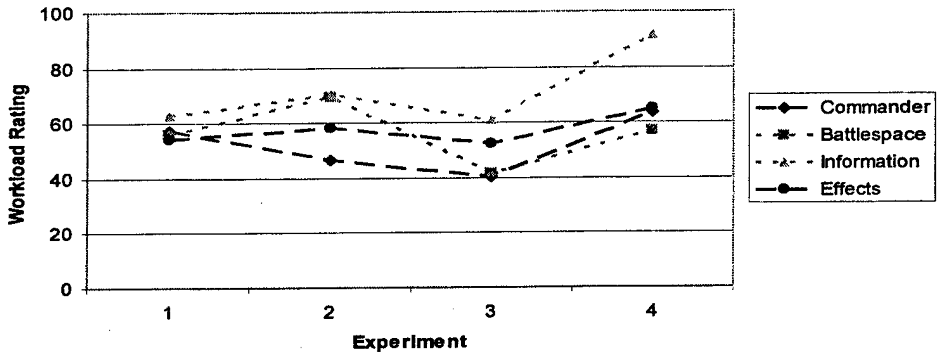

Figure 6. Mean workload ratings by duty position, Experiment 3.
(Scale: 0 = Very Low, 100 = Very High)

Human Performance

Performance success is almost always a key concern. From a human performance perspective, ARI focused on participant ratings of successful performance relative to their duty position requirements. Figure 7 summarizes ratings of performance success from Experiment 3 by duty position and run complexity. Results indicate a relatively sharp decline in performance success at the Too High level of complexity across the four command group participants.

Particularly, the Information Manager's low ratings may indicate serious human system integration issues. Issues identified included the difficulty of controlling the Unit Cell's unmanned aerial vehicles (UAVs) and analyzing the larger amount of sensor images in the Too High condition. Performance success ratings by run complexity were similar for Experiments 1 and 2 and were not available for Experiment 4.

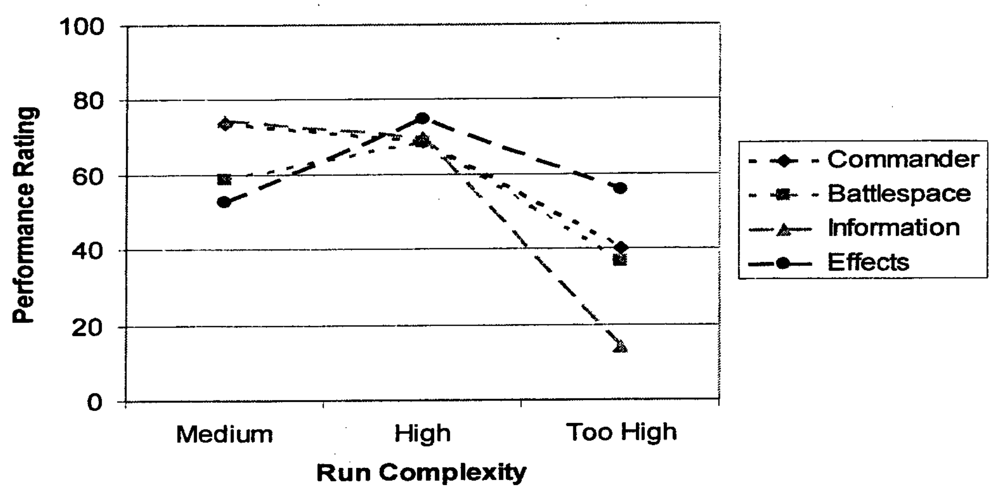

Figure 7. Mean performance success ratings by duty position and run complexity, Experiment 3.
(Scale: 0 = Failure, 100 = Perfect)

System Performance

More precise subjective measures were developed to assess the effectiveness of key new features in the C^2 prototype, as they were progressively introduced into the experiments. The largest suite of new features was inserted in Experiment 3, as suggested by an increase in HCI codes from 53 to 83 between Experiments 2 and 3. The 13 new features added for Experiment 3 are identified in Figure 8.

Figure 8 depicts mean ratings of feature effectiveness averaged across duty position and selected runs (Runs 5 and 10) from Experiment 3. Overall, most of the new features received positive ratings. For example, "Very Effective" ratings were given to two Attack Guidance Matrix (AGM) features that automated some time-consuming and time-limited tasks under the Strike function.

In contrast, a See-related feature called HTR Viewer (Human Target Recognition) and a Move function feature called Group Tasking were rated "Ineffective" to "Neutral." Notably, questionnaire results on new feature effectiveness included written comments obtained from each participant that were routinely used to help assess and refine the features of the C^2 prototype for future efforts.

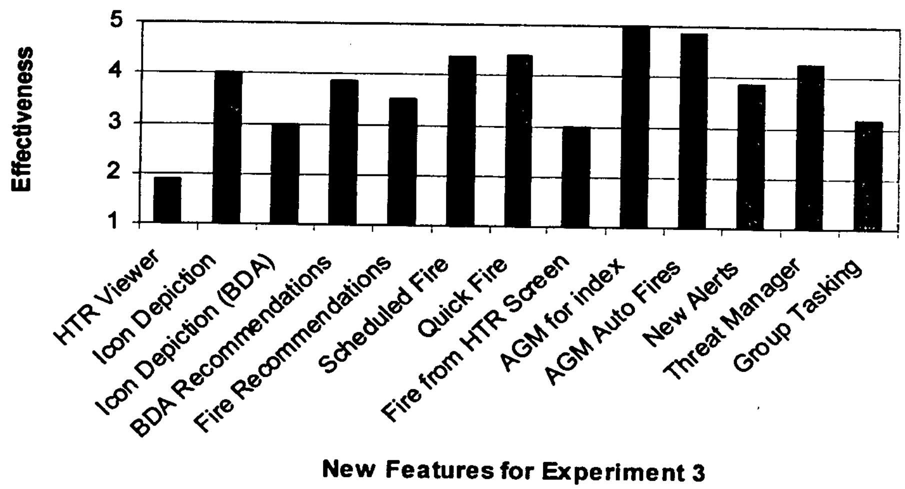

Figure 8. Mean ratings of new features effectiveness, Experiment 3.
(Scale: 1 = Very Ineffective, 5 = Very Effective)

Training

Results on training are based on participant feedback on the training questionnaires and author observations. Overall, training improved substantially over the course of experiments including development and refinement of a User's Manual, primarily for individual training. However, shortcomings in training were observed and confirmed by participants that impacted performance, and may impact future performance in FCS units.

Notably, participants were more critical about training on the Post-Run versus Pre-Run training survey from Experiment 4. This finding seems a reminder that often "you don't know what you don't know" until you do the job, or do the research. Even after Experiment 4, the command group participants who had completed 40+ runs across experiments expressed strong concerns about training and their ability to fully exploit Unit Cell capabilities:

- Need more hands-on in tactical scenarios or vignettes, less lecture. Putting the lesson in a tactical situation really lends credence to the function you are teaching and demonstrates why you want to learn it as well as how it is best employed.
- Training should be more dedicated to actual employment techniques. We could have used more time integrating as a team.
- We get more functional every run, what we need are a couple runs designed for us, not to be critiqued (i.e., in AAR), but for us to re-establish SOPs.... Not an easy task.....

Overall, the training results stressed the need for progressive, structured training with simulation-based feedback during and after performance. These and related training issues will be addressed in subsequent sections of this report titled "Status Report on Research Objectives" and "Conclusions."

In-Place AAR

A sample of comments provided by each of the four participants during the In-Place AAR is provided below. Overall, the data provided to the PM FCS C^2 generally included all participant comments recorded by duty position during the In-Place AARs. Sample comments below are from three runs during Experiment 4. Comments are directly from the participants by run and duty position with minor editing, including acronyms spelled out for clarity.

Battlespace Manager Comments:

- Run 2. What went well was that we did one group mount, no group follow, no auto route; all manual. Zoomed down to identify navigable trails, auto route would not have worked. Good UAV coordination painting the Valley of Death. Flanked him and turned him out of position.
- Run 6. There were more targets than we could service. Almost impossible to discriminate between live and dead targets. The enemy was so close he moved under rounds. Blue could only maneuver North and South as we had our back against the wall.
- Run 8. What went wrong, one vehicle got stuck, and I really don't know why. Turning range fans off and on worked well. Group follow worked, generally happy with the run.

Information Manager Comments:

- Run 2. Had one sector to focus on, the South main avenue. Had no pictures in the Micro UAV (Unmanned Aerial Vehicle) quad view images.
- Run 6. I agree with the Battlespace Manager. There were too many images, too much clutter, smoking, confusing images, dual images. There were a lot of enemy assets up front that knocked out our assets. Couldn't tell whether targets were dead or alive.

- Run 8. Auto functions worked, namely Auto Recon and Recon Location. What went bad was that Shadow died flying low. Micro UAVs worked well to confirm the target set. We could have gotten through to the objective.

Effects Manager Comments:

- Run 2. Changed things today, started with blank AGM (Attack Guidance Matrix) so it didn't interfere with manual fires. The AGM—best ever dealing with all the targets that popped up—saved time and allowed for me to focus on the mid-range battle.
- Run 6. Not too many targets for AGM to engage, the problem was that there were too many images. The tradeoff is that when there are a lot of images there is no time for image assessment. There is not a problem with engaging targets. The test managers have got to extend the terrain box; we would have never put ourselves into that position with Red directly in front.
- Run 8. A bit more ammunition consumption than earlier runs. The commander used me like a lawn mower.

Unit Cell Commander Comments

- Run 2. What went right was the early read, and Blue Higher coordination for A-160 sensors support. Maneuver went good: go South which was his weakness, single envelopment into his move. Best run across all experiments. We got a lot out of Shadow, tradeoff worth it.
- Run 6. We cannot discriminate targets, so we miss some, and those engaged are not all destroyed, an effect of munitions used, so BDA is challenging. There was no room in the box to maneuver. Can't discriminate between dead and live targets.
- Run 8. Good read early. Did not have great read on enemy's air defense. Overall good read, the plan allowed us to destroy him in detail.

Objective Results

A small representative sample of objective results is provided in this section based on the command group participants' verbal and human-computer interactions.

Verbal Interaction

Results on the verbal interactions of command group participants across Experiments 1-4 are organized by C^2 function, source, amount, and valence.

C^2 Function. What is the function of communication? The analysis of verbal interaction addressed this question by relating participant communications to the basic C^2 functions of Plan, See, Move, Strike, and BDA. Figure 9 provides exemplar data on percentage of verbalizations across duty positions by C^2 function during Run 10 from Experiment 4.

Verbalizations related to the See function were clearly the most frequent, about 30% of all participant verbal communications. This result appears to underscore the command group's extensive effort to control and interpret input from a set of manned and particularly unmanned networked sensors to maintain an accurate battlefield "picture." Strike and BDA were also main topics, reflecting the command group's focus on destroying and clearing enemy threats to their Unit Cell and follow-on forces.

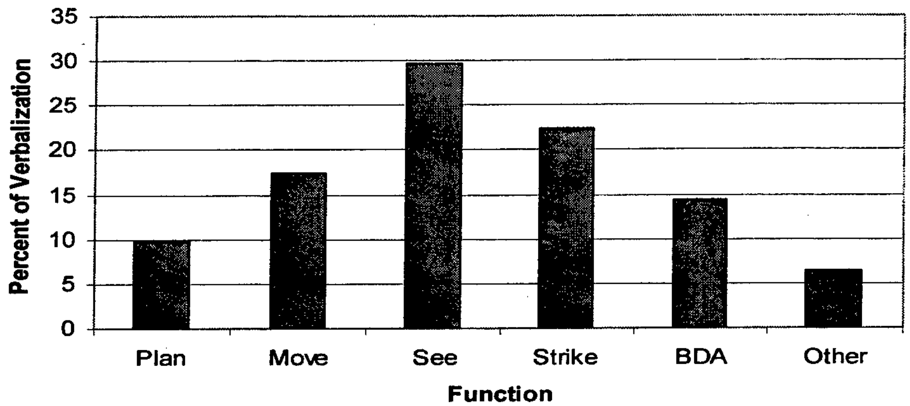

Figure 9. Percent of verbalization by function, Experiment 4.

Source. Who's talking? A key to understanding command and control verbalizations is tracking the source. Initial analysis found that across experiments approximately 90% of all verbalizations occurred within the command group. Remaining verbalizations were primarily between the command group and surrogate higher and lower elements role-played by support personnel. Subsequent analysis more closely examined the source of command group verbalizations. Figure 10 depicts the mean percentage of verbalizations by duty position across experiments. The Commander was clearly the dominant source of the command group's verbalizations. Across the four experiments, the mean percentage of communications initiated by participant was: 53% for the Commander, 19% for the Information and Battle Space Managers, and 8% for the Effects Manager.

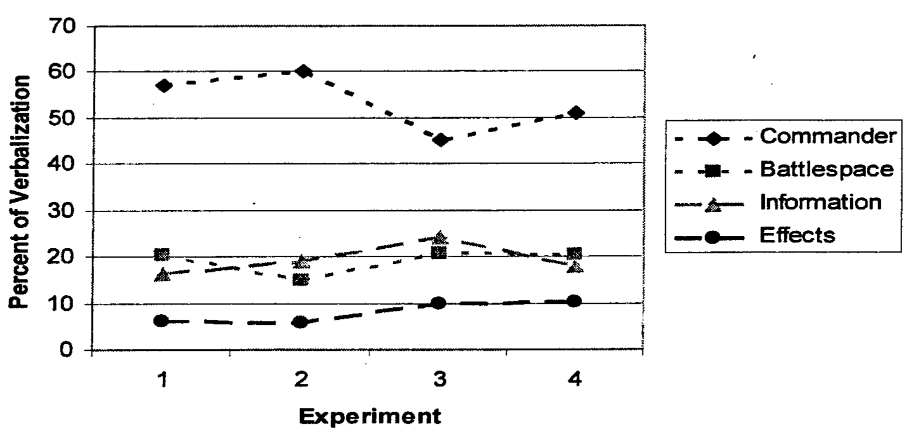

Figure 10. Percent of verbalization by duty position across experiments.

Amount. An interesting aspect of the verbal data is that verbal interaction by the command group was an almost continuous activity. Breaks in verbalization, or silent time, averaged 7% of total run time across experiments. The finding that verbalizations occurred 93%

of the time during the execution phase appears noteworthy. The pattern of steady conversation occurred notwithstanding the participants' common access to a visually rich and timely depiction of the battlefield situation on their C^2 displays. It also occurred despite numerous ongoing human-computer interactions to see the battlefield and control robotic entities (see HCI results below). Such results highlight the very important role of verbal communication for battle command *collaboration*, even with advanced information technologies.

Valence. A perceived shortcoming in verbal analysis after Experiment 2 was a failure to account for positive versus negative information. Evaluative meaning is conveyed, or sought, in nearly all communication. For command and control, evaluative information should directly support the decision making process. Valence codes were added for Experiments 3 and 4, therefore, to discern what verbalizations conveyed on the status of accomplishing C^2 functions and tasks.

Figure 11 shows mean verbalization percentages by valence from Run 10, Experiment 3. This figure provides valence data by C^2 function and time, namely run quartiles. Overall, most verbal communications conveyed positive information on the status of accomplishing C^2 functions and tasks. However, communications related to Move and BDA functions were more negative. Negative verbalizations were especially useful in identifying and addressing shortcomings in the C^2 prototype, such as difficulty with Group Follow tools and BDA.

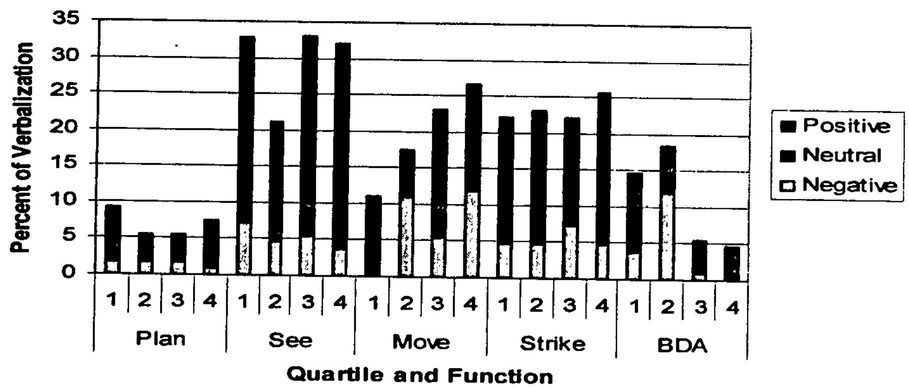

Figure 11. Percent of verbalization by function, valence, and time (quartiles), Experiment 3.

Human-Computer Interaction

Results on the human-computer interactions of command group participants across Experiments 2-4 are organized by C^2 function, duty position, workload, and time.

C^2 Function. FCS concepts, particularly for command and control, rely heavily on an alliance of humans and computers. To better understand and build the alliance, an in-depth HCI analysis was performed on selected runs. The analysis tabulated and related each and every human-computer interaction by the command group to the C^2 functions and sub-functions that were previously identified (see Figure 4). The HCI codes and analysis methods were expanded and revised to address the increase from 53 to 95 different types of interactions, as features were added or modified between Experiments 2-4.

Table 4 provides an exemplar result of the HCI frequency data obtained for the FCS C^2 experiments. Notably, the data provided in Table 4 is from the *planning* phase of a run from Experiment 3. Data from a planning phase is provided to indicate the scope of results provided to and available from PM FCS C^2. The planning data will also be used here to help describe some of the key C^2 prototype features and related human-computer interactions that supported the Plan function.

Table 4 provides a detailed account of the 499 total human-computer interactions performed and tabulated by duty position during the planning phase of Run 10, Experiment 3. Note, only 9 of 17 sub-functions and 26 of the 83 types of interaction available on the C^2 prototype for Experiment 3 were actually performed during the planning phase for this run.

A graphic summary of the same planning data is provided in Figure 12 that depicts HCI frequency by C^2 function. During this relatively typical planning phase the overall percentage of command group interactions across duty positions by C^2 function was: Plan (36%), Move (11%), See (51%), and Strike (2%).

An interaction particularly indicative of the C^2 prototype's features in support of the Plan function was repeated (22 times) use of the Rehearse Plan animation tool. The Rehearse Plan tool pictorially depicted the combined movement of ground and air assets across the battlefield, as planned. This animation tool was used to coordinate plans within the command group and especially to provide dynamic back-briefs of the plan by the Commander to higher echelons.

See-related interactions during planning primarily involved using the Query tool by moving the cursor over Enemy (65 times) and Friendly (44 times) icons to access information such as vehicle type and position, and the Plot Intervisibility tool (27 times) to view cover and concealment during the planning of ground and air asset movement. Other interactions in support of the Plan function primarily involved designating vehicle icon locations and routes, and inserting graphic control measures.

Duty Position. Figure 13 provides an exemplar summary of HCI frequency by function, duty position, and display during the subsequent *execution* phase of Run 10, Experiment 3. Overall, the 1,044 human-computer interactions performed and tabulated in the execution phase were associated with the following functions: Move (5%), See (75%), and Strike (20%).

In general, interactions in support of the See function were most frequent in the execution phase, as in planning. Also, the fact that almost no Plan-related interactions were observed during execution may reflect limitations in system design and analysis methods that should be overcome in future efforts, and that planning was to some extent curtailed by the deliberate practice design.

Table 4

Frequency of HCI by Duty Position in Planning Phase, Experiment 3

Command and Control Function / Sub-function / Interaction	Commander		Battlespace Manager		Information Manager		Effects Manager	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Plan	76	63.3	42	25.8	60	35.7	1	2.1
Create Mission/Course of Action (COA)	76	63.3	42	25.8	60	35.7	1	2.1
Create Overlay Graphics	---	---	1	.6	---	---	---	---
Place Platforms on Map	1	38	---	---	14	8.3	---	---
Rehearse the Plan	4	3.4	10	6.1	8	4.8	---	---
Move Icons (Drag/Drop)	70	58.3	21	12.9	28	1.7	1	2.1
Modify Overlay Graphics	1	.8	10	6.1	10	6.0	---	---
Move	---	---	25	15.3	26	15.5	1	2.1
Move Ground Assets	---	---	24	14.7	5	3.0	1	2.1
Create Routes	---	---	7	4.3	---	---	---	---
Edit Existing Route	---	---	4	2.5	---	---	---	---
Delete all Tasks	---	---	8	4.9	5	3.0	1	2.1
Create Overwatch Task	---	---	1	.6	---	---	---	---
Generate Route	---	---	4	2.5	---	---	---	---
Move Air Assets	---	---	---	---	21	12.5	---	---
Recon an Area	---	---	---	---	21	12.5	--	---
Group Follow	---	---	1	.6	---	---	---	---
Create Ground Follow	---	---	1	.6	---	---	---	---
See	44	36.7	96	58.9	82	48.8	34	7.08
Manipulate Map	10	8.3	10	6.2	15	8.9	18	37.5
Zoom Map	8	6.7	6	3.7	12	7.1	7	14.6
Scroll Map	2	1.6	4	2.5	3	1.8	11	22.9
Use Visualization Aids	6	5.0	47	28.8	14	83	2	4.2
Plot Intervisibility	---	--	27	16.6	---	---	---	---
Display on Heads Up	---	---	2	1.2	---	---	---	---
Select/Change Windows	6	5.0	11	6.7	14	8.3	2	4.2
Change Graphic Control Measure (GCM) Settings	---	---	7	4.3	---	---	---	---
Display Sensor Data	26	21.7	39	23.9	44	26.2	12	25.0
Query Enemy	17	14.2	10	6.1	31	18.5	7	14.6
Query Friendly	9	7.5	27	16.6	13	7.7	5	10.4
Toggle Sensor Fans	---	---	2	1.2	---	---	---	---
Recognize Targets	2	1.7	---	---	9	5.4	2	4.2
Change Icon Type	2	1.7	---	---	9	5.4	2	4.2
Strike	---	---	---	---	---	---	12	25.0
Fire a Weapon	---	---	---	---	---	---	12	25.0
Fire LAM	---	---	---	---	---	---	3	6.3
Fire Precision Attack Missile (PAM)	---	---	---	---	---	---	6	12.5
Fire LOS	---	---	---	---	---	---	1	2.1
Delete Fire Tasks	---	---	---	---	---	---	2	4.2
Total	120	100	163	100	168	100	48	100

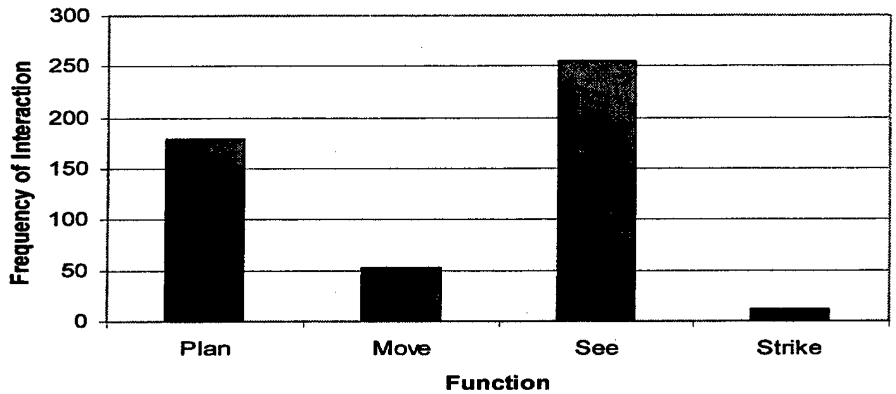

Figure 12. Frequency of interaction by function during planning phase, Experiment 3.

Duty Position. Figure 13 provides an exemplar summary of HCI frequency by function, duty position, and display during the subsequent *execution* phase of Run 10, Experiment 3. Overall, the 1,044 human-computer interactions performed and tabulated in the execution phase were associated with the following functions: Move (5%), See (75%), and Strike (20%). Overall, interactions in support of the See function were most frequent in the execution phase, as in planning. Also, the fact that almost no Plan-related interactions were observed during execution may reflect limitations in system design and analysis methods that should be overcome in future efforts, and that planning was to some extent curtailed by the deliberate practice design.

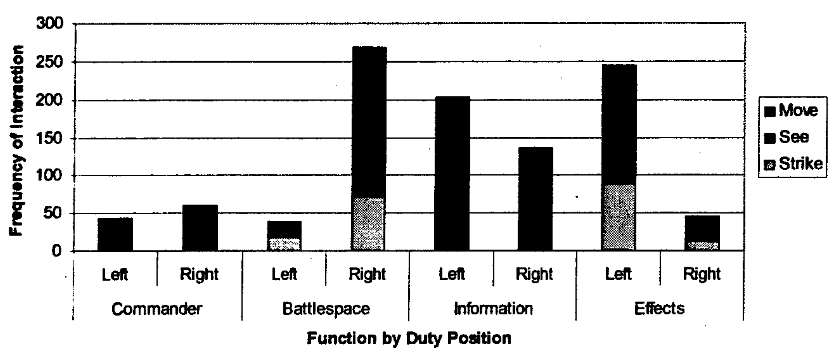

Figure 13. Frequency of interaction by function, duty position and display, Experiment 3.

A brief description of some key command group interactions during the execution phase is provided below by duty position to help clarify the type and range of potential interactions required by a command group in smaller FCS units:

- Commander interactions were almost exclusively (96%) See-related interactions during execution. Majority of Commander's interactions were Display Sensor Data tasks to access Enemy data, and use of the Unit Viewer to maintain situational awareness and status data on key Friendly and Enemy assets.

- Battlespace Manager interactions by C^2 function were primarily See (60%), Strike (29%), and Move (9%) related. Strike interactions were mainly Target Designate (41 times) and Fire Weapon (46 times). Move-related interactions included navigating ground assets by deleting previously entered planned routes and entering new routes, as well as starting, halting, and resuming movement patterns.
- Information Manager interactions were primarily See (89%) and Move (8%) related actions. Particularly, the See-related interactions included repeated call-up and review of sensor images in support of Human Target Recognition (HTR) and BDA. Movement interactions included routing and positioning air assets, mainly unmanned aerial vehicles (UAVs).
- Effects Manager interactions primarily supported See (64%) and Strike (35.4%) functions. Strike actions included Target Designate (28 times), Fire Weapon (32 times), and Monitor LAM/PAM) (Loitering Attack Missile and Precision Attack Missile) engagements (24 times). See-related interactions included numerous Manipulate Map (91 times) and Display Sensor Data (62 times) actions.

Figure 13 also provides HCI frequency by display, or C^2 interface. As the participants' dual displays were equivalent and redundant, Figure 13 indicates how each participant elected to perform interactions by display. Display preferences were clearly not uniform: left display used primarily by the Effects Manager, right display by the Battlespace Manager, and fairly balanced left and right display use by the Commander and the Information Manager. Such results raise interesting questions about individual differences, duty position differences, and interface design that future efforts might address to improve human system integration.

Workload. Figure 14 provides a more comprehensive, across Experiments 2-4, look at HCI frequency by duty position. Of course, the HCI data represents only a portion of each participant's overall duty position activities. The results indicate clear differences between Commander and subordinate interaction patterns.

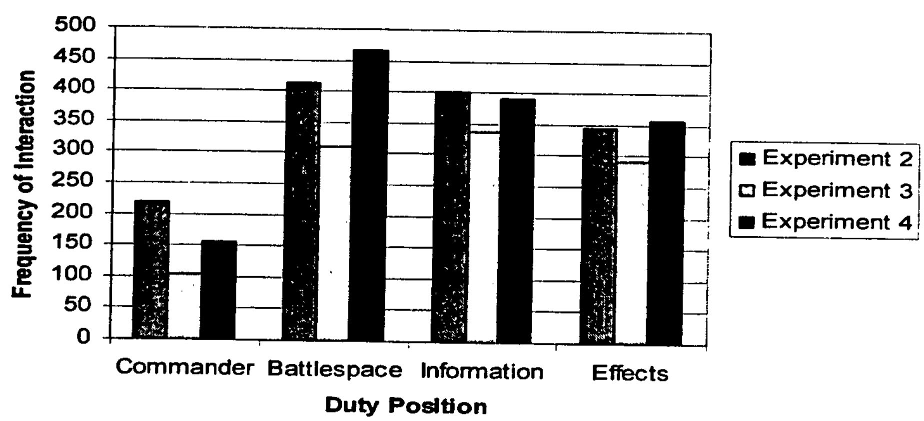

Figure 14. Frequency of interaction by duty position and experiment.

For example, the Commander's relatively low level of interaction, aimed at seeing the battlefield, appeared more consistent with a "thinker" versus "doer" role for battle command. Subordinate interactions were much higher, especially by the Information and Battle Space

Managers. Subordinates averaged four (4) interactions per minute across Experiments 2-4. However, peak performance by subordinates during more intense segments of a run was 9-12 interactions per minute.

A more basic question raised by the results in Figure 14 might be what is the impact of automation on workload? Refinements in the C^2 prototype across experiments, particularly the addition of new features, were expected to at least partially automate many tasks and functions for command and control. However, Figure 14 discloses a sharp and uniform drop in HCI frequency across the command group only for Experiment 3. Notably, participants' subjective ratings of overall workload, previously shown in Figure 6, disclosed a very similar pattern across Experiments 2-4, with respective mean workload values of 61, 49, and 69.

From a measurement perspective, such results provide convergent validity across objective and subjective measurement methods. From a causal perspective, the impact of automation on workload is less certain and arguably more complicated. One explanation for the Experiment 4 increase in interaction and workload may be that performance requirements were increased by *programmatic* expectations about baseline performance capabilities, including repeated requests for faster mission/run completion.

Time. An example of the observable "trends" in HCI performance by duty position and time is provided in Figure 15. This figure depicts interaction frequency in successive ten-minute intervals, or segments, of execution time during Run 10 of Experiment 3. Note the run's final time segment (80-84 minutes) was deleted to avoid comparison across different time intervals. Interesting differences by time and duty position are clearly evident.

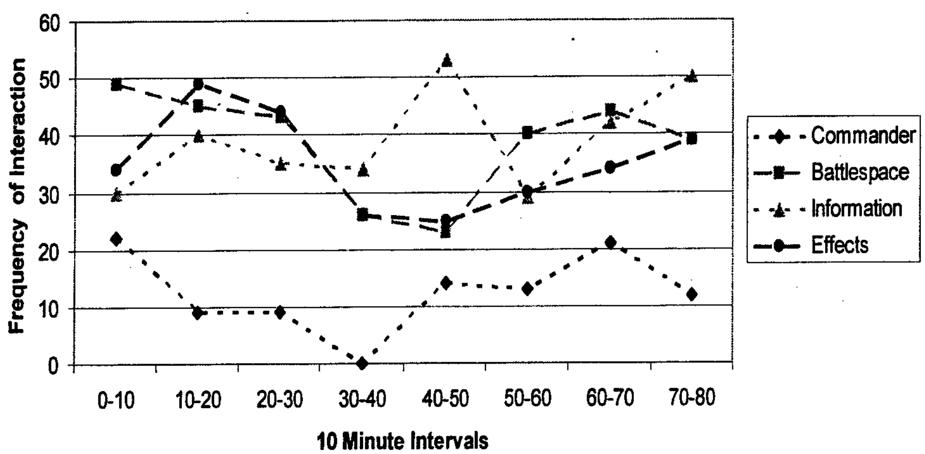

Figure 15. Frequency of interaction by duty position and time, Experiment 3.

Complementary narrations were also developed by the analysts to more fully describe and summarize the interactions performed by each participant during each 10-minute block of each run analyzed. In particular, results such as the frequency by time data indicated in Figure 15 should help to identify and understand variations and collaboration in the performance of future command groups.

Automated Measures

The requirement for automated measures of C^2 performance to support training and evaluation (Unit of Action Maneuver Battle Laboratory, 2003) is underlined by the HCI analyst workload for FCS C^2 experiments. For example, manual reduction of the HCI data for Run 10 from Experiment 3 required 16 analyst workdays to identify and tabulate the 499 human-computer interactions during planning and the 1,044 interactions during execution.

Overall, results on the development and validation of automated measures are promising but quite meager. Only 3 of the 23 automated measures requested by ARI and listed in Table 3 were actually developed. Only 2 of those 3 measures were validated, at least partially. The three automated measures developed were: Alert Acknowledged, Image Requested/Viewed, and Create Ground/Air Route.

Efforts to validate the measure Alert Acknowledged were not successful. As indicated in Table 3, the purpose of this measure was to capture the *time to respond* to an alert by turning it off. However, the parsed logger files provided to ARI for Alert Acknowledged included unnecessary and confusing information.

For example, time data included two, sometimes three, different time stamps that could not be readily distinguished or matched to the run times available with the video recordings used for manual data reduction. Images associated with some alerts were identified on the log with system file names (e.g. \\uc1-images\images\ir__10.ntf) versus the C^2 prototype image names (e.g., Garm 23) available with the video recordings. Moreover, the C^2 prototype provides an array of user options for setting and responding to alerts that complicates measure definition and extraction.

Efforts to validate the measures Image Requested/Viewed and Create Ground/Air Route were fairly successful. Table 5 summarizes the validation results with a comparison of the frequencies tabulated for these two measures by automated and manual measurement methods. There were no discrepancies in the number of images requested/viewed by the Commander and Effects Manager who accessed their images from the Battlefield Assistant in the *Alert* Window.

However, there were notable discrepancies in this same measure for the Battlespace and Information Manager. These discrepancies were due to shortcomings in the measure that did not count images viewed by clicking Chaser round icons that only appeared on the *Map* Window.

Similarly, there were no discrepancies in the measured number of ground routes created by the Battlespace Manager. There was only a small discrepancy (19 versus 18) in the measured number of air routes created by the Information Manager. This appeared to be due to the fact that manual measures tabulated only the number of air routes *actually* generated, rather than the number of air routes *attempted* but not successfully completed.

Table 5

Comparison of Automated Measures to Manual HCI Data Reduction

Duty Position Measured task	Frequency Accounted For Automated Measures	 Manual HCI Analysis
Commander		
Image Requested/Viewed	9	9
Battlespace Manager		
Create Ground Route	11	11
Image Requested/Viewed	2	24
Information Manager		
Create Air Route	19	18
Image Requested/Viewed	62	72
Effects		
Image Requested/Viewed	4	4

In summary, the discrepancies identified in Table 5 for the two automated measures actually developed are notable but should be readily resolvable. Development and validation of automated measures is almost always an iterative process of collaboration between behavioral and technical experts. However, the discrepancies for Alert Acknowledged and especially the failure to develop the additional automated measures underscore the basically unmet requirement for automated measures of C^2 performance (Unit of Action Maneuver Battle Laboratory, 2003).

Status Report on Research Objectives

This section provides a brief recap or summary assessment on the research objectives that directed ARI's involvement in the FCS C^2 research program, as described in the earlier section titled "Human Performance Research Objectives."

Initiate Empirical Database

The research reported here was successful in initiating the development of an empirical database on future command group performance for FCS. The methods and results provide reliable and empirical groundwork, if not benchmarks, on the human performance requirements for FCS command groups and new approaches to command and control. This report emphasizes the scope and depth of empirical data on human performance provided to and available from the PM FCS C^2.

Frankly, ARI researchers and managers were at times concerned the methods used to measure human performance were too detailed and comprehensive, including practically every command group utterance and interaction during the planning and execution of selected runs.

However, new and largely *uncharted* approaches to command and control were at issue. And ARI was committed to better understanding and documenting *how* future command groups envisioned by FCS might perform. Similarly detailed assessments of verbal and computer interaction by command and control performers were made by Navy researchers examining the impact of advanced technology on decision making under stress (e.g., Morrison, Kelly, Moore, & Hutchins, 1998).

In sum, a relatively comprehensive and empirical database on future command group performance for FCS was initiated. The subjective measures about performance addressed multiple research issues including: training, skill proficiency, workload, performance success, teamwork skills, decision making, function and task allocations, prototype effectiveness, and human-system integration. The objective measures of performance related relatively micro behaviors, particularly verbal and human-computer interaction, to relatively macro level command and control functions including Plan, See, Move, and Strike. Measurement methods and data on human performance were documented to support future research in a series of Interim Reports available from PM FCS C^2 and ARI reports (Carnahan, Lickteig, Sanders, and Durlach, in preparation; Lickteig, Sanders, Durlach, & Carnahan, in preparation).

Improve Research Environment

The research reported here was at least partially successful in iteratively improving the FCS C^2 research environment for latter experiments. Shortcomings in human-human interaction and human-computer interaction in particular were routinely identified and documented by ARI during and after each experiment. Refinements were made to redress many, certainly not all, of the shortcomings identified in subsequent experiments to improve system design, experimental design, training, and methods for measuring human performance.

At times, improvements were actually implemented within an ongoing experiment to overcome unacceptable problems including user-identified shortcomings in the functions and features of the C^2 prototype. More often improvements were made between experiments, as in the expansion of new features on the C^2 prototype from 53 to 95 between Experiments 2-4. For more responsive feedback, ARI provided a Quick Reaction Report to PM FCS C^2 approximately 30 days after each experiment that summarized participants' responses on subjective measures to document and expedite the improvements requested.

The Interim Reports from ARI provided to PM FCS C^2 approximately 90 days after each experiment included a section titled "Recommendations for Future FCS C^2 Experiments." This section would typically identify key sustain and improve recommendations that covered a range of topics including experimental design, performance measurement and the distillation and dissemination of findings.

Notably, many of these recommendations should apply to other research efforts, and particularly research on future battle command and on the C^2 systems under development in FCS simulation and acquisition efforts. Accordingly, a sample set of recommendations to improve future research efforts are:

- Invest as much in training and evaluation, as simulation.
- Employ a deliberate practice design to base findings on proficient performance.
- Use simulation-based training exercises to develop tactical and technical skills.

- Provide structured and progressive training from individual, to intra-unit, to cross-unit levels.
- Vary mission complexity levels to determine performance limits.
- Assess the full range of performance including planning and execution phases.
- Include novel missions and terrain to broaden the spectrum of operations.
- Balance subjective measures *about* performance with objective measures *of* performance.
- Capitalize on the requirement for, and value of, automated measures of performance.
- Employ methods to identify and codify new approaches to command and control by documenting the C^2 lessons learned during After Action Reviews (e.g., TTPs and SOPs).
- Disseminate findings across doctrine, organizations, training, materiel, leadership, personnel, and facilities (DOTMLPF).
- Ensure technology complements human performance.

Transfer Measurement Methods

It may be too early to assess the success of our effort to transfer the human performance measurement methods developed to future research efforts. However, the authors conclude that the research effort was successful in documenting and refining the measurement methods in a manner that should facilitate transfer to a broad range of future research efforts on command and control, particularly battle command and command group research issues.

Subjective Measures

For subjective measures, the wide range of questionnaires and interviews including the In-Place AAR that were developed, adapted, and refined by ARI are fully documented (Lickteig, Sanders, Durlach, & Carnahan, in preparation). As indicated, these measures were used to obtain participant feedback on multiple research issues including: training, skill proficiency, workload, performance success, teamwork skills, decision making, function and task allocations, prototype effectiveness, and human-system integration.

The transition of most subjective measures to electronic format by Experiment 4 should facilitate the transfer of measurement methods across future research efforts. Overall, electronic administration worked fairly well, however, two shortcomings were noted in ARI's Quick Reaction report for Experiment 4. The recommendations provided below to redress these shortcomings may apply to future research on battle command and C^2 systems.

First, the goal of in-place administration (in the C^2 vehicle) was not met. After each run, participants were escorted to a remote area in the building to complete questionnaires. Second, and more importantly, while participants were completing the questionnaires they did not have access to a C^2 prototype, particularly a prototype depicting the operational run just completed. Future efforts should ensure participant access to a C^2 prototype during administration to review their operational situation as well as the tools and features they are being asked to evaluate.

Objective Measures

For objective measures, more automated approaches to identifying and coding verbal and particularly human-computer interaction are sorely needed. As noted, automated measures of C^2 performance to support training and evaluation are a formal FCS requirement (Unit of Action Maneuver Battle Laboratory, 2003). The research reinforced that requirement by quantifying the HCI analyst workload in identifying and tabulating over 1,500 interactions by the command group participants in an experimental run. Particularly, the development of automated measures will greatly facilitate the transfer of measurement methods to future training and evaluation efforts.

Typically, the development and validation of automated measures is an iterative process. This process generally requires the collaborative efforts of behavioral, technical, and operational subject matter experts. Behavioral scientists often initiate the process by identifying, describing, and defining the measures of interest. Technical experts then attempt to develop the measures specified, including the software codes required to identify and log the measures as defined. As reported, there are often discrepancies between behavioral scientist inputs and technical engineer outcomes. Resolving such discrepancies requires additional refinements, often by the behavioral and technical experts. Ultimately, operational experts must help determine the practical utility of the automated measures developed and validated.

Only minimal progress was made toward the goal of developing and validating automated measures for human-computer interaction during Experiments 3 and 4. The approach taken and lessons learned, however, were documented in this report to underscore the work required and the potential payoff of automating many of the human-machine performance measures integral to future command and control. Clearly, additional development, refinement, and validation are needed to develop a useful set of automated measures to support training, evaluation, and C^2 system design. In particular, automated measures are needed to measure the *process* of learning to provide the feedback instrumental to learning in more complex and dynamic settings.

Automated measures of verbal interaction were not attempted for Experiments 1-4. However, the results from verbal analysis (for example Figure 10) stress the vital role of verbal communication in battle command collaboration, even with advanced information technologies. Recently, the development of automated mathematical analysis tools, including Latent Semantic Analysis has resulted in powerful statistical methods for extracting and representing the meaning of words and phrases (Landauer, & Dumais, 1997).

The authors conclude such tools may provide automated methods for chunking and coding verbalizations into more meaningful classifications, including the C^2 function used to categorize participant verbalizations for FCS C^2. Importantly, ARI's documentation on methods for chunking and coding verbalizations should greatly facilitate development of such tools for command and control research efforts.

Develop Innovative Training

A final objective was to identify training requirements and develop innovative training approaches based on empirical measures of command group performance. Success on this objective is a primary focus of the ongoing work by ARI to address the STO Objective "Methods and Measures of Commander-Centric Training." As a complement to the FCS C^2 research, ARI is developing an in-house laboratory to help develop the innovative training required by FCS, including simulation-based training and structured, embedded training (Lickteig, et al., 2002). Two aspects of ARI's in-house training development efforts most directly related to the FCS C^2 program will be briefly described.

Training Requirements and Approaches

Training requirements and recommendations for future command groups were a primary focus of the previously noted ARI research comparing novice versus expert participants in the FCS C^2 research environment (Carnahan, Lickteig, Sanders & Durlach, in preparation). As expected, significant differences in tactical and technical performance between novices versus experts were obtained. Based on the findings, and literature on novices versus experts, a set of training recommendations were presented to help turn novices into expert command groups.

This set of training recommendations is re-presented below in Table 6 to provide a more complete account of ARI's FCS C^2 research efforts in this report. Although briefly described here, more complete description and discussion of these recommendations is provided in Carnahan, Lickteig, Sanders and Durlach (in preparation).

Overall, the recommendations in Table 6 reflect ARI's basic conclusion that the training requirements for FCS command groups entail unprecedented levels of tactical and technical expertise. These recommendations stress the need to: master basic skills, train part-task, ensure consistency, and provide feedback. They reinforce new FCS training requirements, including structured and embedded training, for transforming novices into expert command groups.

For each recommendation, training implications and examples from FCS C^2 research are identified. These examples were based on training problems observed in the FCS C^2 experiments across novice and expert participants. The authors' intent was to provide training development efforts more specific and tangible instances of future training problems and requirements.

A Prototype Training Example: Battle Command Visualization 101

As an example of ongoing training development efforts by ARI, the training example called Battle Command Visualization (BCV) 101 in Table 6 will be briefly summarized here. With support from the FCS C^2 program, a prototype training program called BCV 101 is being developed by ARI to provide simulation-based and embedded training on basic visualization skills required for future battle command.

Recall that the See function required the command group participants to control and interpret input from an array of manned and unmanned networked sensors to maintain an accurate battlefield "picture." However, empirical measures of command group performance disclosed that novice and even expert participants had repeated difficulty in understanding and exploiting the capabilities and limitations of the sensor systems available to the Unit Cell.

For the current force, serious shortcomings in visualization training and skill are well documented, particularly at command and staff levels (Reilley, 1997; Solick, 1997). In general, training on visualization is not readily available or provided, and lecture-based training on visualization is not efficient or effective.

Table 6

Training Recommendations, Implications and Examples for FCS Command Groups

Training Recommendations	Training Implications	Training Examples
Master Basic Skills	Tactical Skills	METT-TC
	Technical Skills	HCI Taxonomy
	Integrate Tactical and Technical	Intervisibility Plotting
Train Part-Task	Segmentation	LAM Fire Execution
	Simplification	Reduce Duty Position Requirements
Ensure Consistency	Consistent Conditions	Battle Command Visualization 101
	Consistent Venues	C^2 System/Simulation/Personal Computer (PC)/Personal Data Assistant (PDA)
Provide Feedback	Timeliness	System Alerts and Mentor
	Standardization	Systematic and Comprehensive
	Diagnostic Precision	"Personalize" Feedback
	Presentation	Tailor Presentation Mode

For the future force, the tactical and technical skills required to See First are formidable as indicated by results from the FCS C^2 program. The FCS goal that small command groups will control a wide range of manned and unmanned networked sensors and correctly interpret the outputs from these sensors substantially raises skill requirements. For example, a potential set of sensor outputs that must be correctly interpreted includes: direct view and infrared images from unmanned aerial and ground vehicles, moving target indicators, synthetic aperture radar pictures, counter-fire target acquisition and ground surveillance radar detections, and signature results from acoustic, communication, and electronic sensors.

New training approaches and programs are needed to provide the tactical and technical skills required by FCS. The BCV 101 focuses on the skills required to control and interpret sensor systems, identified here as basic battle command visualization skills for FCS command groups.

Skill mastery, or reliably high levels of performance, is generally the product of consistent training conditions and feedback. Research on automaticity stresses that consistent conditions and feedback are needed to provide experts the ability to perform basic skills through automated processing (Fisk & Rogers, 1992). Notably, computer-based and/or embedded training coupled with simulation are ideal mediums for ensuring consistent training conditions and feedback.

The BCV 101 training will provide consistent task conditions and feedback across different training venues, or mediums, any time and anywhere. The performance-oriented nature of BCV 101 training will exploit the power of digital systems, including embedded C^2 systems to perceptually augment sensor coverage and simulation to provide realistic performance feedback on sensor outputs.

The BCV 101 prototype training development effort will address two primary objectives for providing basic battle command visualization skills for FCS command groups:

- Develop a representative subset of training exercises to control and interpret individual sensors and complementary networked sensors.
- Design an overall training program to provide a comprehensive and progressive set of training exercises modeled on the Conduct of Fire Trainer (COFT) training program.

The COFT program for tank gunnery uses simulation to help commanders and gunners develop and practice their firing skills in a variety of increasingly difficult, day and night scenarios (U.S. Army Armor School, 2003). Progressively structured exercises range from single, daylight, stationary, near-range targets to multiple, night-time, moving, far range targets; from working as an individual vehicle to fighting as part of a larger unit. Training progression and skill proficiency are systematically controlled and assessed through a series of pass the gate exercises.

Design for the BCV 101 training program is committed to providing a consistent multi-media approach to training battle command visualization skills. The design will be layered across training venues to include: wireless personal data assistants, desk- and lap-top computers, virtual simulation facilities, internet-linked gaming sites, and fully embedded training in operational systems. Layers across media may correspond to crawl, walk, and run training levels for individual and collective battle command visualization skills. A goal of the BCV 101 prototype training development effort is to provide a cornerstone example of the simulation-based, embedded training required for FCS.

Conclusions

This section provides some preliminary conclusions about human performance issues for future battle command based on the FCS C^2 research program. More problematic conclusions on workload and training are followed by more promising conclusions on user-based involvement and proactive research, particularly their potential for solving many of the problems anticipated in workload and training.

Workload

The human performance findings from Experiments 1-4 suggest workload may be a serious problem for future command groups in small FCS units. The negative impact of workload on performance was underscored by participants' low ratings of their own performance success after more complex runs. Objective data confirmed that participants were heavily engaged in verbal and human-computer interactions during more complex runs and more intense run segments.

Automation may eventually reduce workload but it is a double-edged sword in early development of a system such as FCS. A striking example of how automation can reduce workload was a comparison on number of *same* sensor images viewed at different times and by different participants in Experiment 2 versus Experiment 3. For Experiment 3, an automated audit trail on images viewed was introduced that clearly indicated if, when, and by whom each image had been opened and viewed. This automated feature reduced the number of same images viewed in Experiments 2 versus 3 from 62% to 16%.

Notably, the overall decrease in workload and interaction between Experiments 2 and 3 was attributed to the array of new and increasingly automated features added to the C^2 prototype for Experiment 3 based on results such as the reduction in same images reviewed.

Why then the increase in workload and interaction in Experiment 4 with more automated features and more experienced participants? One plausible explanation is that programmatic expectations about baseline capabilities including faster mission completion may have raised performance requirements. The "High" complexity run requirements of Experiment 4 may have actually exceeded the "High" and even "Too High" levels of Experiments 1-3 because the participants were repeatedly urged to reach the objective for each run faster.

If so, the increase in participant workload during Experiment 4 may be an artifact common to exploratory versus controlled research, and a reality common to expectations about doing "more with less" through technology (Cordesman & Wagner, 1996).

Training

Training requirements for FCS command groups may entail unprecedented levels of tactical and technical expertise. Given the FCS organization examined, a small command group with highly automated and interdependent network-based systems must reformulate battle commands into computer commands. More succinct verbalizations—such as commander's intent and guidance—with many implied tasks, must be issued in computer-mediated/dictated formats in which most tasks must be explicitly and precisely defined.

More automated features such as Auto Recon and Route Generation for unmanned platforms may relieve players of routine tasks such as entering route points or doing repeated terrain analysis checks on intervisiblity and mobility. However, automation often raises the demand on players to understand the decision rules and parameters designed into automated task features and to monitor task execution. For example, during Experiment 3 the Shadow UAV tended to "wander off" toward enemy elements under Auto Recon and be destroyed, a critical loss to the See First capability of the Unit Cell. This unintended consequence of high automation was due to misunderstood recon parameters, information overload that limited monitoring, and lack of an effective human override to abort an automated routine in a timely manner.

Understanding the limits and strengths of technology was a severe challenge to relatively expert participants. A key part of the challenge was to comprehend the user input requirements and operational consequences for more automated functions including Plan, See, Move, and Strike. After Experiment 4, participants who had completed 40+ experimental runs across the four experiments expressed strong concerns about training and their ability to fully exploit Unit Cell capabilities. Moreover, the high rank and operational experience of the participant command group will be the exception, not the rule, in small FCS units.

The ARI's conclusions on training stress the need for three basic but far-reaching improvements in the training of individuals and units in future FCS organizations, and particularly command groups:

- Develop progressive simulation-based training exercises directed at *individual* tactical and technical skills, particularly user input requirements for, and the operational consequences of, automated functions including Plan, See, Move, and Strike.
- Develop a parallel set of collective command group training exercises directed at *intra*-unit tactical and technical skills.
- Develop a parallel set of multi-echelon, distributed training exercises directed at *cross*-unit tactical and technical skills.

User-Based Involvement

The C^2 interface is increasingly the primary locus, or means, of interaction between war fighters and systems. Developing an optimal interface requires intense user-based involvement, not a bunch of guys/gals sitting around a table (BOGSAT) or a drive-by user jury.

A distinctive hallmark of the FCS C^2 research program is the sustained use and refinement of a prototype C^2 system and interface by an exceptional set of command group participants. For over two years, the command group participants led the Operational Team's committed and sustained effort to design, test, and develop the unique and challenging C^2 system and interface required for FCS.

As a result, the FCS C^2 program continues to explore and develop a cutting-edge C^2 system and interface for the command and control challenges raised by the emerging concepts of FCS (Unit of Action Maneuver Battle Laboratory, 2003). Much work remains, but unlike many other fielded and prototype C^2 systems, the FCS C^2 system and interface provide:

- Value grounded by experts' sustained use and refinement.
- An increasingly effective interface to autonomous systems.
- A common interface for human and robotic forces.

Proactive Research

Historically, Army acquisition research has had difficulty conducting an adequate early assessment of the human dimension in system performance. This human performance issue is especially critical for FCS because the empowerment of the commander through advanced C^2 systems is at the heart of the FCS concept. Moreover, the revolutionary nature of the Army's transformation embodied in the FCS acquisition program increases the risk of relying exclusively on traditional assessment methods such as C^2 hardware and software component tests, or the outcomes of simulation without Soldiers-in-the-loop.

The FCS C^2 program exemplifies the proactive research on human performance that is essential to improving human system integration. The ARI's methods and results on human performance provided reliable and empirical data for important and timely decisions on training, materiel, manpower, and personnel. Findings were also readily transitioned to acquisition efforts because of DARPA's dual roles in FCS simulation and acquisition. The FCS C^2 program was cited by the FCS Lead System Integration team, the FCS Integrated Product Team for Training, as a key contributor to their design planning. Findings shaped the C^2 prototype showcased in the FCS Capstone Demonstration of C^2 systems prior to the FCS Milestone B decision.

The ultimate value of a research and development program is determined as much by the resources spent on training and evaluation, as the resources spent on simulation. The ultimate value of FCS and future C^2 systems is determined not so much by technology, but by shaping technology to complement human performance.

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Appendix A

List of Acronyms

AAR	After Action Review
AFRU	Armored Forces Research Unit
AGM	Attack Guidance Matrix
AH-64D	Attack Helicopter-64D
ARI	U.S. Army Research Institute for the Behavioral and Social Sciences
BCV	Battle Command Visualization
BDA	Battle Damage Assessment
BOGSAT	Bunch of Guys/Gals Sitting Around a Table
C^2	Command and Control
C^4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CECOM	Communications Electronics and Engineering Command
COA	Course of Action
COFT	Conduct of Fire Trainer
CSE	Commander's Support Environment
DARPA	Defense Advanced Research Projects Agency
DCSOPS&T	Deputy Chief of Staff for Operations and Training
DIS	Distributed Interactive Simulation
DOTMLPF	Doctrine, Organizations, Training, Materiel, Leadership, Personnel, and Facilities
FBC	Future Battlefield Conditions
FCS	Future Combat Systems
FCS C^2	Future Combat Systems Command and Control
GCM	Graphic Control Measure
HCI	Human-Computer Interaction
HTR	human target recognition
HUD	Heads-Up Display
IFV	Infantry Fighting Vehicle
LAM	Loitering Attack Missile
LOS	Line of Sight

METT-TC	Mission, Enemy, Terrain, Troops, Time and Civilians
NAI	Named Area of Interest
NASA	National Aeronautics and Space Administration
NTC	National Training Center
O/C	Observer/Controller
OneSAF OTB	One Semi-Automated Forces Testbed Baseline
PAM	Precision Attack Missile
PC	Personal Computer
PDA	Personal Data Assistant
PM	Program Manager
RDEC	Research, Development and Engineering Center
SAMS	School of Advanced Military Studies
SME	Subject Matter Expert
SOP	Standing Operating Procedure
STO	Science and Technology Objective
TLX	Task Load Index
TRADOC	Training and Doctrine Command
TTP	Tactics, Techniques and Procedures
UAV	Unmanned Aerial Vehicle
UGS	Unmanned Ground Sensors
WIMP	Windows, Icons, Menus, and Pull Downs