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John E. Morrison
Stephen H. Konya
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Susan S. Turnbaugh
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Richard D. Gilson

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PREFACE

This work documented in this report was part of the "Analyses of the Soldier Machine Interface Issues of Future Combat Systems" task performed for Future Combat Systems (FCS) Program Manager (PM), Defense Advanced Research Project Agency (DARPA) Tactical Technology Office (TTO). Technical cognizance for the work was assigned to COL William Johnson, FCS PM. The Institute for Defense Analyses (IDA) Point of Contact (POC) was Dr. Peter Brooks.

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INTRODUCTION

The Future Combat Systems (FCS) effort employs “leap-ahead” technologies and concepts to provide unprecedented levels of situational understanding and synchronization of effects. The same high level of technical sophistication used to develop FCS hardware and software should apply to the development of the soldier-machine interface (SMI). Guidance is needed to ensure that FCS SMI design is a soldier-centered process that accommodates a system-of-systems approach to warfighting; includes all soldiers, mounted and dismounted; and is effective across the full spectrum of warfare.

REVIEW OF THE LITERATURE

Several common themes unite contemporary design philosophies. One is that effective interactive designs are multimodal, thereby taking advantage of known efficiencies in human memory, cognition, and performance. Another is that development should be iterative to match products to requirements more closely. The iterative redesign process should be based on soldier feedback. Also, usability should affect each stage of development. Prototypical users [e.g., subject matter experts (SMEs), warfighters] should determine what is usable, in keeping with demands from leadership, the environment, and unknown factors.

For specific guidance, approximately 300 documents were retrieved and organized into a database. Five military documents were identified as being key to SMI design: MIL-STD-1472F, MIL-STD-2525B, MIL-STD-411F, North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 2019 (North Atlantic Treaty Organization, 1990), and an Army Research Institute (ARI) technical report on human-factors guidelines for command and control (C2) systems (Lewis and Fallesen, 1989). Guidance offered in these documents converged on highly structured rules (e.g., font size or window placement) that resembled instructions or directions more than general guidelines. The academic and industry literature was more heterogeneous, and it diverged into broad philosophical issues, such as “design as engineering” vs. “design as art” and the utility of controlled studies or usability studies. In both the military and academic domains, interfaces were largely concerned with visual representations. The academic literature also revealed some recurring themes (e.g., promoting iterative prototyping) and some general guidelines for interface design (e.g., understand users and their tasks and use consistent display formats, language, labels, and system operation procedures throughout the course of the dialogue).

Ten actual digital interfaces that have been used in virtual, live, or operational environments were identified and discussed. Each provides real-time command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) information to individual platforms. These projects cover almost 20 years of research and development (R&D), including examples such as the InterVehicular Information System (IVIS), which was developed in the 1980s and implemented in variants of the M1-series tank; the Force XXI Battle Command Battalion/Brigade and Below (FBCB2) appliqué, which was appended to a variety of vehicles; and the Warfighter-Machine Interface (WMI), which was proposed for the evolving FCS platforms. Several generalizations and trends were noted across the interfaces:

- **Terrain.** Terrain is central to all reviewed interfaces. Also, the representation of the terrain has become increasingly sophisticated.
- **Display technology.** Display technology continues to focus on video monitors. There has been less interest nonvisual input approaches (e.g., tactile, aural displays) and no apparent interest in displays based on chemical senses (e.g., taste and smell).
- **Control technology.** Control technology focuses on conventional manual devices. Most employ technologies borrowed from personal computers (e.g., keyboard, mouse), with some emerging interest in voice recognition and eye tracking as control devices. However, established oral control devices, such as mouthsticks, are not being considered.
- **Intelligent agents.** Intelligent agents are beginning to emerge as important components of interfaces. They have been use to pre-process information presented to user and to configure displays automatically.

DESIGN MODEL

The model that was devised to guide the interface design process was based on several assumptions and considerations concerning human capabilities and limitations:

- The interface must be designed to conserve mental resources.
- The interface must address display and control functions.

- The interface must promote a shared understanding among echelons, which is not a necessary result of sharing a common operational picture.
- The interface must address the special problems of the dismount to exploit the full value of Network Centric Warfare (NCW).

The model was also constrained by proposed FCS concepts and the environment within which the system will operate. In particular, the FCS interface design is envisioned to be a multiechelon, user-centered process that balances operational variables with the four-dimensional (4-D) battlespace (i.e., including time), employs appropriate sensory and response modalities to optimize performance, and develops innovative and eclectic display and control methods.

The resulting model (see Figure ES-1) is based on the interaction among four sets of variables:

1. Operational variables
2. Battlespace
3. Sensor modalities
4. Echelon.

The ordinate depicts information-processing capabilities along a continuum, with selected modalities placed in relative order of evolutionary sophistication. The abscissa depicts increasing battlespace complexity and time available that are associated with successive echelon levels. The notional curve represents increasing organizational echelon and processing complexity. Whereas the exact shape of the relation is unknown, we postulate that it is monotonically increasing [higher echelons benefit from high-bandwidth processing modalities (e.g., vision), whereas lower echelons benefit from less sophisticated but faster responding modalities (e.g., olfactory cues)]. Furthermore, the relation is thought to be discontinuous, with the relationship differing between mounted and dismounted warfighters. Mounted warfighters benefit disproportionately from the higher modes of processing, whereas dismounted warfighters benefit the most from more primitive modes. The model presented in Figure ES-1 is highly aggregated and simplified version of an n-dimensional relationship. Future research should isolate and validate some of the fundamental relationships that this model implies.

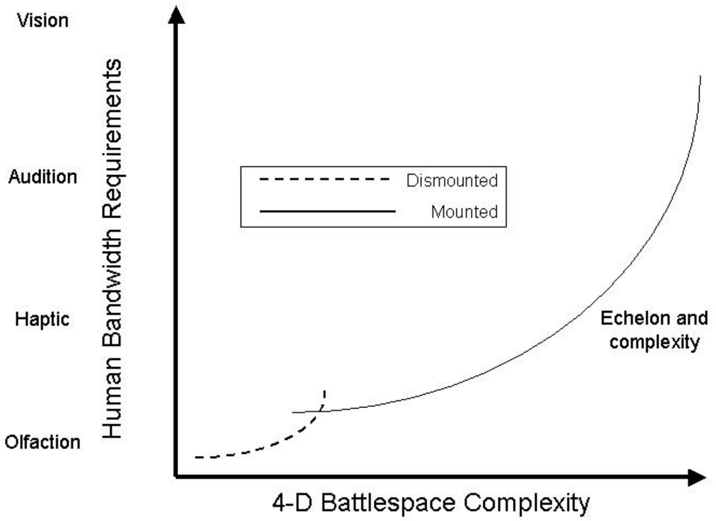

Figure ES-1. Design Model for FCS Interface

Despite the tentative nature of the model, it can be used for devising FCS design guidelines. For instance, the model suggests the following design principles:

- The high-definition visual displays designed for high-echelon staff members are not appropriate for lower echelons (especially for dismounted soldiers). In other words, dismounted infantry will require nonvisual and nonauditory displays and controls.
- Auditory, haptic information should be pushed down the echelon to augment the highly detailed terrain information available to the dismounted warfighter.
- Detailed terrain information and other mission-related information available to dismounted warfighters should be pushed up to augment visual displays available at higher echelons.
- The auditory modality may provide the common link across echelons.
- Visual displays might be appropriate to all echelons during planning, when all warfighters have increased time to process data. Such displays are not appropriate for lower-echelon warfighters during execution phases.

I. INTRODUCTION

A. BACKGROUND

Future conflicts will be fought in increasingly dynamic, nonlinear, and unpredictable battlespaces that are populated with authoritarian regimes and criminal interests armed with asymmetric capabilities and weapons of mass destruction (WMD). To meet this multidimensional challenge, the Chairman of the Joint Chiefs of Staff (CJCS, 2000) issued his vision, articulated in Joint Vision 2020 (JV 2020), which seeks to transform the U.S. military into a force that is dominant across the full spectrum of military operations. JV 2020 identifies two key enablers of this transformation: information and innovation. Information provides the primary weapon against the uncertainty of future battlespaces. Information is also the necessary requirement for decision superiority—the ability to make better and faster decisions than the enemy. Innovation refers to the development of new technologies, new ideas, and new concepts. The unorthodox and dangerous nature of evolving threats must be met with audacious research and development (R&D) programs that seek true leap-ahead advances in technological and doctrinal capabilities.

1. Network Centric Warfare (NCW)

To translate information superiority into combat power, military thinkers are developing the construct of NCW, which provides a high-level system of Information Age constructs for integrating vast bodies of information and disparate capabilities into a system of decentralized and autonomous networks. By introducing Information Age concepts and technologies into warfare, these thinkers intend to foster a revolution in warfare analogous to the ongoing revolution in business and commerce (e.g., Kelly, 1998).

In traditional warfare, sensor and weapon functions are associated with specific platforms or systems. NCW, in contrast, seeks transfer the intelligence and complexity of military systems from sensors and weapons to the information infrastructure (Alberts, Garstka, and Stein, 1999). Two implications of this scheme are that sensors and weapons are no longer paired in stovepiped fashion and that sensors and weapons are no longer tied to specific platforms. The decoupling and networking of sensors and weapons not only increases their potential range and flexibility, but also decreases their unit cost and battlefield footprint. The biggest potential impact, however, is in the command and control (C2) arena. For instance, NCW has the potential to forge the traditional separation of planning and execution phases into a single, seamless dynamic planning process. Further, spreading intelligence and combat assets throughout the network dramatically increases the number of potential decision-makers and the speed and accuracy of their decisions.

2. Future Combat Systems (FCS)

The FCS program provides the innovative technologies required to transform land-based warfare according to NCW concepts. Developed by the Army and the Defense Advanced Research Project Agency (DARPA), this program comprises a family of manned and unmanned air- and ground-based maneuver, maneuver support, and sustainment systems to equip the Unit of Action (UA), the Army's primary tactical unit for future combat. FCS technologies supply the UA the combat power, sustainability, agility, and versatility required for full spectrum operations. FCS entities will be networked through an architecture of command, control, communications, computers, intelligences, surveillance, and reconnaissance (C4ISR) assets to provide networked communications, operations, sensors, and battle command systems. The C4ISR systems are designed to provide unprecedented levels of situational understanding and synchronization of action.

Perhaps the most salient feature of the FCS program is its revolutionary nature. In particular, FCS employs numerous "leap-ahead" technologies that mix intelligence and three-dimensional (3-D) perspectives from ground-level detail to over-the-hill panoramas for overmatching tactical and operational advantage. Not since the development of night-vision devices has the U.S. military had the opportunity to overwhelm the enemy by sensing, analyzing, planning, and then acting before counterdetection. These capabilities ensure that U.S. forces will continue to overmatch their opponents in technology and information.

3. The Soldier-Machine Interface (SMI)

In simplest terms, a network is a system of nodes and links. Nodes represent system components, human or machine, and links are the relationships and/or information flows between pairs of nodes. As a human-machine system, the links between The FCS's human and nonhuman elements are crucial to the effectiveness of the entire system. The SMI provides the technological means for ensuring the dynamic exchange of information between the human and nonhuman elements of FCS. To realize the full potential of FCS, the SMI must provide an effective exchange of information between the FCS technologies and the human operators of those technologies.

B. PROBLEM

In accord with NCW concepts, the intent of the FCS SMI is to provide a shared understanding of tactical situation from individual soldier-operators (actors) to UA commanders (decision-makers) and in-between, mid-echelon leaders who perform as both actors and decision-makers. To address the full-spectrum of warfare, the FCS incorporates several different functional platforms including maneuver [e.g., Non Line of Sight (NLOS) cannon], maneuver support [e.g., Intelligent Munitions System (IMS)], and sustainment [e.g., Family of Medium Tactical Vehicles (FMTV)].

Traditional interfaces emphasize visual displays and manual controls that are tailored to higher echelon decision-makers performing C2 functions. This sort of interface is not appropriate to lower echelons, particularly to the dismounted warfighter who presents several special display and control problems. A model (based on cognitive psychology and human factors) that describes the relationship between echelon and interface requirements is needed.

C. REQUIREMENT

The FCS program requires guidance to ensure that the same level of technical sophistication used to develop FCS system technologies also applies to the SMI's design and development. Specifically, FCS SMI design and development must be a soldier-centered process that

- Accommodates a system-of-systems approach to warfighting
- Includes all echelons of warfighters (mounted and dismounted)
- Is effective across the full spectrum of warfare.

D. APPROACH

The overall objectives of the FCS SMI task are

- To identify and assess the important SMI issues within the human dimension of FCS that impact on system viability and design
- For selected critical issues, to develop experiments and conduct analyses to identify potential solutions that will lead to enhanced soldier performance.

This document addresses the first objective (identify SMI issues), which provides the foundation for future R&D programs.

Section II provides a review of the literature related to the design of C4ISR interfaces. Section III presents a model for designing FCS interfaces and some preliminary guidelines derived from the model.

II. REVIEW OF THE LITERATURE

Our review of the literature spanned three different, yet somewhat overlapping, content domains: general philosophy toward the design of interactive technologies, published design guidance from military and academic sources, and instances of C4ISR interfaces that directly relate to the FCS.

A. DESIGN PHILOSOPHY

1. Phases of Development

The development of systems involving humans and machines includes a broad number of approaches and methods—some claiming to be the "definitive" method, thereby supplanting previous methods, and others marking a stage in the evolution of human-machine interaction. Some of the most relevant approaches by Tullis and others are reviewed in Section II.B.3.b. Rather than commit to a specific approach, this section summarizes the most salient and general aspects of the many approaches pertinent to the scientific method, the engineering process, and the artistic process as they apply to the development of interactive, multimodal environments in FCS. "Interactive" refers to human activities that are coordinated, harmonized, enhanced, and immersed—for better or worse—with electromechanical machines. "Multimodal" denotes several forms of external representations, including text, graphics, sounds, numerals, tables, nonverbal gestures, utterances, motions, events, and so forth, that are picked up by the corresponding human senses and maintained in different forms of human memory (coded as internal representations—verbal, visual, acoustic, haptic, and so forth).

A significant portion of the literature and the development efforts emphasizes display, not control. From an academic perspective, sources that are not considered as "core" literature are available. These sources include gaming and entertainment, academic and corporate research conducted at smaller institutions or overseas, ecological perspectives, the graphic arts, and design principles from other industries, such as automotive. To be fair, when faced with this vast amount literature—encompassing several disciplines—designers have little choice but to grasp the closest and most familiar sources, or they could become overwhelmed. Constrained by the demands of time, the first priority will usually be the composition of the display. Secondary to the composition of the display is how users can interact with the display via the keyboard, mouse, button, or other input devices. The secondary literature is available and captures many essentials of the mixed-mode character of input and output; however, the larger picture, as originally sketched by Card, Moran, and Newell (1983), for instance, remains to be unified. The FCS program should seek to draw upon these various techniques and not worry about unification.

For FCS, design principles transpire at four levels. From the general to the specific, the four levels of analysis are

1. The scientific method, engineering processes, and artistic design processes
2. Known human capabilities or principles in the areas of cognitive science, human factors, and ergonomics
3. Principles that have emerged within a certain domain (e.g., aircraft, automotive, appliances, computers)
4. A specific problem, such as FCS.

In general, the principles are goal-oriented and result in a product for a particular group of peers, consumers, customers, or users. In fact, in addition to being a development effort, FCS also serves as a source of knowledge for other elements inside and outside of the Department of Defense (DoD).

In this hierarchy, it is assumed that a higher level generally subsumes and constrains a lower level (see Table II-1). For this phase of the FCS effort, the remainder of this section will focus at Level 1 and will describe three complementary processes relating to science, engineering, and the arts, their salient characteristics, and what the three have in common. More specific details at the lower levels are addressed in Sections II.B and II.C. As the project team gains more knowledge about FCS requirements in 2003, a successive iteration of this section will "drill down" to specific topics that will have to be addressed under the purview of these three disciplines.

Scientific research can be considered a systematic investigation (i.e., the gathering and analysis of information) designed to develop or contribute to generalizable knowledge. Engineering follows a similar premise, but the "generalizable knowledge" is an improved efficiency realized in an artifact (tool, machine, environment) or process (a

Table II-1. Four Levels of Analysis

Level	Participants	Characteristics
1. Science, Engineering, Design	Philosopher of science Policy/doctrine official Management Philosopher at-large	Sequenced, interdependent phases of activity: • Requirements • Design/ideation • Implementation/production • Evaluation/test/usability • Release/publication/maintenance/marketing
2. Cognitive Science, Human Factors, Ergonomics, Marketing, Product Development	Researcher Scientist Engineer Artist	Human memory and cognition (with known limitations): • Sensation • Perception • Short-term/working memory • Long-term memory: procedural, declarative, episodic, implicit, linguistic • Cognition: problem solving, visual reasoning, decision-making, deduction, induction, abduction, … • Proprioception • Language and communication • Emotion, affect, personality • Stressor or Insult: fatigue, hunger, fear, nuclear, biological, and chemical (NBC) agent, … • Enhancer: caffeine, amphetamine, sleep, food, … • Behavior, action, performance, grasping, walking, …
3. Domain-Specific Constraints	Researcher Scientist Engineer Artist	External elements map to internal elements from Level 2 • Images: shade, color, placement, hue, motion, … • Sounds: tone, pitch, location, duration, amplitude, … • Proprioception: first-person sensation, orientation, perception, cognition • Tactile/haptic: action, sensation, perception, cognition • Smell: familiar and unfamiliar smells, odors • Taste

Table II-1. Four Levels of Analysis (Continued)

Level	Participants	Characteristics
4. Program, Project, Product	Researcher Scientist Engineer Artist Subject matter expert (SME) User Consumer	Aspects of Levels 1–3 constrained by: • Requirements (particularly user-driven requirements) • Human expertise, capabilities, limitations • Environmental constraints • Market forces, market demand • Program/project leadership, goals
FCS – an instance of Level 4	***Developers:*** *Military program leadership* *Government scientist* *Federally Funded Research and Development Center (FFRDC) scientist* *University scientist* *Corporate scientist and engineer* ***Users:*** *Commander* *SME* *Warfighter*	*Many aspects of Levels 1–3, with emphasis on:* • *Terrain* • *Navigation* • *Shared communication and understanding* • *User-centered requirements, knowledge acquisition, task analysis, design, test/evaluation* • *Use-cases* • *Iterative prototyping* • *Rapid information delivery* • *Input/output (I/O) device control loop*

Note for Table II-1: *Lower levels inherit some or all characteristics from higher levels.*

way of doing things). Simply put, the scientific method seeks to answer questions, explain phenomena, or solve problems, whereas the purpose of engineering is to build better tools or processes. The scientific method follows five interdependent phases:

S1. **Formulate hypothesis/identify problem.** Propose a hypothesis or identify a phenomenon that seeks to explain a phenomenon or solution to a problem.

S2. **Design the method.** Construct a method wherein the main purpose is to generate or gather evidence that provides support for the hypothesis or proposed solution.

S3. **Execute method/gather evidence.** Conduct the experiment or study according to the procedure described in the method. Gather the evidence produced by the method.

S4. **Evaluate evidence.** Compare the observed evidence resulting from the method with the expected evidence proposed in the hypothesis. If the evidence supports the hypothesis or solves the problem, the method can be considered successful (go to S5). If enough evidence from various sources and investigations has been gathered, a theory might be the result. If the evidence, however, is not conclusive, the hypothesis or proposed solution must be amended, giving rise to a new method (go to S1).

S5. **Disseminate knowledge:** If the evidence is conclusive, publish the results in the appropriate medium, such as a peer-reviewed journal, conference proceedings, and so forth.

The goal of engineering is to make an artifact or process more efficient product. Regardless of what specific approaches may suggest, the general framework is structured according to the following interdependent phases:

E1. **Define problem/gather requirements:** Identify the problem (e.g., an inefficient or nonexistent artifact or process). Determine the human or user's needs with respect to an acceptable solution.

E2. **Design the product:** Construct a blueprint or plan for how the solution, or product, will be realized as a new or improved artifact or process

E3. **Implement the product.** Build the proposed solution.

E4. **Test and evaluate the product.** Determine whether the product or process meets the user's needs or requirements. If no, go to E1, else E5.

E5. **Release and maintain the product:** Market, sell, distribute, and maintain the product or process.

Note that phases S1–S5 and E1–E5 correlate strongly and differ only in their goals and products or end results.

Although contentious, processes within some of the arts can be considered consistent with science and engineering. The contention rests in the process of *creation,* or the "art," which, historically, has been set apart from engineering and science as some mysterious event or ability stemming from creative genius. However, some of the perceived differences might be considered social constructs, not epistemic or ontological truths. Sadly, little has been written about bridging these three disciplines (B. Schneiderman, personal communication, 2002; D.A. Norman, personal communication, 2002), although new curricula have been established at Carnegie Mellon University (CMU), Stanford, and the University of Southern California (USC) to meet the growing demand of Web-based design, gaming, and entertainment. The following portrayal of the artistic process focuses on the similarities rather than differences among science, engineering, and the arts:[1]

A1. **Gather requirements/analysis.** Gain a thorough understanding of the customer, user, game player, listener, and so forth and understand the requirements—a comprehensive "customer profile." Isolate core themes and/or functional requirements. Allow customer to review and then commit (by signing off) before proceeding to the next step.

A2. **Gain feedback from customer.** Constrained by the profile, requirements, and themes from A1, translate this knowledge into a basic "ideation," not unlike a sketch, rough layout, musical phrase, architectural mock-up, clay model of vehicle, and so forth. The customer must again commit and sign off. Refine as necessary or even refine elements of A1 if necessary. Customer must sign off.

A3. **Design the product:** Broaden the ideation into a design for the final product. In architecture—a blueprint, in graphic arts—a detailed layout, and so forth. Present the design to the customer, refine the design, go back to A2 or even to A1, as necessary. If the customer is capricious, remind him/her that he/she has approved (signed-off) various phases.

A4. **Implement the product:** Manufacture the final product. Depending on the medium, if immutable (e.g., building, logo, vehicle, annual report), go to A5. If malleable (e.g., software, website, interface, video game), gain more feedback, as required, and refine, as needed. In the case of a malleable product and capricious customer, remind customer that preceding phases have been signed off.

A5. **Release and maintain the product:** Market, sell, distribute, or maintain the product.

Note the requirement for the customer to sign off and commit during or after each phase of the process. Based on extensive experience (Hooton, 2002, personal communication), graphic artists, in particular, are familiar with customers who fail to pin down their needs or adequately describe their wants. If the customer cannot adequately articulate these parameters, the likelihood is strong that additional knowledge will continue to surface, which then affects—interrupts, interferes with—the design process. For example, the successful development of the simple Nike "swoosh" logo—implying speed, direction, agility, motion—required near-intimate knowledge of the organization and its needs.

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[1] This process was first defined by Hooton from Pictogram Studios (Garrett Park, Maryland), J. Toth (IDA), and A. Graesser (University of Memphis) and will be published in a separate IDA report.

In examining the similarities among science, engineering, and art, first note that these activities are goal-directed—they produce *products* for a particular end user or customer. Even though one might balk at the notion of the painter or composer as goal-directed individuals, their activities produce a result in a given *medium*. In gaming, entertainment, and graphic arts (the artistic activities most relevant to FCS), this is particularly true. Second, these activities are motivated by requirements. Science requires solutions and answers, engineering requires better artifacts and processes, and the arts require effective media that communicate a particular message, emotion, theme, or idea. In the setting of shared understanding for FCS, the arts, coordinated with science and engineering, should permit rapid, efficient conveyance and acknowledgement of various forms of information among warfighters and their leaders. Finally, all three activities are inherently creative, requiring little discussion concerning any argument against the creative nature of science or engineering. For each discipline, an important issue regarding creativity is *when* it occurs or when it *should* occur to produce the best results. In science and engineering, creativity is required in noticing a phenomenon or identifying a problem and in constructing the appropriate method, solution, artifact, or process compelling enough to convince scientific peers or users. In the artistic process described previously, the creative aspect is constrained to phases A2 and A3. The remainder of the phases involves requirements gathering and producing the final product.

2. Rigid Sequenced Development vs. Iterative Design

Following the general descriptions of science and engineering discussed previously, research and product development efforts place relative emphasis on certain phases or all the phases, depending on the problem and requirements. As such, one might envision a continuum flanked on one end by a strict, serial approach to phases S1–S5, E1–E5, or A1–A5, and a concurrent or iterative approach on the other end. The serial approach, usually referred to as “Design From Specification” in Engineering and “First Principles” in Science, is a more rigid means by which scientists and engineers do not begin the next phase until the current phase is complete. The choice of approach on the continuum is constrained by user requirements, the medium, and with what is known to be the state of the art (Figure II-1).

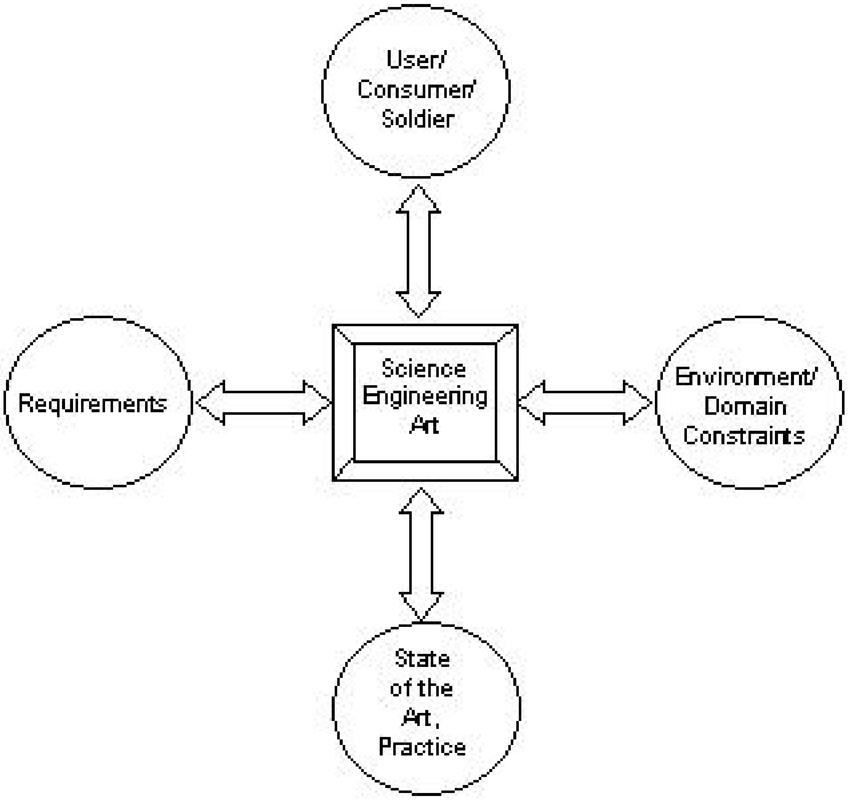

Figure II-1. Factors Affecting the Disciplines of Science, Engineering, and Art

For instance, in the graphic arts, when the final product is a logo, pamphlet, or annual report, a significant amount of time might be spent in the earlier phases—in an attempt to "get it right"—before the final product is generated and propagated on various forms of indelible immutable media (paper, soda cans, billboards, and so forth.). The designer does not have the luxury of retracting a corporate logo or annual report simply because a new requirement demands a rework of the product. In essence, the customer or end user is "stuck" with the product. However, if the designer is good at his or her trade, the product will also be good. Likewise, in science, particularly if resources are highly constrained (Hubble telescope, linear accelerator, super computer), a well-developed research plan including the problem and the method is usually required before resources are allocated for a particular experiment or procedure. In engineering or architecture of "hard" products such as buildings and vehicles, once the skyscraper is built or vehicle is rolling off the assembly line, redesigning the product is not an option. This is precisely the reason why automobile manufacturers first develop models in clay (phases A2, A3) before plants are retooled to manufacture the final product.

On the other end of the continuum, the phases may proceed in an iterative or concurrent fashion. Particularly, in *soft*ware development (note the emphasis on "soft"), where the medium is less rigid and far more malleable, several iterative prototypes may evolve before the final product is released. In other words, engineering phases E1–E4 and artistic phases A1–A3 may iterate through several cycles until a final design is realized. And, even after release, successive releases or versions are easy to assimilate into a common platform (Windows, Play Station 2, and so forth).

For this FCS interface task, the iterative approach will be possible since many of the display and input elements will be software or smaller hardware prototypes. It is recommended that development proceed through the careful gathering of requirements (and subsequent evaluation by DoD leadership) from SMEs and the warfighter familiar with domains most applicable to FCS. DoD can no longer afford to gather requirements from the outmoded BOPSAT (bunch of people sitting around a table) technique because this technique has given birth to multi-million dollar debacles that could have been avoided had the designers asked the most important group people—the users—what they need.

Norman (in particular Norman and Draper, 1986; Norman, 1993; now joined by Nielsen, 1995) persistently argues for user-based, user-centered designs. The relatively few staff hours and telephone calls required to summon the appropriate users during early phases of development pay handsome dividends years down the road when the product is finally operational.

3. Getting to Know the User: Designing for Usability, Utility, and Pleasure

A recent volume by Jordan (2000), *Designing pleasurable products: An introduction to the new human factors*, is so unique, practical, and comprehensive in its approach that some discussion is required. The concept of "pleasure"—setting the war fighter's domain—is so antithetical to the rigid, serious, principled, structured approaches present in the mainstream defense human-factors literature that some may bristle at the very thought.

To begin, Jordan identifies three phases in the recent history of human factors:

- **Phase 1: 20–30 years ago.** The user, with the exception of defense, was simply ignored in the engineering or manufacturing process. A product need was identified by the corporate hierarchy and executed by corporate scientists and engineers.

- **Phase 2: 10–20 years ago.** Human-factors engineers became integrated into the development process but were only engaged in a "bolt-on" sense. In other words, the core product was developed, and, if time, resources, and constraints permitted, human-factors issues were "bolted on" to the product.
- **Phase 3: 10 years ago to the present.** Integrated human factors have begun to appear. In other words, the needs of the user are considered from the very start of the product development process.

A simple thought experiment illustrates this shift in perspective, comparing (1) the bulky metal computing keyboards from the 1970s with the slender plastic keypads of today or (2) the evolution of the workstation mouse, to trackball (which had problems), to touch pad, and onward to the mouse, again. The functions text entry (keyboard) and windows manipulation (mouse) remained somewhat invariant through this evolution. What changed were the forms of interaction with the devices and the emphasis on the manner in which the user felt satisfied with the interaction.

Although usability has emerged as an important principle (Nielsen, 1995), Jordan (2000) argues usability alone is not sufficient when attempting to meet all the user's needs. Beginning with Maslow's (1970) hierarchy of needs [from bottom to top: (1) physiological, (2) safety, (3) belongingness/love, (4) esteem, and (5) self-actualization], the more complete approach to design is based on the user's needs (not to be confused with the engineering concept of "requirements"), and how they are satisfied within and among these five levels. Once a lower level has been satisfied (e.g., hunger), humans, according to Maslow, will always pursue higher needs. However, humans continually move up and down these levels on a daily, if not hourly, if not moment-by-moment basis.

Jordan (2000) maps the Maslow hierarchy to three levels of product needs:

1. **Functionality.** The product must function so that at a minimum, the user can perform and complete a task.
2. **Usability.** The product must not only function, but it must be easy to use. That is, interaction with the artifact should not be cumbersome, thus impeding the user's task.
3. **Pleasurable.** The product is not only usable, but it is also a pleasure to use. In other words, form, function, usability, and aesthetics become one. The user reaches a state that Jordan refers to as "pleasure." Similar concepts have been discussed as "experiential thought" (Norman, 1993), "flow" or "optimal flow" (Csikszentmihalyi, 1990), or even the experience of "being in the zone" as described by amateur or professional athletes. This mental state is consistent with the more principled concepts of automaticity, implicit

memory, and procedural knowledge. From a formal standpoint, aspects of this state include an effortless, unconscious, enjoyable experience, ostensibly allowing the user to attain the higher levels of Maslow's hierarchy.

From the perspective of the DoD human-factors specialists and their customer, the soldier, very little might be considered pleasurable when it comes to an experience as harsh and potentially terminal as combat. With the exception of experiencing or incurring injury, however, the following question is posed:

> Given the harsh and unpleasant context of combat, the tedium of training, and the myriad related activities, why shouldn't products for the soldier be as usable and pleasurable as possible?

This question first compels us to distinguish between the pleasure associated with work, daily tasks, and other activities vs. the *displeasure* of combat and casualty. With the exception of terrorists, despots, and anarchists, few will argue that killing is pleasurable. Nevertheless, the aim of the design process should facilitate the DoD precept of *readiness* to the greatest extent possible. A weapon that jams, a display that is confusing, a switch or button that is difficult to locate, a command or piece of vital information that is lost in the fog of war all place the soldier at risk. Thus, the concept of *pleasure* herein is examined from the context of product development as it occurs in mainstream industry but takes in the principles described previously (item 3. above), referring to the mental state in which satisfied users find themselves. Users who are satisfied with their work are facilitated by tools that support their work. In addition, in the realm of product development, Jordan (2000) has advanced a myriad of principles directly applicable to DoD's purposes. One goal for future work should be to bridge the gulf between industry and DoD. Industry takes great strides to understand the market and user/consumers by gaining the attention and loyalty of existing and potential customers. On the other hand, DoD has sometimes pursued product development in isolation, seemingly unaware of (or unwilling to heed) the methods that industry routinely employs. Even though the economic forces in industry are different from those in DoD, some lessons from the private sector have clear relevance to the defense establishment.

Keeping these distinctions in mind, given that a product meets the requirements of functionality, usability, and aesthetics and provides some sort of user benefit, Jordan (2000) identified four levels of pleasure—corresponding to Maslow's (1970) hierarchy:

1. **Physiological.** The product or activity meets the user's physical needs. When necessary, all aspects of the soldier ontology (see Section III.B) have been

addressed and afford the most efficient and direct interface that optimizes behavior and performance and minimizes negative properties such as discomfort, fatigue, and boredom.

2. **Psychological.** The product or activity meets the user's psychological demands (i.e., at the "cognitive" level). The product is mentally stimulating. Soldiers at all echelons can think about the strategic, tactical, and operational modes for which they are trained.
3. **Sociological.** The product or activity facilitates social interaction in the broadest sense. This includes the perception of authority in the chain of command; a menacing appearance that intimidates the enemy—in the form of clothing, weaponry, and accessories—and other labels, icons; and insignias that convey mutual respect, self-sacrificing trust, and a willingness to collaborate within the team.
4. **Ideological.** The product or activity facilitates or speaks to the user's higher purposes. Industry depends on branding and product ideology to grab and maintain a loyal customer base. The DoD ideology, one can assert, is to preserve and defend the Constitution. The enemy, on the other hand, should receive the ostensible message that the American soldier is a force to be reckoned with if a clear picture of DoD ideology has been apprehended.

Some may ask the following question: What does this have to do with DoD? Now that engineers and scientists are at least acknowledging—and, in some instances putting into practice—the transition from machine-centered design to user-centered design, the answer is *quite a bit*. A good portion of Jordan's volume is devoted to getting at the best way *to understand the user* and then developing products, artifacts, and processes that meet the various needs listed previously, based on a deeper understanding of the user. Furthermore, user feedback is not limited to the ubiquitous user survey. Appendix A describes the methods for understanding users.

The following list summarizes the major techniques for obtaining user/participant feedback:

- **Private camera conversation.** The user first interacts with the product or prototype, and then, seated alone in front of a video recording device, describes his/her impressions of the product.
- **Co-discovery.** Two users who know each other work together to explore the product or a concept and articulate their ideas and impressions. The designer, scientist, or engineer may or may not be with the dyad.
- **Focus groups.** A small group of people (5–12) are seated together and led by a facilitator, who guides the group in discussing a product or concept. The

facilitator usually follows an agenda, prompts the group when stuck, and mediates the discussion so that all the group members have an opportunity to speak.

- **Think-aloud protocols.** The user, seated with the investigator, articulates his or her thoughts while using the product and following a reasonably structured task [e.g., programming a videocassette recorder (VCR), driving a car, and so forth].
- **Experience diaries.** Users carry diaries with them for a few to several weeks as they use a product. The entry in diary can be a combination of a miniaturized questionnaire, a list of brief questions, a checklist, and so forth.
- **Reaction checklists.** While interacting with the product, the user checks off a list of positive and negative experiences.
- **Field observations.** Users are observed as they interact with the product in as close to natural a setting as possible. Whenever possible, the influence of the investigator is kept to an absolute minimum.
- **Questionnaires.** The users complete a questionnaire after using the product. In fixed-response questionnaires, users answer questions according to multipoint interval scales. In open-ended response questionnaires, the users are allowed to provide written replies to questions.
- **Interviews.** A designer or facilitator interviews the user in three ways (structured, semi-structured, or unstructured) to gain insights into the product or concept. This method is similar to a face-to-face questionnaire.
- **Immersion.** The designer becomes the user and records his or her own impressions of the product or concept. Immersion (described in greater detail in Appendix A) is the prevailing method in DoD but is riddled with bias and should be avoided.
- **Laddering.** A designer or facilitator asks the user about a positive or negative aspect of the product or concept (e.g., one calorie drink). The user answers the question (e.g., I want to be thinner; i.e., Maslow Level 1), and the designer asks why. The user replies again (e.g., Because if I'm thinner, I'll feel better; i.e., Maslow Level 2), and the designer again asks "why." The user again replies and so forth.

  The purpose of laddering is to gather information about formal and experiential properties and benefits of the product, detailed information about the user (e.g., Maslow needs or general requirements), and relationships among these three criteria.

- **Participative creation**. A group of users and the designer collaborate on the design of the product. This method is similar to the focus group but is considered more hands-on.
- **Controlled observation.** This method is also known as the controlled experiment. It identifies independent/dependent variables, statistical tests, and so forth and is the mainstay of principled human-factors research.
- **Expert appraisal.** A small group of SMEs or content experts who are not affiliated with the design process (e.g., a seasoned video game players evaluating a new game) evaluate the product. SMEs may even be human-factors experts and function in a Red Team capacity.
- **Property checklists.** The designer organizes a list of positive and negative properties associated with the product. These properties can be derived from the product requirements. As development process proceeds, the product is evaluated according to this checklist.
- **Kansei engineering.** This method allows the designer to understand the relationship between formal and experiential properties of a product and gives insight into benefits that the users want to gain from products and into the properties that realize these benefits. The designer either manipulates various individual properties or features of the product and statistically validates the users' impressions of these differences via cluster analysis or conducts observations in situ [unlike field observations, however, these observations occur while users interact with the product (e.g., determining the requirements for refrigerators by visiting users' homes and observing their interactions with the refrigerator)].
- **Sensorial Quality Assessment (SEQUAM).** Like Kansei engineering, this method manipulates various properties of the product and tries to understand how properties are linked with product benefits. Correlational statistics are used instead of cluster analysis, so fewer properties can be examined.
- **Product Personality Assignment (PPA).** Humans tend to anthropomorphize (i.e., assign human personality traits) to many objects in their environment—even animals. This method analyses users' impressions of products through individual product "personality" traits. Research has determined that people tend to assign general traits to products (e.g., Volkswagen Bug is "cute") and project their own individual traits onto products. For example, an introvert on Myers-Briggs scale may perceive a product as introverted.
- **Mental mapping.** This method is similar to PPA, but traits focus on famous public figures or on extemporaneous stories users make up about the product. This technique is highly successful in industry, but the methods employed by each designer are typically proprietary. This method keys in on unconscious,

even archetypal (Jungian or Freudian) concepts that create a strong link between the user and the product.

- **Expert case studies.** In this method, experts evaluate products—technical, functional, aesthetic—according to features and benefits that have led to success or failure.
- **Experiential case studies.** This method is similar to expert case evaluation, but, in this instance, theusers evaluate the product.

B. PUBLISHED GUIDANCE

1. Background

The intent of this literature review is to examine and identify issues relating to interface design guidance for the FCS SMI. This review contains a bibliography (see Appendix B for references) and identifies the types of human-factors information currently available. This is an evolving review. It not intended to provide exhaustive coverage but to cover enough of the research to make decision-makers aware of the important issues during FCS SMI development so that soldiers can eventually be presented with an integrated and seamless system.

2. Methods

A search of the literature was conducted using STILAS, the Institute for Defense Analyses (IDA) Library Catalog. Searches were also conducted using PsycInfo (through George Mason University) and the World Wide Web (WWW) using the Google and Yahoo! search engines. Examples of search elements included combinations of the following key words: “Human-Factors Evaluation,” “Soldier-Machine Interface Design,” “Human-Computer Interface Guidelines,” “Human-Factors Checklist,” “Design Philosophy,” “Interface Standards,” “Interface Interoperability,” “Interface Design,” “Systematic Approach to Interface Development,” “Guidelines for Developing an Interface,” “Custom User Interface,” and related variations. More than 300 books and articles were retrieved, and approximately 200 were reviewed for utility. Both paper and electronic copies of these documents are stored at IDA. A database was constructed in MS Excel and MS Word to catalog these items.

The database of reviewed documents contains the following field names: Internal document name (for electronic copies), Author(s), Year, Title, Source, Media (Paper; Web), Type (Literature Review; Design Guidelines), Status, Description, Taxonomy

(DoD; Other Non-DoD; Academic; Industry). The physical database contains paper and electronic versions of documents.

3. Results

The initial literature search was restricted to military references. The results of this search yielded a variety of precision detailed articles and Military Standards (MIL-STDs) involving interface display design guidance. These highly structured and detailed standards include guidance on the display and use of colors, auditory signals, image blink rates, menu layout, data formatting, input devices, displays of warning messages, the use of shortcuts, and time intervals between actions. The following two examples from Avery and Bowser (1992) illustrate the depth of detail contained in some guidelines:

> Minimum height of displayed characters should be 1/200 of viewing distance. For example, a viewing distance of 36 inches requires a 0.18-inch character height on the display screen. Character width should be 50–100% of character height. Character stroke width minimum is 10–12.5% of character height. Maximum text size should not exceed 10% of the available vertical display area on a full-size screen (10.3.5.3—Character Height and Width).
>
> Do not indicate window movement by an outline only. Provide either full movement of the window or move an outline, leaving the window visible on the screen (7.2.3.1—Window Movement Feedback).

The specificity of these guidelines is highly structured and contains detailed design guidance, but design principles are lacking. In fact, one could argue that these are not guidelines; rather, they more closely resemble directions or instructions. In addition, the details in this example may or may not generalize from one domain to another. True design principles, on the other hand, guide the designer from the general to the specific through a multiphased process, as described earlier.

a. Military Documents Relevant to FCS

The initial review yielded the following military documents, which were deemed relevant to the FCS interface effort:

- **MIL-STD-1472F: *Department of Defense Design Criteria Standard: Human Engineering* (DoD, 1998).** This standard establishes general human engineering criteria for designing and developing military systems, equipment, and facilities. Its purpose is to present human engineering design, criteria, principles, and practices to be applied in the design of systems, equipment, and facilities so as to achieve required performance by operator, control, and maintenance personnel; minimize skill and personnel requirements and training time; achieve required reliability of personnel-equipment combinations; and foster design standardization within and among systems.

- **MIL-STD-2525B:** ***Department of Defense Interface Standard: Common Warfighting Symbology*** **(DoD, 1999).** This standard is designed to eliminate conflicts within various symbol sets and to bring a core set of common warfighting symbology under one DoD standard. It provides sets of command, control, communications, computer, and intelligence (C4I) symbols, a coding scheme for symbol automation and information transfer, an information hierarchy and taxonomy, and technical details to support systems.
- **North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 2019:** ***Military Symbols for Land Based Systems*** **(North Atlantic Treaty Organization, 1990).** This standardization is aimed to promote interoperability for the exchange of secondary imagery among NATO C4I systems to ensure that colors, symbols, line size/quality, and fonts are consistent throughout a given system. The major features include the application of four distinctive frame shapes to identify unknown, friendly, neutral, and hostile forces and the addition of tactical task graphics.
- **MIL-STD-411F:** ***Department of Defense Design Criteria Standard: Aircrew Alerting Systems*** **(DoD, 1977).** This standard covers aircraft aircrew station alerting systems, including physical characteristics of the alerting system's visual, auditory, and tactile signals to establish uniform aircrew station alerting systems to maximize recognizability.
- **Lewis and Fallesen (1989):** ***Human-Factors Guidelines for Command and Control Systems: Battlefield and Decision Graphics Guidelines.*** This document provides graphics guidelines in detail.

b. Academic Literature

In an effort to tease out firm design principles, the focus of the literature review was broadened to include academic articles. Whereas the military literature converged into structured rules as illustrated previously, the academic literature, alternately, diverged into broad, philosophical discussions on design approaches (e.g., Laurel, 1991). This literature often approaches interface design as an art and is a stark contrast to the detailed, somewhat rigid military specifications, which follow the engineering process and scientific method.

Several key articles (Tullis, 1988; Kelley, 1984) stress the notion of iterative prototypes and evaluations with significant emphasis on the end user. "Screen design is a dynamic process. It has elements of art and requires creativity and inventiveness" (Tullis, 1988). He described six steps of an iterative design process, as illustrated in Table II-2.

Table II-2. Tullis' Six-Step Iterative Design Process
(Source: Tullis, 1988)

Step	Process
One	Requirements and constraint analysis
Two	Task analysis and scenario development
Three	Development of design rules
Four	Development of an implementation philosophy
Five	Early design, prototyping, and evaluation
Six	Full-scale prototyping and implementation

Kelley (1984) also described a systematic, empirical methodology for developing a computer application (a personal calendar). Although the computer application itself is somewhat out of date, the six evaluative steps again illustrate the process of iteration. Table II-3 illustrates these steps.

Table II-3. Kelley's Six-Step Evaluative Process
(Source: Kelley, 1984)

Step	Process
One	Task analysis
Two	Structure development
Three	First run of program (simulation mode/storyboard)
Four	First approximation (inputs from step three used to develop first draft of product)
Five	Second run of program/intervention phase ("iterative design phase"): as this step progresses and bugs augmented, the experimenter phases out of loop after point of diminishing return
Six	Cross-validation with new participants: no experimenter intervention and/or assistance in product

These earlier attempts proposed one or two iterations before the final product was realized. Later, an iterative spiral approach emerged, in which many iterations are possible before the final product is realized.

Blackwood et al. (1997), in their guidance for helmet-mounted displays (HMDs), suggest a three-tier, highly integrated research, testing, and evaluation strategy. This approach represents a shift from current practice because it includes an intermediate, semi-controlled set of research and testing experiments between laboratory and bench testing and operational field operations. Equally important, it incorporates the active involvement of users in every stage in the development sequence. The three tiers are defined in Table II-4.

Table II-4. Three-Tier Design Process
(Source: Blackwood, 1997)

Tier	Process
One	Controlled laboratory or bench testing of system's technical performance —both with and without human users
Two	Controlled field experiments with a variety of users, from experienced to new entry, and with system experts from design teams involved
Three	Operational test and evaluation (OT&E) exercises employing soldiers from the target population in virtual-type simulations and live simulations in a realistic operational environment

As described in Table II-4, this methodology brings the end user into the testing and evaluation process earlier through controlled testing that combines the varied environmental and personnel conditions from operational testing with the structured data collection and controlled conditions characteristic of laboratory testing. The mid-level tier of trials allows for the interaction of the potential users and the design team in conditions that combine structured data collection with variability in environmental conditions (e.g., day, dusk, night for visual factors; camouflage for terrain variations) and individual variation in users (e.g., effects of regional accents on the performance of a voice recognition system for acoustics) (Blackwood et al., 1997).

Blackwood et al. (1997) also suggest that for the display to be both performance enhancing and cost effective, subsequent operational testing should be implemented at the small-unit level (minimizing larger scale testing scenarios). This soldier "in-the-loop" testing should also have an increased scope, with longer durations or cycles of task performance than those that have been used in the past.

In the early stages of the research, development, test, and evaluation (RDT&E) process, critical design decisions are often made by scientists and engineers who are knowledgeable about the technology but have less expertise in the operational employment of the new system. Without consistent and thorough collaboration with knowledgeable user representatives, the evolving design is often driven by the engineer's or technician's view of what is important or what is possible—with less focus on what is most needed by the soldier. FCS represents a major step forward in technology. To be effective, the research, development and design process must have soldier input, involvement, and commitment. User-centered design is a significant aspect of the three-tiered process described previously.

Though not exhaustive, the following references are considered particularly relevant to FCS. They are listed and briefly described, as follows:

- **Kroemer, Kroemer, and Kroemer-Elbert (1994):** ***Ergonomics: How to Design for Ease and Efficiency.*** Serving as a reference manual, this book organizes standards, physical limitations, controls, and displays for human-factors engineering.
- **Laurel (1990):** ***The Art of Human-Computer Interface Design.*** This book is philosophical in nature. Each chapter describes a different author's view on interface design. Some author's discuss color use and sound use for display cues.
- **Norman (1991):** ***The Psychology of Menu Selection: Designing Cognitive Control at the Human/Computer Interface.*** This book does a thorough job adressing interface menu design issues. Norman writes, "Menus allow for a relatively effortless selection of paths through a system." One empirical finding is that users favor distinctive icon menus over either the word menus or the representational menus.
- **Shepard (1991):** ***Report of Results of ATCCS Contingency Force Experiment-Light (ACFE-L) Group B, Soldier-Machine Interface (SMI) Assessment.*** This article provides a protocol template for iteration evaluation. Each design issue is examined—followed by results (from structured interviews) and conclusions.
- **Flach and Dominguez (1995):** ***Use-Centered Design: Integrating the User, Instrument, and Goal.*** This article stresses that interface designers should focus attention on the functional relations among users, instruments, and goals.
- **Norman (1993):** ***Things that Make Us Smart: Defending Human Attributes in the Age of the Machine.*** This book adresses the gap between the designer's expectations and the user's experience, which are often at odds. It points out weaknesses in machine-centric approaches to design, in which the end user is largely left out of the design process.

- **Carroll (1991):** ***Designing Interaction: Psychology at the Human-Computer Interface*** **and Nardi (1996):** ***Context and Consciousness: Activity Theory and Human-Computer Interaction.*** Both of these volumes address the disembodied nature of mainstream cognitive science. For instance, a GOMS[2] analysis might serve a keystroke model well but be entirely insensitive to the fact that the user might be of Western or Eastern descent. Soviet theories of activity (e.g., Vygotsky, 1962), which promote a unified conception of the user and an environment, help motivate much of this theory.

An important note is that most of the articles in this review have centered on interface display rather than interface control. This is not an omission but is caused by the large and broad volume of articles related to information display. Another important note is the publication year of most of the journals referenced. Most of the articles precede the "Age of the Internet," and, as such, the results may need to be reexamined.

c. Display Usability Research

Previous research of pilot use with heads-up displays (HUDs) has demonstrated utility because the displays do provide the pilots an advantage by enabling them to stay on course and to conduct successful instrument landings. However, research has also shown that pilots who use an HUD are more likely to miss occasional, low-probability events, such as an aircraft moving onto the runway during an approach for landing (Wickens and Long, 1994).

Alternately, the use of HMDs by the dismounted soldier poses its own particular set of constraints that are quite different from those encountered in the cockpit. Because the soldier is mobile, the issue of providing a stable base for the display becomes even more important than it is in the cockpit, making helmet fit and weight potential critical issues. In addition, part of the advantage of HUDs in the aircraft results from the symbology that can be made to conform to various aspects of the scene (Weintraub and Ensing, 1992). For example, a runway with associated symbology can be superimposed on an actual runway scene, which helps to integrate the two sources of information and reduce attentional interference (Wickens and Andre, 1990). Conversely, it is difficult to

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[2] GOMS is an acronym, coined by Card, Moran, and Newell (1983), that stands for Goals, Operators, Methods, and Selection rules. These were components of a model originally intended to analyze the routing of human-computer interactions. However, the GOMS has proved to be more general and has been applied to variety of operator-machine interface issues.

imagine how this sort of conformal mapping between symbology and scene features could be achieved in the infantry environment. Therefore, it is important to analyze the use of different displays within the context of the physical and task environments in which infantry soldiers operate (Blackwood et al, 1997).

Blackwood et al. (1997) list some of the negatives of helmet-mounted visual displays, including a tendency to load the user with more information than is needed, motion illusions resulting from unstable symbology, soldier disorientation, and loss of balance. They propose the implementation of display devices that provide information in the form of enhanced sensory or symbolic displays. In the proper circumstances, these displays can contribute greatly to the safety and effectiveness of the dismounted soldier. In addition, soldiers using display equipment will often be in dual-task situations. For example, a soldier may be navigating terrain with the aid of a map display and a Global Positioning System (GPS) when an auditory message comes in. The message has to be checked for its importance relative to the navigation task; therefore, the speed and accuracy of response to such messages would be expected to be a function of the ease of using the map system.

d. Evolving First Principles

The underlying themes contained in a large part of the academic literature are concepts of iteration (the repeated evaluation and refinement by potential end users) and controlled experimentation. Tullis (1988) explained that interface design is an iterative and dynamic process and should be approached as such. Toward that end, the literature review has yielded several recurring design practices and principles for both display and control interfaces. The result is a set of preliminary design principles:

- Understand the users and their tasks (Galitz, 1993).
- Involve the user in the design (Galitz, 1993).
- Test the system on actual users and refine as necessary (Galitz, 1993).
- Use common language (Galitz, 1993).
- Provide an obvious display starting point (Galitz, 1993).
- Provide consistent component locations (Galitz, 1993).
- Provide only information that is essential to making a decision (Galitz, 1993).
- Provide all data related to one task on a single screen (Galitz, 1993).

- The display formats, language, labels, and operation of the computer system should be consistent throughout the course of the dialogue (Chao, 1986).
- Users should always be aware of where they are in a transaction, what they have done, and where their actions may have been successful (Chao, 1986).
- Since users will make errors, the designer must have a system for detecting, communicating, and correcting errors (Chao, 1986).
- The user should be able to restart, cancel, or change any item in an entry before or after the "ENTER" key is activated. The user should be able to abort or escape from a partially processed entry without detrimental effects to the stored data or other system functions (Chao, 1986).
- Representation is the critical aspect of interface design. Different surface representations of the same content (text, graphics, tabular, numerals) can oftentimes yield effortless or effortful performance (Norman, 1993).
- Visual literacy should be considered in design. Nomic capabilities (e.g., Gestalt principles, just noticeable differences in shading and texture) provide innate building blocks for visual displays (Dondis, 1973).
- Avoid distractions (e.g., chart junk, color pollution, visual clutter) that take away from the efficacy of the design. Sometimes less is more (Tufte, 1983).
- Design is *not* a black art. Creative design can be accomplished through a phased, structured approach. The creative leap from requirements to design is facilitated by a thorough understanding of the customer or user (Toth, Hooton, and Graesser, in preparation).

Relating to controls, additional questions will require research to resolve. Because of the complexity of FCS, many single variables need assessment by research, and many tradeoff functions and interactions will require systematic study in a field setting. For example, basic questions concern how a given control will be put to use and additional crucial questions about how one mode of use relates to the other modes.

It seems unlikely that there is a single location (wrist, helmet, chest, belt, weapon stock, and so forth) where the full complement of controls can be located without penalty. It seems equally unlikely that any one mode (keyboard, trackball, voice, and so forth) will provide the ideal means of control. However, trying various arrangements in the field or field-like conditions is a straightforward test project that could lead directly to a minimally disruptive array of control locations.

Such an effort would be congruent with the goals of the overall FCS program, which is to give the dismounted soldier as much of a tactical advantage as possible while not adding to his problems. This general goal also leads to some reasonable specifications for the designers of the controls:

- The controls should be kept as simple (and rugged) as possible (Blackwood et al., 1997).
- They should also be protected from inadvertant activation—by the soldier or by obstructions in the environment—but, at the same time, should be easily and quickly accessible (Blackwood et al., 1997).
- Whenever possible, there should be strong cues to the function over which the control presides. Such cues include location in sets, proximity to the device being controlled, and some easy abstraction such as a shape cue or a color coding that is not ambiguous (i.e., red = stop) (Blackwood et al., 1997).

4. Summary and Future Considerations

The aim of the literature review is to examine and identify issues relating to interface design guidance for the FCS SMI. Documents are being continuously obtained and reviewed for utility. The pattern emerging from the military sources is one of precise and highly detailed design guidance, whereas the pattern of the academic sources leans toward philosophical design principles, stressing the importance an iterative process of user feedback and refinement and the implementation of controlled studies.

One potential problem with the literature is the publication genealogy. While the search identified a significant number of relevant documents, many of the articles have been published pre-1995, before the Internet boom of the late 1990s. It is quite possible that advances in computing technology have made much of the display research outdated, and the next generation of Web-based research underway will eventually appear in the open literature. A more ecumenical view, however, identifies common themes no matter what date of research. Prime examples are the desktop/window/menu/mouse metaphors, which have not changed for nearly 20 years despite the fact that individual instantiations of the metaphors have.

One area in need of research attention is the hierarchical ordering of information from immediate threat to minor operational concerns and evaluating alternative presentation sequences and formats (Blackwood et al., 1997). Another research area concerns the allocation of information to visual vs. auditory channels and the applicability of advanced technology, such as 3-D audio, in making these allocation decisions. Research is also needed on the way in which graphic displays are structured and how these displays are formatted into standard iconic symbols for action. Blackwood et al. (1992) explain that it is possible that new information-processing and display capabilities could be used to reduce stress by providing a global help function (e.g., location of nearest friendly force) at all times. Also, a critical area of software development is the provision of this information in a secure manner. One could even imagine that an adaptive interface system could also be used to on-load the soldier during periods of boredom and off-load the soldier during periods of high workload (Blackwood et al., 1997).

Ongoing research continues to examine interface issues relating to control and display. The literature often reveals new areas for exploration, and research relevant to the FCS will be incorporated into the review as the task proceeds. Current reviews are focused on interface controls as a way of optimizing access to information. Other topics include examining the concept of cultural affordances or naturally encoded information and determining how these affordances might serve to reduce the cognitive demands on the soldier. Another topic for future review is that of augmented reality, or the superimposing of audio or other sense-enhancements over a real-world environment, and how this display might aid the soldier in understanding the battlespace, particularly terrain (Goudeseune and Kaczmarski, 2001; Hromadka, 2001).

C. RELEVANT INTERFACE CONCEPTS

In addition to approaches and guidance related to interface design in general, several actual C4ISR interface concepts are relevant to the FCS problem. Subsection (II.C.1) identifies and describes those concepts, and Subsection (II.C.2) identifies trends in design of C4ISR interfaces and discusses the application of trends to the FCS project.

1. Descriptions

A total of 10 C4ISR interface concepts have been developed that are either indirectly or directly related to the FCS. These concepts are described below in approximate chronological order of development and/or implementation.

a. InterVehicular Information System (IVIS)

The IVIS was designed as a command, control, and communications (C3) aid to enhance the situational awareness of the Abrams tank commander. R&D efforts on IVIS date back to the mid-1980s; however, IVIS was first fielded in 1992 when it was incorporated into the vetronics of the low-rate initial production (LRIP) versions of the M1A2. Fielding of the M1A2, equipped with IVIS, began in 1996 with the 1st Cavalry Division.

The IVIS is significant to the history of NCW because it was the first attempt to establish horizontal digital links from direct-fire platforms to artillery and aviation systems (White, 2000). Functionally, IVIS units interconnect similarly equipped M1A2 tanks at the level of the battalion and below (Dierksmeier et al., 1999). The interconnections are implemented by the transmission and reception of digitally encoded signals over the Single-Channel Ground and Airborne Radio System (SINCGARS). This technology enables the M1A2 tank commander to

- Provide continuously updated position location information for own vehicles and others in the unit
- Send and receive 22 preformatted reports, including spot reports and calls for fire
- Tansmit and receive graphic overlays and display five different overlays on each IVIS unit: OPERATIONS 1, OPERATIONS 2, ENEMY, FIRE SUPPORT, and OBSTACLE.

Figure II-2 provides two views of IVIS. In the left panel, the IVIS is shown as it is integrated in the M1A2 Commander's Integrated Display (CID). The CID includes the Commander's Independent Thermal Viewer (CITV) and the Command and Control Display (CCD), which includes access to/from IVIS and the GPS-based Position Navigation (POSNAV) system. The right panel shows a close-up of the IVIS display. This particular graphic is a screen capture taken from the IVIS Intelligent Computer-Aided Training (ICAT) program. Although this is a simulation, it is intended to provide a high-fidelity emulation of the IVIS display and controls.

The M1A2 technical manual (Headquarters, Department of the Army, 1995) procedural information about operating and maintaining the IVIS. The field manual for the Abrams tank platoon (Headquarters, Department of the Army, 1996) provides tactical information about employment of IVIS. In addition, Wright (2002) recently described some detailed tactics, techniques, and procedures (TTP) in which he emphasized the potential for IVIS as a navigation aid.

Although the IVIS system represents a relatively primitive interface, it is significant because it provided a baseline approach for subsequent systems, including the FCS. FCS developers should not have to repeat the difficult lessons learned through 20 years of IVIS R&D.

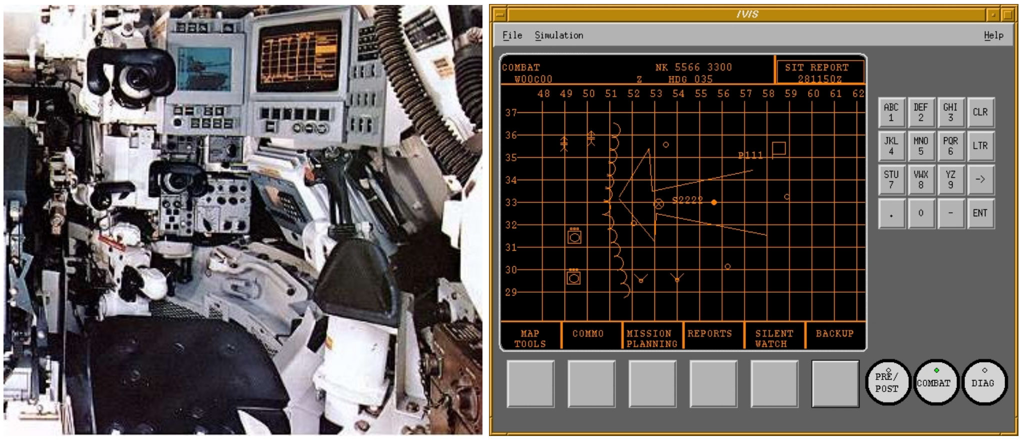

Figure II-2. Different Views of the IVIS

b. Force XXI Battle Command Brigade and Below (FBCB2)

The FBCB2 system represents an evolution of the interface concepts first developed in IVIS. However, it differs from IVIS in several key ways:

- First, the connectivity of FBCB2 is based on the Tactical Internet, a secure web-based technology derived from the commercial WWW. The Tactical Internet consists of SINCGARS, the Enhanced Position Location and Reporting System (EPLARS), and the Internet Controller router.
- Second, the FBCB2 is not embedded into vehicle systems; rather, it is designed as an appliqué or an appended technology. Consequently, FBCB2 can be fitted (and retrofitted) to a variety of combat vehicles and stations.
- Third, FBCB2 extends connectivity from battalion up to brigade level. As a result, FBCB2 represents a significant increase in capability.
- Finally, FBCB2 is based on the Tactical Internet, which is derived from technology developed for the commercial WWW and wireless telephony. Because the interface can be added on to vehicles, it applies to a potentially larger variety of vehicles and other stations. For instance, it is estimated that the typical brigade will have over 1,000 FBCB2s when fielded.

FBCB2 is in LRIP and is currently undergoing advanced soldier testing and evaluation in the 4th Infantry Division. The prime contractor, TRW, has received an order for 60,000 units with full-rate production (FRP) contingent upon performance during Initial Operational Test and Evaluation (IOT&E) scheduled for December 2001 at the National Training Center (NTC). However, this large-scale test was downgraded to a Limited User Test (LUT) when the DoD Director for Operational Test and Evaluation (DOT&E) did not accept the Army’s IOT&E concept. One of the key assumptions of that concept was that FBCB2 would exchange data with components of the Army Tactical Command and Control System (ATCCS). Reports indicated that components of the ATCCS—in particular, the Maneuver Control System (MCS), the C2 system for brigade and above—were not ready for IOT&E but that the FBCB2 had performed well in an electronic warfare environment ("FBCB2 full-rate …" 2002). Despite delays in FRP, elements of the FBCB2 continue to be fielded to operational units. Under the program known as the Balkan Digitization Initiative (BDI), the U.S. military was able to track the location of 700 vehicles equipped with FBCB2 software and ruggedized commercial hardware (Kontron Mobile computers), linked by a Qualcomm OmniTRACS Ku-band satellite system. In September 2002, the Army approved a sole-source contract to TRW to equip vehicles operating in the Persian Gulf region. The new Gulf Digitization Initiative (GDI), which is similar to the BDI, will link 200 vehicles but using a new L-band satellite hub and data server (Gourley, 2002).

Figure II-3 provides two views of the FBCB2. The left side shows the three components of the system: display, processor, and keyboard. The right side shows a close-up of the display, showing several software buttons controlled by keyboard, mouse, or thumbpad. The current computing environment is the Intel computer running a Unix operating system (Bowers, 2002).

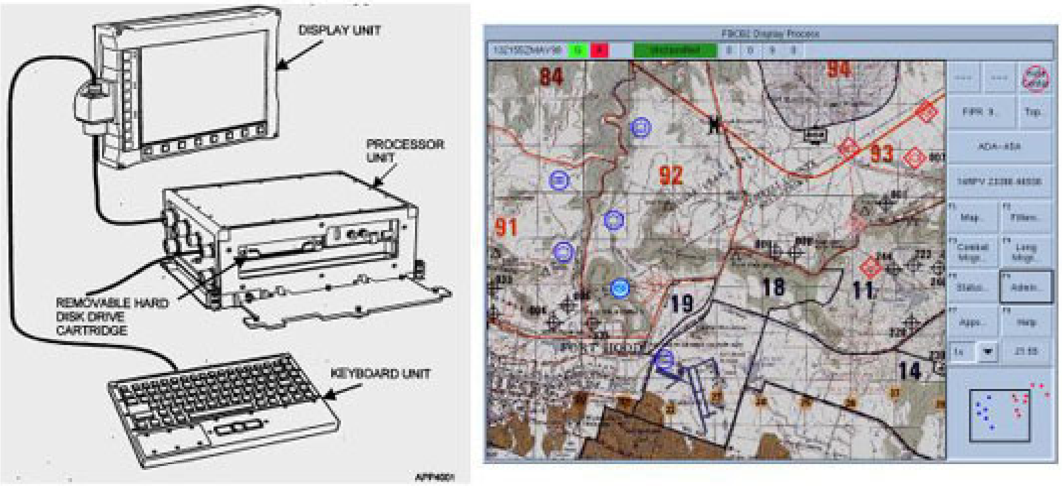

Figure II-3. Different Views of the FBCB2

FBCB2 is key to the project because it represents the state-of-the-art in C4ISR interfaces. The FCS interface must have access to and control over information in the FBCB2 and that Tactical Internet to be able to maintain links with legacy systems.

c. Surrogate digital Command, Control, Communications, and Computer (SC4) System

The Surrogate digital Command, Control, Communications, and Computer (SC4) system was developed as part of Battle Command Reengineering (BCR) experimentation program at the Mounted Maneuver Battle Laboratory (MMBL). The MMBL [in association with Illinois Institute of Technology Research Institute (IITRI), AB Technologies, Lockheed Martin-Marietta, and other supporting contractors) developed the SC4 to be used in virtual simulation experiments to emulate the functions of an advanced C4ISR system and interface. In the context of current capabilities, SC4 emulates the FBCB2 and the other five components of the ATCCS: the All Source Analysis System (ASAS); the MCS; the Advanced Field Artillery Tactical Data System (AFATDS); the Forward Area Air Defense Command, Control, Computers, and Intelligence (FAADC3I); and Combat Service Support Computer System (CSSCS) (Ray, 2000). The SC4 has also been modified to simulate future (post 2015) C4ISR capabilities, including automated target recognition and sensor fusion (Mounted Maneuver Battle Laboratory, 2002).

The SC4 system is typically installed in the battalion commander's simulated vehicle and those of his staff and in each company commander's simulated vehicle. The exact components of SC4 have differed as the system has evolved for different purposes. To provide an example SC4 configuration, we present one reported by Deatz et al. (2000) in Figure II-4 and describe the capabilities of its components below:[3]

- **A C2 display.** This display provides a 2-dimensional (2-D) top-down view of the battlefield derived directly from the the Modular Semi-Autonomous Forces (ModSAF) Plan View Display (PVD).
- **A stealth display.** This display provides a 3-D, 360° view of battlefield from the view of all friendly vehicles and detected threat vehicles.
- **A satellite imagery display.** This display emulates the capability to downlink imagery directly from electro-optic satellite sensors or unattended air vehicles (UAVs).
- **Video teleconference functions.** These functions provide face-to-face communication between the commander and his staff.

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[3] In addition to these major components, the SC4 includes several automated tools, including those for calculating or determining unit location, line of sight (LOS), time-distance measurements, and combat service support (CSS) Class III/V consumption.

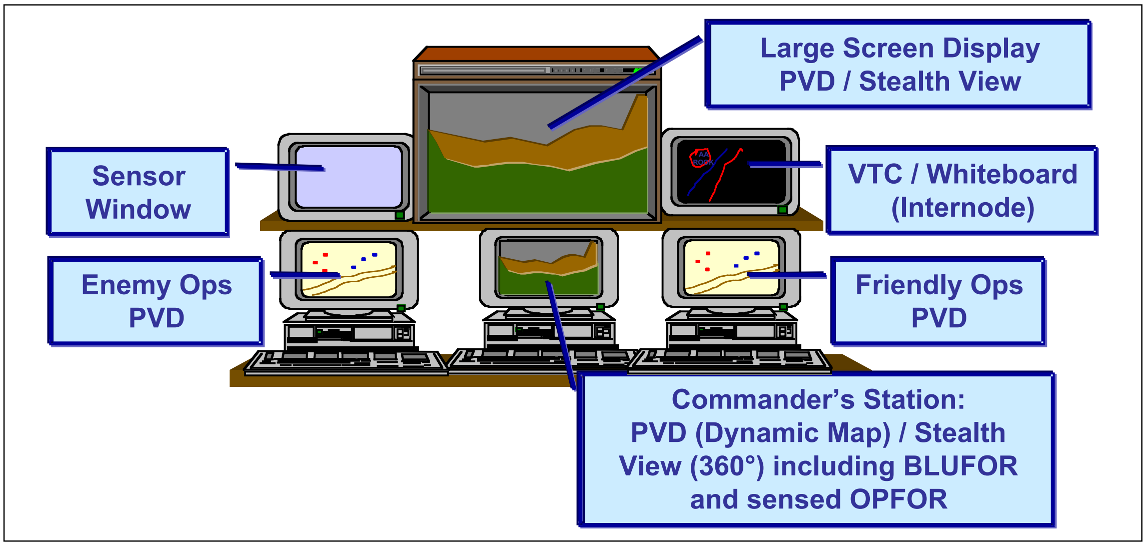


Figure II-4. Components of the SC4 System
(Source: Deatz et al. 2000)

- **A collaborative digital environment.** This environment provides e-mail and virtual whiteboard capabilities.
- **A large screen display.** This display shows a 3-D representation of the battlefield, with all of the systems that are visible on the PVD, Stealth, Whiteboard, or UAV screens. This screen also includes the capability to automatically display information normally contained in the multiple combined obstacle overlay (MCOO).

The fact that SC4 is implemented in a simulation environment limits the applicability of this system to the FCS interface. For example, the simulation environment is relatively benign, so the systems do not have to be ruggedized. As implied earlier, SC4 systems also can be reconfigured rather easily to incorporate additional capabilities or technological innovations. Ray (2002) pointed out a particularly important difference between SC4 and current systems: It has been relatively difficult to make the different components systems within ATCCS to share data. In contrast, the SC4 system was designed so that every SC4 machine is able to display and transmit the same data to any other SC4 machine on the network.

Because the SC4 does not share the impediments of actual C4ISR systems, it is able to demonstrate the potential advantages of such systems if the impediments were rectified. Subjective appraisals of SC4 are almost universally positive. In the context of simulation-based experiments at the MMBL, the impact of SC4 on tactical processes and outcomes has been nothing short of revolutionary:

> It is difficult to overstate the significance of the SC4 in the operations of the UA. The SC4 was the central technology that permitted execution focused battle command and was the symbol of network centric warfare at the UA, Team, and Cell echelons. It provided the information necessary for planning, preparation, and execution of tactical missions in the UA and did so in a graphic representation that was tailorable to the specific user. The SC4 also served as the "gateway" to information from tactical electronic mail and as a way to access an information data base that contained a wide breadth of information on enemy forces, their organization, and their weapons. This data base also included record copies of operations orders, fragmentary orders, overlays, collaborative "white board" back briefs, and other information important to planning, preparation and execution. All of this was available to anyone with an SC4. Because of those capabilities, the UA never conducted "orders groups" or meetings; the issuing of orders and the back briefs associated with them was done over the information network with the SC4. Requests for information (RFI) from the UA to the UE were made—and fulfilled—using tactical electronic mail over the network. As a result, planning and preparation for operations was significantly reduced from current timeframes to around two hours. Additionally, the UA was able to quickly adjust its plans to anticipate enemy actions based upon the common relevant battlefield picture presented across the UA on the SC4: execution-based battle command became the norm. The UA "fought the enemy, not the plan" (Jarboe, Ritter, Hale, and Poikonen, 2002, p. 12-2).

The SC4 is a reconfigurable system that continues to be used in experimentation at the MMBL. Results from those experiments provide concepts and applications that must be considered for any FCS interface.

d. Common Army Aviation (AVN) Situational Awareness (SA) Soldier-Machine Interface (SMI)

The Common Army AVN SA SMI currently exists as a preliminary software requirements specification (SRS), which defines the requirements for common SA displays in Army aviation platforms (Program Executive Office – Aviation, Aviation Electronic Systems, 2001). Another purpose of the SRS is to ensure the interoperability of aviation-to-ground units equipped with FBCB2 systems (including the Tactical Internet) by providing a common set of symbols for air and ground entities. The SRS applies to interfaces in the UH-60L+(M) Black Hawk utility helicopter, the OH-58D Kiowa reconnaissance helicopter, the CH-47F Chinook cargo helicopter, the AH-64D Apache attack helicopter, and the RAH-66 Comanche reconnaissance helicopter. The display imagery and icons for the AVN SA SMI are based on two DoD interface standards: MIL-STD-2525B. *Common Warfighting Symbology* (DoD, 1999) and MIL-STD-1787C, *Aircraft Display Symbology* (DoD, 2001).

The AVN SA SMI displays the Aviation Mission Planning System (AMPS) information and the Joint Variable Message Format (JVMF) messages from the Tactical Internet. The information is organized into “layers,” which the aviator can select or deselect singly or in combination with one another.

Figure II-5 illustrates several default layers: *Self* (top left), *Mission (Aviation)* (top center), and *Initial Battlefield Graphics* (top right) layers. Updates to Initial Battlefield Graphics layer are obtained from JVMF messages. The bottom graphic in this figure is a *Default* layer that combines information from the Self, Mission, and Initial Battlefield Graphics layers.

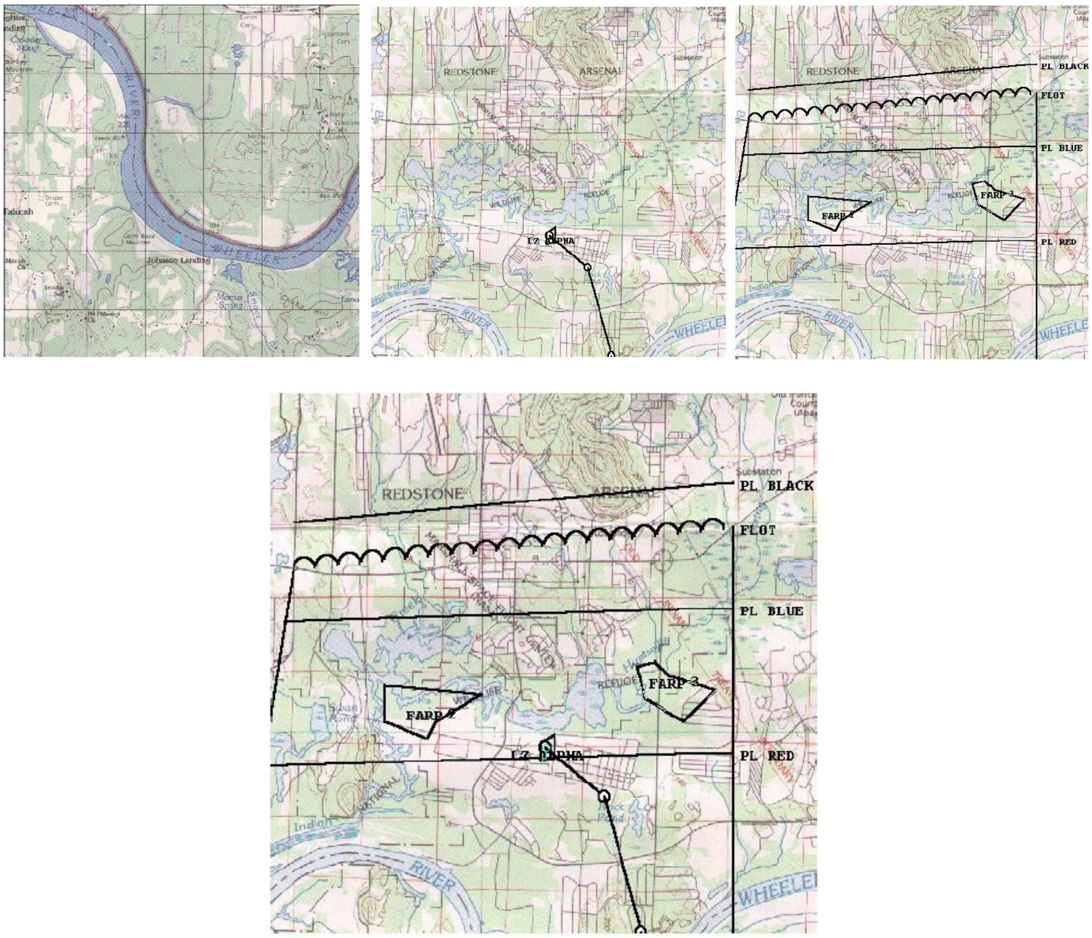


Figure II-5. AVN SA SMI Informational Display: Default Layers

Figure II-6 shows five different layers pertaining to the tactical situation. The top row displays friendly situation graphics: the *Friendly Aircraft* (top left) *Friendly All* (top center), and *Friendly Air Defense Artillery (ADA)* (top right) layers. The bottom row

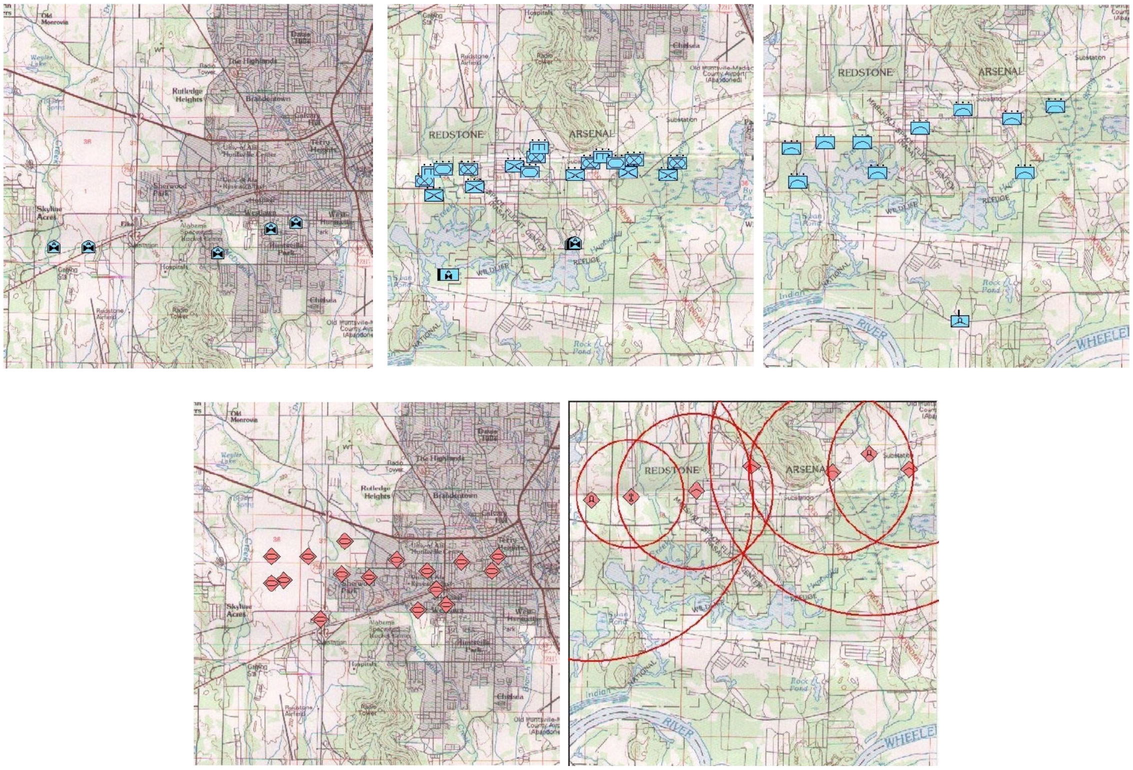


Figure II-6. AVN SA SMI Informational Display: Layers Pertaining to the Tactical Situation

pertains to the enemy situation, including *Enemy All* (bottom left) and *Enemy ADA With Engagement Rings* (bottom right) layers. The enemy ADA rings indicate the maximum engagement ranges of the ADA weapon subtype if the subtypes are known.

Focusing exclusively on display issues, the AVN SA SMI standards do not address control interface matters. Nevertheless, these standards are significant for at least two reasons. First, the aviation displays are focused on a 2-D top-down view of the terrain, emphasizing the land-centric mission of Army aviation. Second, the AVN SA SMI provides the technology for current aviation systems to share a common operating picture with FBCB2-equipped, land-based systems.

e. Rotorcraft Pilot's Associate (RPA)

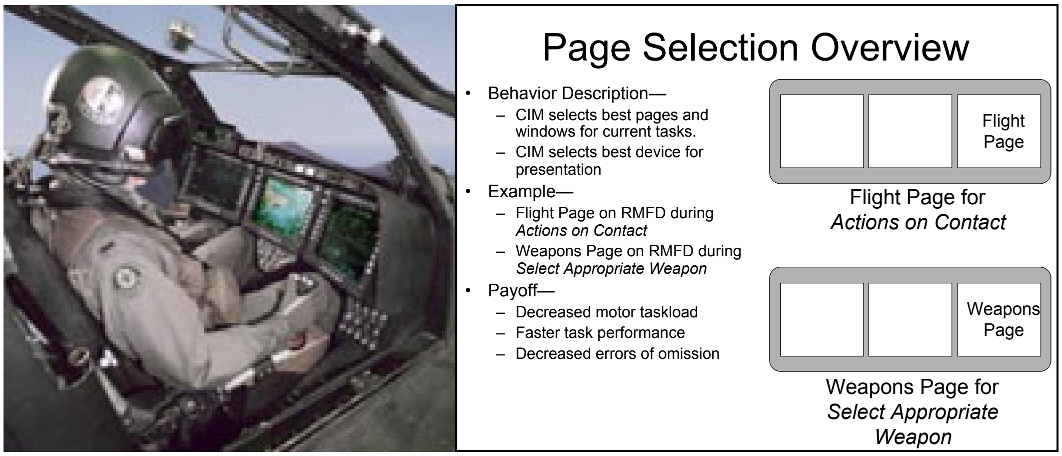
The Army's RPA, which grew from the Air Force's Pilot's Associate program, was a 5-year, $80-M Advanced Technology Demonstration (ATD) conducted from 1993 to 1998 and managed by the Army's Applied Technology Directorate. A consortium of contractors, led by McDonnell Douglas Helicopter Systems (now the Boeing Company), conducted this large-scale effort, which involved artificial intelligence (AI) and state-of-the-art computing technology. The overall purpose was to increase battlefield

SA, lethality, crew system performance, and survivability of the next-generation attack and reconnaissance helicopters by using a knowledge-based cognitive associate to fuse and interpret the wide range of sensor information impinging on future attack and reconnaissance aircraft. One aspect of the information management problem was to design an adaptive human interface that automatically selected and configured information to be displayed to the aviator. The system was flight tested in 1999 using a modified AH-60 Apache attack helicopter.

One of the RPA major components is the Mission Equipment Package (MEP), which receives and integrates the more than 12 sources of sensor data that are currently available to attack helicopters. These data are fused and interpreted by the Cognitive Decision Aiding System (CDAS). One subcomponent of the CDAS is the Cockpit Information Management (CIM) module, which configures and controls the pilot interface based on two sources of knowledge shared with other CDAS components: (1) the Task Network, which represents the current beliefs that the CDAS has about what tasks the pilot is performing and what he or she will be performing in the immediate future and (2) Context Knowledge, which stands for the CDAS's beliefs about the current state of the aircraft and the external world (Funk and Miller, 1997). While tasks proceed in parallel, the CIM prioritizes and filters information for display according to two rules: meet the information needs of the most important tasks first and do not exceed the workload and display capacities. Using this information and logic, the CIM performs the following interface-related functions (Miller and Funk, 2001):

- **Page (or format) selection.** Select a display page (e.g., weapons or sensors on one of three multifunction visual displays) or format (e.g., visual or 3-D auditory)
- **Symbol selection/declutter.** Turn specific symbols ON or OFF on a selected page.
- **Window placement.** Control the type and location of pop-up windows that overlay information in multifunction displays
- **Pan and zoom.** Control centering and magnification of maps and sensor displays
- **Task allocation.** Assign tasks among two human pilots and an automated "associate."

Figure II-7 graphically depicts the RPA interface. The graphic in the left panel is a photograph of RPA multifunction displays as installed in an AH-60 prototype. Although the interface includes innovative displays and controls (e.g., voice recognition, 3-D audio, HMDs, and a head/eye tracking system), this particular figure focuses on the multifunction visual displays. The graphic in the right panel describes the *Page Selection* function. It shows the configuration of the three multifunctional screens in the cockpit. The right-panel graphic illustrates how one of these displays automatically changes on the right multifunctional display (RMFD) (e.g., from "Flight Page" to Weapon Page") as CIM detects a change in task (from actions on contact to engage a target).



Page Selection Overview

- Behavior Description—
  - CIM selects best pages and windows for current tasks.
  - CIM selects best device for presentation
- Example—
  - Flight Page on RMFD during *Actions on Contact*
  - Weapons Page on RMFD during *Select Appropriate Weapon*
- Payoff—
  - Decreased motor taskload
  - Faster task performance
  - Decreased errors of omission

Figure II-7. The RPA Interface

Note for Figure II-7: *The right panel is from Miller and Hannen, 1999.*

The RPA represents several different innovations in interface design, but perhaps its most important contribution is the use of adaptive technology (Scerbo et al., 2001). Funk and Miller (1997) pointed out that many context-sensitive displays are "adaptable," meaning that human input is needed to select the appropriate mode. The problem is that human selection increases the workload and the probability of error. The truly "adaptive" nature of the RPA is unique because the process of selecting information and configuring displays based on context is completely automated. As shown in Figure II-7, Miller and Hannen (1999) suggested that the payoff of an adaptive interface is decreased motor task load, faster task performance, and decreased errors of omission.

f. Crew-integration and Automation Testbed Advanced Technology Demonstration (CAT ATD, Unpublished Briefing)

The CAT ATD is currently being conducted in the Vetronics Technology area by the U.S. Army Tank-automotive and Armaments Command and Tank-Automotive Research, Development, and Engineering Center (TACOM-TARDEC) (TACOM-TARDEC, 2000). The CAT ATD is an outgrowth of the earlier Vehicle Technology Testbed (VTT) and incorporates many VTT technologies. The purpose of this ATD is to demonstrate crew interfaces and automation, and integration technologies requirements needed to operate and support future combat vehicles. Specifically, the CAT ATD is testing a multimission-capable, 2-man crew station concept that embeds control of both unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs). The ATD was begun in FY00, and successful technologies will be transitioned to the future FCS demonstrator at Fort Knox in FY04 (Joint Robotics Program, 2001).

The CAT ATD plan for calls for implementing and testing several SMI technologies, including interactive touch screens, indirect vision, speech recognition, 3-D audio, head trackers, HMDs, and the crewman associate—an adaptation of the AI-based technology developed for the RPA. The SMI design is notional and can be reconfigured on the basis of test results. The concept is to evaluate SMI concepts in the context of a C-130-transportable test vehicle, as depicted in the left panel of Figure II-8. The demonstration vehicle is fully mobile but includes a safety driver to sit ahead of the two test crew stations. The right panel of Figure II-8 shows a single crew station. The configurations of three screens and control handles serve as the basic I/O devices for both operators. Figure II-9 also shows a close-up of the control screens. As illustrated in this figure, the display configuration changes as a function of operator roles and functions.

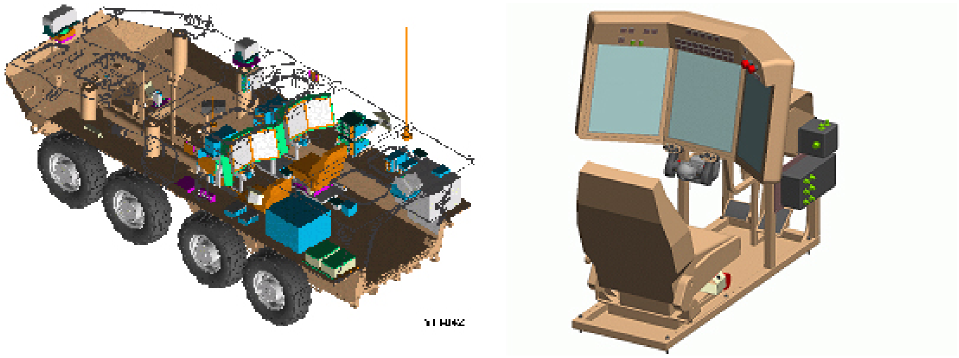


Figure II-8. Views of the CAT ATD Crew Station in Context of Test Vehicle (Left) and as an Isolated System (Right) (Source: CAT SMI IPT, n.d.)

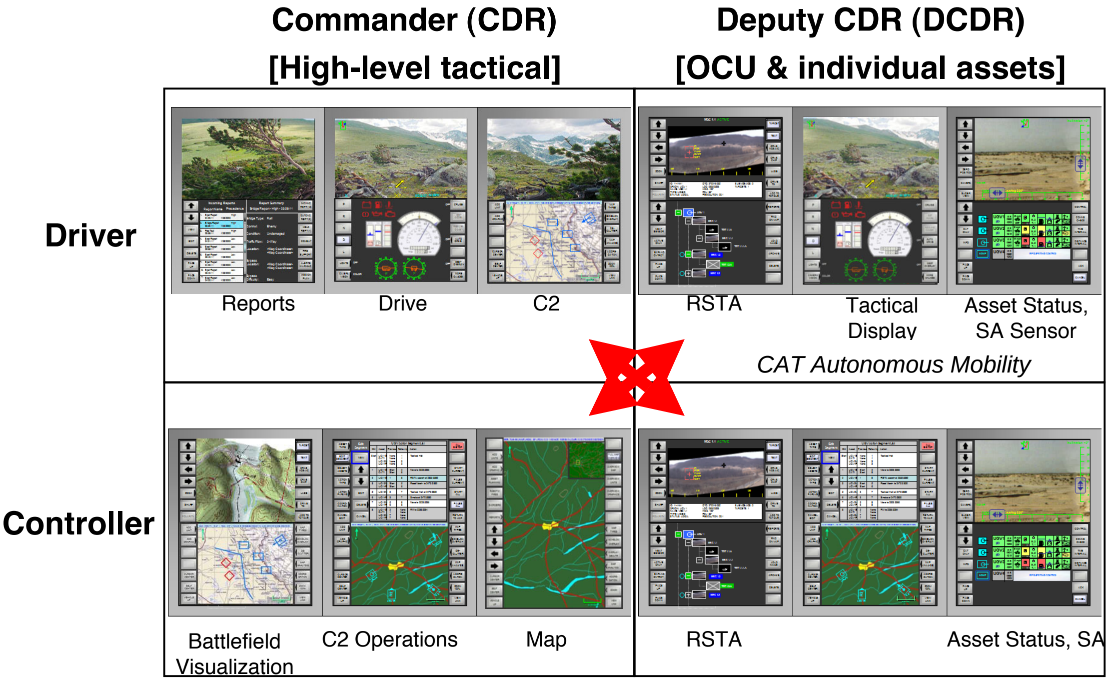


Figure II-9. Close-Up of CAT Screen Configurations for Different Roles and Functions (Source: CAT SMI IPT, n.d.)

Although the CAT ATD is an experimental system, it was designed to be directly applicable to the FCS project. In fact, plans call for promising SMI technologies and concepts to be transitioned to future improvements of FCS (i.e., to versions after Block I).

g. Commander's Support Environment

The goal of DARPA's FCS Command and Control (FCS C2) program is to create a C2 architecture for the FCS Unit Cell that integrates the currently stove-piped battlefield functional areas (BFAs) into a single information environment, the Commander's Support Environment (CSE) (DARPA, 2002). The CSE provides an advanced C2 aid designed to free the commander and staff from routine tasks associated with operational planning and to provide execution support for operational exercises. The intent is to reduce the number of personnel in the C2 element of the FCS Unit Cell. Traditionally, the C2 staff keep track of their individual BFAs and integrate information through communication with the other staff members. The FCS C2 system reduces the personnel requirements by automating routine staff tasks (e.g., map posting, route planning) and by incorporating a knowledge base that, in real time and in a single environment, integrates information from across all BFAs relevant to the planning and the execution phases of battle. The CSE provides information the commander and staff can see and share and on which they can base operational decisions. By so doing, the FCS C2 converts the Army's "…current intense, plan-centric C2 process into an execution-based, battle-command process…" (Gumbert, Cranford, Lyles, and Redding, 2003, p. 81).

As illustrated in Figure II-10, the CSE interface has a Microsoft Windows™ look-and-feel, including the use of multiple graphic layers and windows-like menus and tool-bars. The upper left screen provides a screen shot of the Situation Awareness window that provides both 2-D and 3-D representations of the battlespace. This window displays and differentiates between entities derived from intelligence templates and those detected by sensors so that the commander can develop and update his intelligence preparation of the battlefield (IPB) in real time. This figure also shows that various windows can be used to access information and task assets across all BFAs. Data across those BFAs are integrated in real time such that threat detections, classifications, and identifications displayed in the Threat Manager Matrix are shared with the Attack Guidance and Battlefield Damage Assessment Matrixes and updated based on how systems are currently employed and on battle outcomes. Furthermore, all the tactical information is derived from a physics-based model and terrain base that emulate the physical environment to a high degree of fidelity. These functions allow the commander to plan and execute missions. Planning is facilitated by the ability to animate friendly and enemy movements in real time or in fast or slow motion. Because the CSE is a single presentation layer for all staffers in the Unit Cell, it promotes shared situational understanding and the ability to conduct parallel planning.

The FCS C2 program developed the system architecture, implemented it in a Distributed Interactive Simulation (DIS) environment, and executed a series of four human-in-the-loop (HITL) experiments. The experiments were conducted from October 2001 to March 2003, and the lessons learned were passed on to the FCS Lead Systems Integrator (LSI) (Lickteig, Sanders, Lussier, and Sauer, 2003). As configured for the FCS C2 experiments, the CSE is designed for four key members of the FCS Unit Cell: Commander, Battle Space Manager, Information Manager, and Effects Manager. As shown in the center picture in Figure II-10, each of these staff members is provided two CSE displays, which are configured in conformance with staff functions and individual preferences. In addition to individual monitors, there is a shared head-up display on which staff members can share/broadcast either one of their two individual displays.

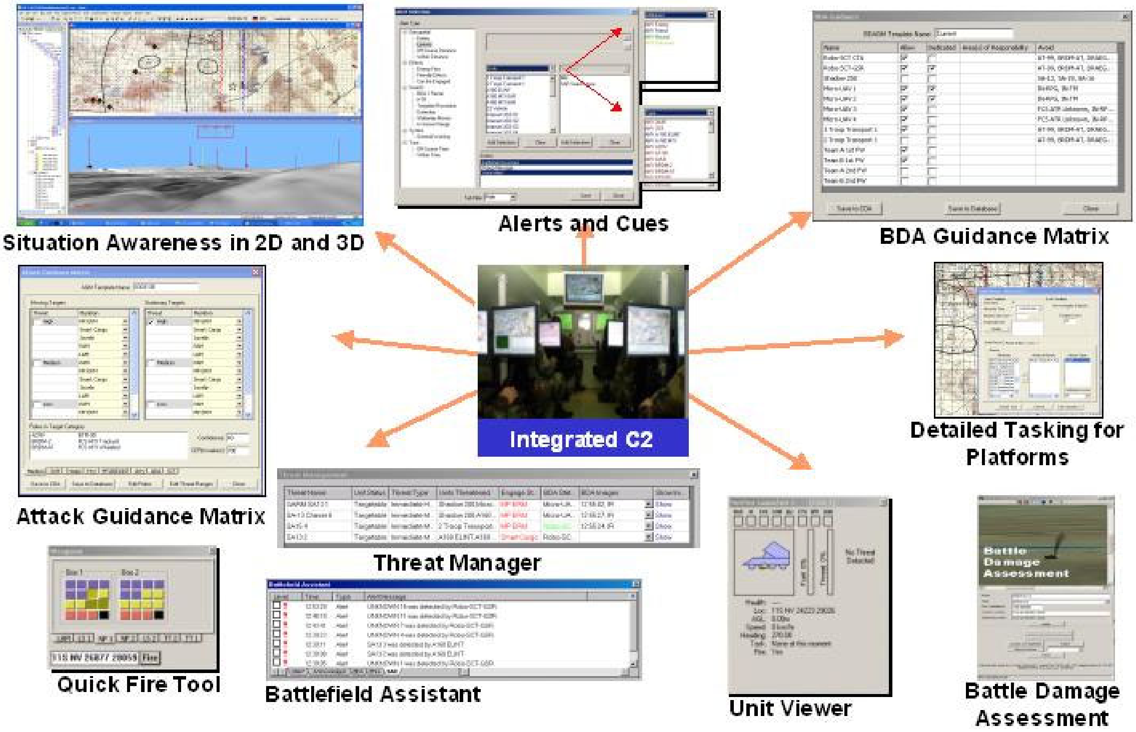


Figure II-10. Various Screens From the CSE
(Source: *Commander's Support Environment User's Guide,* 2002)

In 2002, FCS C2 was selected for the Army's C4ISR "On the Move" program, indicating that it represented the "best of breed" C2 technology for FCS (Baumgardner, 2002). It also has applications to Objective Force and Agile Commander initiatives. In its present form, FCS C2 is configured to support command-in-the-loop simulations of the FCS Unit Cell, the lowest tactical command echelon in the Unit of Effect. The next phase of development seeks to mature FCS C2 technology by expanding its capabilities to include operation of multiple FCS-equipped units with higher headquarters, dismounted soldiers, and connections to joint forces.

h. Command Post of the Future (CPOF)

The CPOF is an ongoing 3-year DARPA project that was initiated in February 1999. The objectives of the project, through the use of advanced visualization technologies, are to increase the speed and quality of command decisions, disseminate those commands more effectively, and decrease the size and increase the mobility of command structures (Information Exploitation Office [IXO], DARPA, n.d.).

The initial concept of CPOF was to build a high-technology C2 facility for land-based forces akin to combat operations centers (COCs) aboard aircraft carriers. Senior military advisors to the project vetoed this idea in favor of the BattleBoard—a handheld digital device designed to display and communicate C2 information and knowledge (Waldrop, 2002). Figure II-11 provides a rendering of this portable device.

Figure II-11. Rendering of Proposed BattleBoard Device
(Source: Waldrop, 2002)

Much of the CPOF work concerns the presentation of useful visual information about battlefield terrain. Figure II-12 illustrates some of the proposed terrain-viewing capabilities. Most tactical views are top-down, or plan-view, displays with contour lines or color-coding to describe terrain features. CPOF provides several enhancements for understanding subtle features of the terrain, one of which is to view the landscape at a continuously variable oblique angle in addition to the traditional top-down view.

To use this information in a tactical situation (e.g., to develop military COAs), the commander must not only understand the tactical situation, but must also communicate that understanding to others up and down the chain of command. One way to facilitate collaborative understanding is to provide users the ability to tailor their own visualization

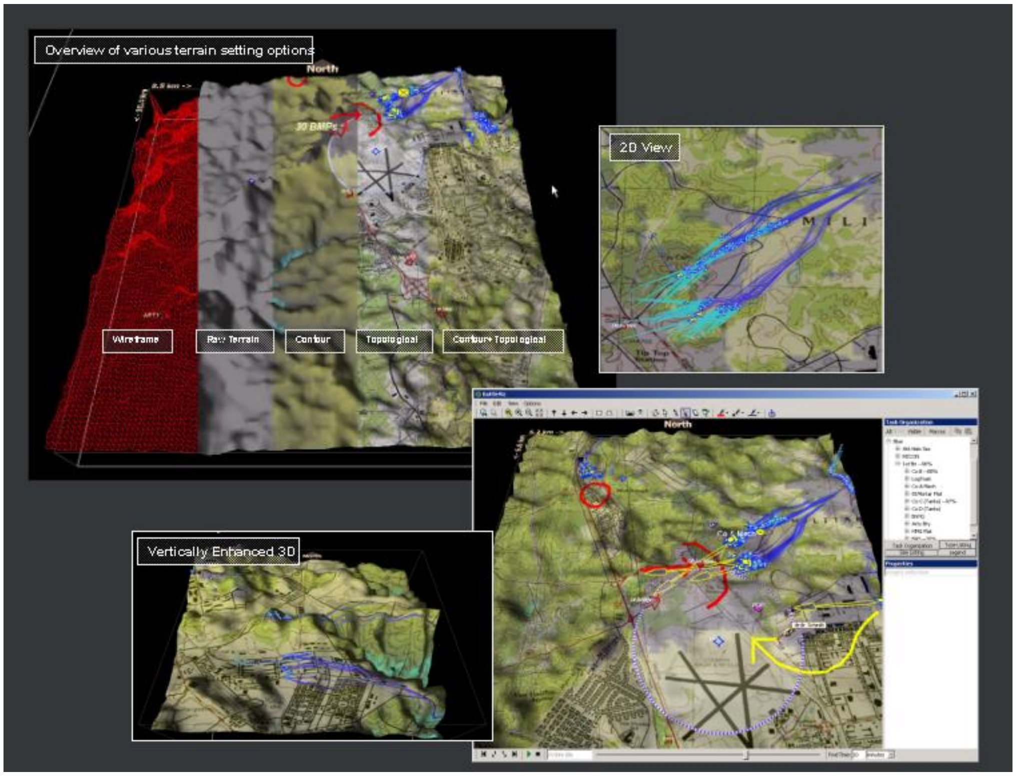


Figure II-12. Various Views of Terrain in CPOF (Source: Page, n.d.)

to their specific situation and transmit to other users. Waisel (2002) pointed out, however, that collaborative understanding requires more than sharing pixels. It also requires users to share data objects that behave logically and consistently and that maintain that behavior wherever they go. Supporting contractors in the visualization effort include Maya Viz., Ltd.; Lockheed-Martin Space Systems Company/University of Maryland; Intermetrics, Inc.; Visible Decisions, Inc.; and Sarnoff Corporation

Traditional control devices (e.g., keyboard, touch screen, mouse) would present a potential bottleneck to accessing and communicating knowledge from the system. Instead, CPOF is developing more natural interfaces for accessing information and knowledge. Research and development conducted at Carnegie Mellon University, Massachusetts Institute of Technology, Northwestern University, Oregon Graduate Institute, and the University of Massachusetts addresses the development of reliable speech, handwriting, and gesture recognition, along with the controlling software necessary for integrating these multiple modes of input.

The CPOF receives information from a number of tactical sources, including FBCB2 and other databases. The access to the information, including visualizations, is controlled through a dialog management process. Similarly, information is filtered and interpreted through a process of context tracking, which adapts the presentation to fit the immediate situation. Regarding these issues, contractors are conducting related research on knowledge-based and analogical reasoning. Supporting contractors include Boeing/East Carolina University; General Dynamics/Duke University; Cycorp; MITRE Corp.; and Carnegie Group, Inc.

Another goal of the CPOF is to create technologies that fit and support actual cognitive processes used to make tactical decisions. In that regard, CPOF is supporting research into recognition-primed planning and decision-making models developed and promoted by Gary Klein and Associates. This model maintains that the actual decision-making process is not a systematic evaluation of mutually exclusive alternatives. Rather, most of the process is devoted to gaining a detailed understanding of what is going on ("situation awareness") with the actual decision based on a quick, approximate match of the current situation to the decision-makers previous experiences. Thus, the CPOF technologies are designed to enhance situation understanding but do not provide aids for supporting formal decision-making processes (e.g., utility modeling).

Although the CPOF project offers some innovative control technologies, the major implications of CPOF technologies for the present FCS interface project are in the area of display and visualization concepts. In that regard, Waisel (2002) commented that the most innovative concept from the CPOF program was its rejection of the premise that tactics must be driven by a Common Operating Picture (COP)—a top-down model of ground truth that can be shared among users in literal, pixel-by-pixel fashion. Instead, the CPOF approach is to implement a belief-based Collaborative Operating Picture (ColOP), which is superior to the COP in the following ways:

- **Multiple beliefs.** Incorporating multiple beliefs, instead of the single set of "truths" used in the COP, lessens the chance of overlooking a critical piece of information.
- **Collaborative pictures.** Building collaborative pictures strengthens team-building processes.
- **Private views.** Allowing users to maintain private views separate from public views permits individuals to explore their own hypotheses about the tactical situation.

i. Integrated Mounted Warrior (IMW)

The purpose of the IMW program[4] is to demonstrate and test an interface that allows the mounted crewman to access and control FBCB2 and vehicle systems while away from his mounted vehicle crew station. The program is jointly sponsored by Program Managers (PMs) for the Abrams Tank, Bradley Fighting Vehicle, FBCB2, and the PM Soldier Systems. A consortium of contractors, with General Dynamics serving as the prime developer and integrator, is developing this wireless, voice-activated, helmet-mounted display and control system. The contractor team also includes ITT Industries for voice recognition software, TRW for FBCB2 interface software, and Harris Corporation for the secure wireless local area network (LAN) card.

As depicted in Figure II-13, the test vehicle is the M1A2 System Enhancement Program (SEP) tank, but the system is potentially applicable to other fighting vehicles such as the Bradley, the Stryker, or future FCS vehicles. Patterson (2002) identified three components of the IMW:

1. **The Wearable Crewman Computer.** Adding about 6 lbs in equipment, the Wearable Crewman Computer comprises the HMD, which is mounted on the standard combat vehicle crewman (CVC) helmet, and the load-bearing vest, which incorporates the portable computer, communications security (COMSEC) wireless LAN, cursor controller, and battery.
2. **The Wireless Communication Gateway.** This component links the wearable computer to the vehicle electronic and communications system. It is located on the vehicle bulkhead at the commander's station and measures about 4 × 5 × 9 in.
3. **The Commander's Display Unit/Commander's Electronic Unit (CDU/CEU).** Linked with the Wireless Communication Gateway via the Ethernet, the CDU/CEU processing unit includes the FBCB2 and the activation/control software.

The IMW program is important because it addresses the most difficult interface problem for FCS—the link between the information network and the individual dismounted soldier. Although the system is intended for the vehicle crewmen, the extensions

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[4] The IMW program was previously named the wireless Tactical Voice Activation System/Helmet-Mounted Display (TVAS/HMD).

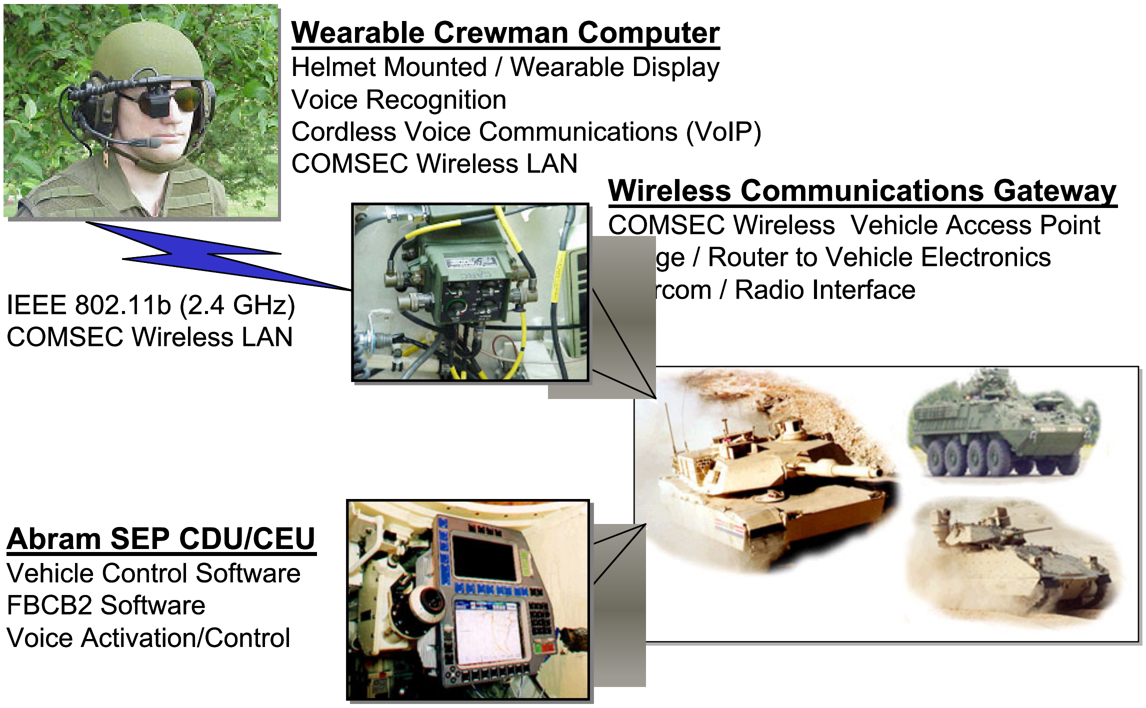


Figure II-13. Conceptual Diagram of IMW Components
(Source: Patterson, 2000)

and applications to the dismounted infantry soldier are obvious. In particular, the voice recognition and wireless communication technologies are particularly relevant to the FCS effort.

j. Warfighter-Machine Interface (WMI)

The WMI is currently under development for the FCS program by the LSI, a contractor team led by Boeing Corporation and Science Applications International Corporation (SAIC). General Dynamics Decision Systems, General Dynamics Robotics Systems (and including its subcontractor, Micro Analysis and Design), and Honeywell International, Inc., are assisting the LSI in its effort to develop the WMI.

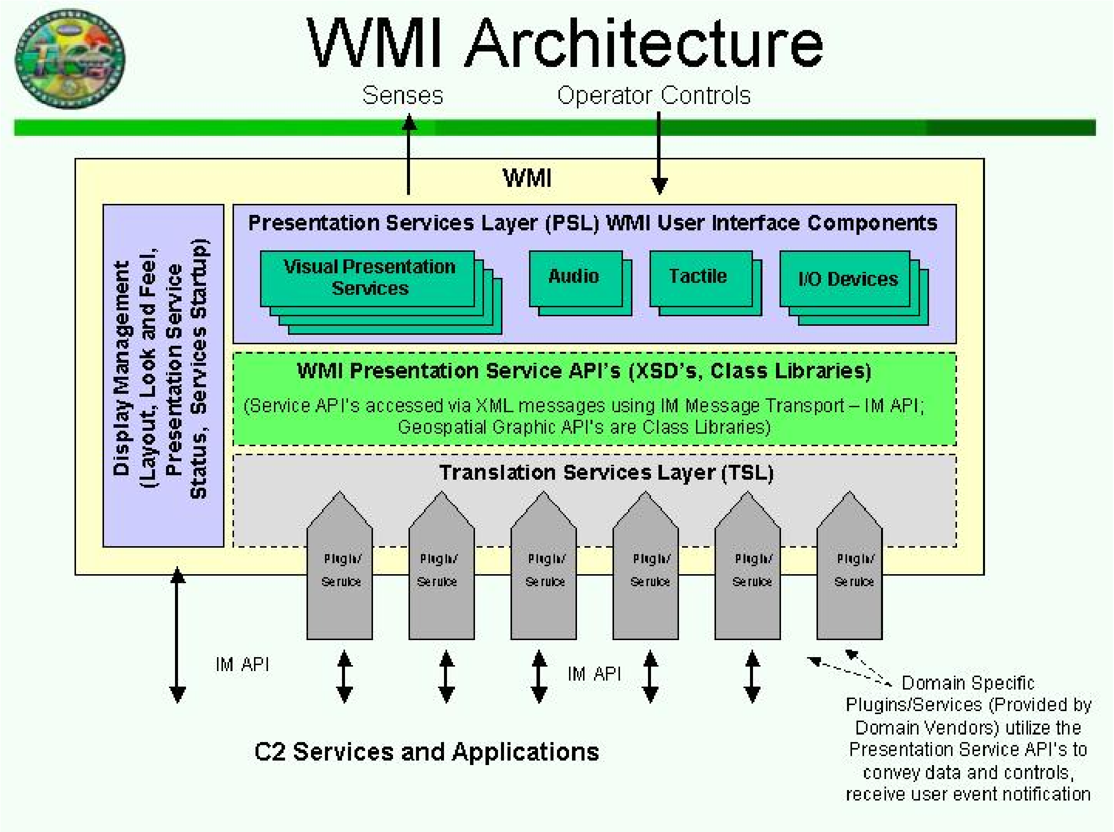
Howard and Less (2002) indicated that the WMI provides the interactive interface between the warfighter and the rest of the FCS system, including unmanned vehicles, ISR, and effects systems. However, they described the WMI as more than the hardware and software related to displays and controls. It also includes the software architecture to integrate the "…warfighters visualization and interaction needs for data and services across all manned ground vehicles and associated off-vehicle equipment" (Slide 3 of the presentation). A standard set of APIs will be developed to address these data and service requirements. These requirements are based on detailed use-cases, which include services such as display route, enter new waypoint, consent to fire, display sensor video, and so forth. However, because of the FCS's revolutionary nature, these requirements cannot be pre-specified. Consequently, the design and implementation of the system will precede the validation of all requirements. The requirements will, in essence, emerge as the system develops and matures.

The emergent nature of the FCS interface requirements requires a flexible architecture. The concept for this architecture was described in a briefing by Mark Boyd (n.d.) and is illustrated in Figure II-14. The architecture organizes WMI services into four layers:

1. **Presentation.** This layer is the set of services relating to communication with the human operator through displays and controls.
2. **Display management.** This layer is the common layer across systems and pertains to services related to initialization, monitoring, and establishing a common look-and-feel.
3. **Transition.** This layer includes services that provide plug-and-play capabilities for role-specific C2 applications.
4. **Presentation service APIs**. This layer primarily functions to isolate the knowledge- or domain-independent presentation layer from the domain-specific C2 services.

A recent DARPA briefing ("Concept evaluation," n.d.) described the evolution of the WMI operator display. The design has already evolved from multiple displays in the initial concept (Build 0) to an integrated display (Build 1), which is illustrated in Figure 15. As shown, this display is organized into various menus, windows, and panels. Nevertheless, the dominant display is the terrain view in the center of the screen.

The WMI is clearly the premier program for investigating and developing an FCS interface. This program intends to adopt many of the innovations and advances described in past and current C4ISR R&D projects. The unique advance in this program is the recognition that software architecture is key factor in building an interface for a system of heterogeneous systems.



WMI Architecture

Senses

Operator Controls

WMI

Presentation Services Layer (PSL) WMI User Interface Components

Visual Presentation Services

Audio

Tactile

I/O Devices

WMI Presentation Service API's (XSD's, Class Libraries)

(Service API's accessed via XML messages using IM Message Transport – IM API; Geospatial Graphic API's are Class Libraries)

Translation Services Layer (TSL)

Display Management (Layout, Look and Feel, Presentation Service Status, Services Startup)

Plugin/ Service

Plugin/ Service

Plugin/ Service

Plugin/ Service

Plugin/ Service

Plugin/ Service

IM API

IM API

C2 Services and Applications

Domain Specific Plugins/Services (Provided by Domain Vendors) utilize the Presentation Service API's to convey data and controls, receive user event notification

Figure II-14. Schematic Representation of WMI Architecture (Source: Boyd, n.d.)

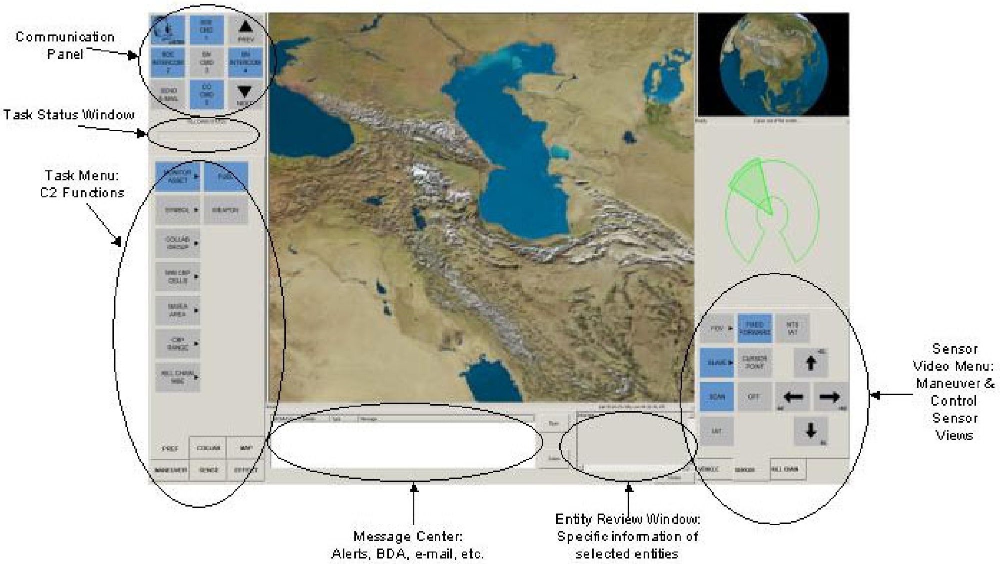


Figure II-15. WMI Build 1 Integrated Display (Adapted from "Concept Evaluation...," n.d.)

2. Generalizations and Trends in Interface Design

These 10 interfaces (reviewed in II.C.1.a–II.C.1.j) represent a variety of approaches and technologies. Nevertheless, several generalizations and trends can be noted across the interfaces.

All interfaces focus on some representation of the terrain, which is an obvious and appropriate orientation for land-based forces (Collins, 1998). Over time, these representations have become increasingly sophisticated and based on more detailed terrain databases. The CPOF embodies the current state-of-the-art in terrain representation, providing true 3-D representations, terrain settings, and variable viewing angles.

Display technology has evolved substantially from the low-resolution, monochrome monitors used in IVIS. Since that time, displays have employed high-resolution, full-color representations of the battlespace. HMDs are currently under investigation in the IMW project, and alternative interface modes (e.g., aural, tactile) are being considered in the CAT ATD and the WMI.

Control technology, in contrast, has evolved more slowly. The IVIS relies on push button inputs. The newer interfaces incorporate standard personal computer (PC) input devices, such as keyboards, mouse devices, and touch-sensitive screens. For FCS actors, these standard approaches are problematic because they draw attention from the visual field of view (FOV) or from manual actions. In that regard, IMW program’s investigation of voice recognition controls for the dismount seems particularly promising. The IMW program is also looking at eye-tracking as another possible control mode. The possibility of oral control devices (e.g., “mouthsticks”) has curiously not been pursued.

None of these interfaces have implemented some of the advanced display and control technologies developed by the interactive gaming industry. For instance, game “controllers” are often integrated I/O devices, including information such as tactile and vibratory cues. Progress has probably been impeded by the lack of formal testing and evaluation of these technologies. On the other hand, the more popular game controllers have passed one of the severest tests of operator usability (i.e., consumers have voted for them with hard-earned cash). Developers of the FCS interface should examine this area for potentially valuable applications.

The most recent interfaces employ intelligent software agents. To date, intelligent agents have been used to perform two interface-related functions:

1. To process data to provide warnings and/or interpretations of patterns, thereby converting information into knowledge (e.g, the “Sentinels” in CPOF)
2. To adapt the display configurations automatically (e.g., the agents in the CIM module of the RPA).

The use of intelligent agents will likely increase as interfaces become more complex and the data processing pace accelerates.

III. MODEL FOR INTERFACE DESIGN

Based on the literature review and our own experience, we developed a general model for the design of FCS interfaces. The model describes general relationships between FCS operator requirements and interface design approaches. Although general in nature, this model was used to derive specific guidelines for FCS interface design.

A. ASSUMPTIONS AND CONSIDERATIONS

To derive the model, we began with general assumptions and considerations relating to fundamental human capabilities and limitations and to specific constraints imposed by the FCS operating environment.

1. Limitations on Working Memory

Humans are limited in information processors. These limitations are commonly attributed to constraints in working memory, the seat of conscious awareness and processing. Any FCS interface design must consider the limited working memory resources.

2. Terrain Focus

The logical and natural focus of land-based forces is on the terrain (Collins, 1998). Lickteig and Throne (1999) recently suggested that C2 displays should be designed around factors of mission, enemy, terrain, troops, and time (METT-T), which includes terrain. The ordering of factors in METT-T is appropriate for conducting a situation estimate and for constructing an operations order (OPORD). For interface design, however, we suggest that the factors be reordered to make terrain preeminent [i.e., the acronym should be redefined as ***T***-METT (***terrain***, mission, enemy, troops, and time)].

3. Display vs. Control Functions

Although actual interfaces often integrate display (output) and control (input) functions, distinguishing those two functions in the design stage is, nevertheless, useful. In that regard, we assume our goal is to design controls that optimize operator access to information and knowledge and displays that optimize operator understanding.

4. Shared Understanding

Given the diversity of functions with a UA, striving for operators to acquire a common or shared “mental model” of all roles and situations is neither realistic nor useful. Rather, the goal is for operators to have a “shared understanding” of the high-level mission objectives and their role in achieving those objectives. To promote this understanding, displays and controls must be consistent and interoperable but tailored to specific echelon and function.

5. Focus on the Dismounted Soldier

The intent of the FCS project is to define interfaces for all echelons—from the UA commander to the individual dismounted soldier. In accord with the National Research Council’s Panel on Human Factors in the Design of Tactical Display Systems for the Individual Soldier (1997), we propose that the lowest echelon presents the greatest challenge for interface design. Instead of applying the interfaces designed for high-echelon personnel to personnel in the lower echelons, we propose to start with the lowest echelon and build up.

6. Use of Advanced Technology

Our survey of interface technology indicated that most implemented systems employ conventional technologies. Table III-1 compares some of the more dominant current approaches to interface design with the corresponding possible future approaches. FCS interfaces should advance the state of the art and employ some of the more promising technologies.

7. Summary

These assumptions and considerations suggest that the FCS SMI design must be a multiechelon, soldier-centered process that

- Balances operational variables with a 4-D battlespace (3 spatial dimensions plus time)
- Employs appropriate sensory and response modalities to optimize performance
- Develops innovative and eclectic display and control technologies.

Table III-1. Comparison of Current and Future Interface Technologies

Current Approaches	Future Exemplars
Visual displays augmented with auditory and/or tactile cues	• Integrate interface modalities by function – Vision (planning) – Audition (guidance) – Tactile (warning) • Introduce additional presentation modalities – Haptic (pressure, vibratory) – Temperature – Chemical senses (taste and smell)
Manage "translations" in displays by selecting/deselecting features	• "Layered" displays to – Declutter irrelevant information – Redundantly enhance key information
Tailor display to needs of operator	• Automatic active configuration of displays in response to situation • Operator selects amount/type of information in display
Manual/pedal control modes	• Head/eye-tracking • Voice recognition/control • Tonguesticks
Minimize errors through training and concept of operations (CONOPS)	• Automated error detection, communication, correction • Systems to prevent or warn against errors
Ease decoding by using common language and eliminating unnecessary information	• Exploit natural and cultural affordances • Intelligent agents to convert data to information • Create "instant experts" by facilitating development of automated processing
Reduce drain of resources by time-shared tasks through overtraining	• Automation routines, intelligent agent • Expert task-shedding strategies
Support task/skill retention by overlearning or job aids	• Embedded training and simulation (include ability to practice "what if" scenarios) • Intelligent "helps" that sense problems

B. TOWARD AN ONTOLOGY OF SOLDIER-CENTERED DESIGN

As illustrated earlier in Figure II-1 (Section II.A.2), the design process is mediated by four sets of interacting constraints:

1. **The soldier.** Observable capabilities and limitations of the soldier corresponding to general and specialized processes in sensation, perception, attention, memory, cognition, emotion, personality, culture, and task.
2. **The environment.** Characteristics of the environment (e.g., terrain, blue and red forces, equipment) within which the soldier is situated or immersed and an understanding of how the soldier interacts with these characteristics.
3. **The state of the art and practice**. In soldier-machine interfaces, human-computer interaction, human factors, ergonomics, and other relevant topics in cognitive science or related sciences.
4. **Requirements.** Articulated by the soldier, leadership, programmatic constraints, and other constraints because of lessons learned and which are documented in the state of the art and practice.

1. Disparate Approaches, Common Goals

The goal of any successful design should be to provide users the tools and processes that make the best use of their capabilities. However, given the fixation on the visual and auditory modalities (see Section II), the disembodied nature of predominant theory, and set against the war fighter's needs, the FCS-SMI faces a significant problem—an incomplete picture of the soldier—and is now poised to solve that problem.

This concept is further illustrated in Figure III-1. the flow of control and data/information between external representations and morphology and between morphology and internal representations is bi-directional. This underscores the *transactional* nature of the model, where behavior is mediated by the *interface* and *constraints* intrinsic to the interface; indicated by the large double-headed arrow in the left of Figure III-1. Likewise, internal representations, memory, and cognition are mediated by the ongoing state of the human's morphology, indicated by the other double-headed arrow as *perception* and *action.* This approach is in contrast to the "Model Human Processor" from the Human-Computer Interface (HCI) literature (see Figure III-2), which led to the GOMS method of analysis, for instance.

Earlier models not only de-emphasized the role of the limbs, but also the details of early and middle attentional and perceptual processes. The models were extensions of broader cognitive architectures, such as Soar or ACT-R[5]; however, the disembodied

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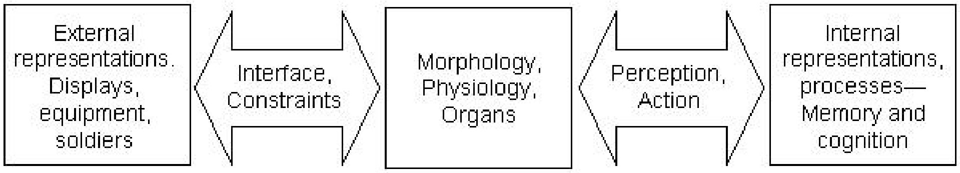
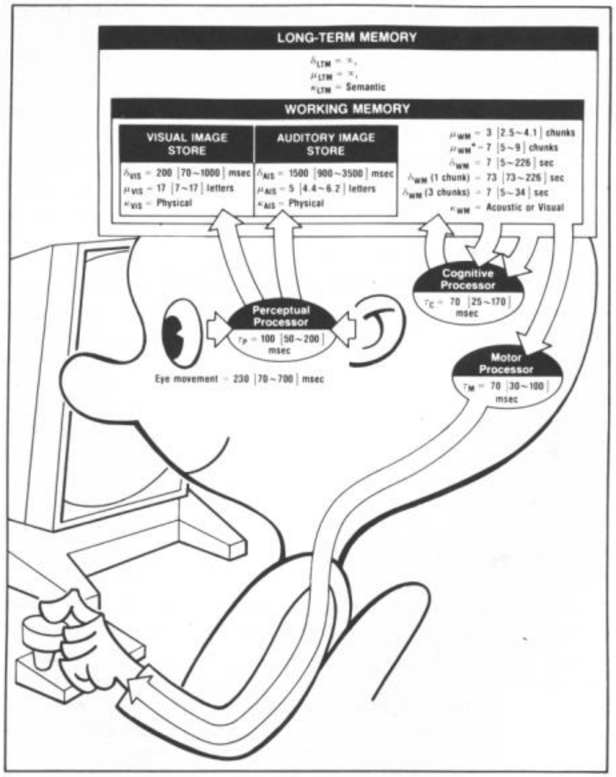
[5] Soar and ACT-R are symbol manipulation architectures.



Transactional model highlights three primary components: external representation, morphology, and internal representation. Note bi-directional flow of data/information/control—interface mediates the display and morphology, perception/action mediate morphology and internal cognitive processes.

Figure III-1. Conceptualization of FCS-SMI Soldier-Centered Design Ontology



Note the uni-directional flow of signal/data/information in from the eye and ear and out through the hand. FCS-SMI requires that limbs and skin serve both the needs of input and output, but the interface between limb and environment are so tightly integrated that mediation might be the more appropriate term.

Figure III-2. Model Human Processor
(Source: Card, Moran, and Newell, 1983)

nature of these models—operating solely in the realm of symbols, much like variables in a programming language—made for good theory but failed to produce working systems, particularly in real-time and dynamic environments. Another class of methods (summarized in Appendix A), are more firmly grounded in human factors and ergonomics, and based largely on behavioral evidence, cognitive theory, and experience from the development of industrial products. The fixation is on practice and not on theory. Thus, certain aspects from this body of literature can be applied directly to most if not all this design ontology.

Finally, a third class of theories, exemplified in Carroll (1991), Nardi (1996), and Norman (1993), focus on aspects of the human that may have been overlooked or "disembodied" in other traditions of human factors and HCI. One such central idea is activity theory, for example, which pursues the notion that humans engage in *activities* that unfold moment by moment and evades description as static symbolic knowledge structures or cleanly definable models of boxed processes. Some activities are considered *emergent* and are the result of the transactions between humans and their environments. In fact, Bartlett had pointed this out in the 1930s. His notion of the *schema* referred to active reconstruction that occurs in the moment, not because of a stored plan. Each new action is unique and may never be replicated. In the extreme, a form of activity theory known as *situated action* is tantamount to anarchy since any notion of a pre-stored plan or knowledge structure in computational terms is stringently eschewed (among the best summaries can be read are in Nardi, 1996). This view is so extreme that the observed, verified, and replicated notions of short-term working memory and long-term memory have no place in the analysis of the here and now. Cognitivism, in its attempts to distance itself from behaviorism, had, in a complementary way, eschewed the role of the environment, just as the behaviorists dismissed the contents of the head.

2. Toward an Ecumenical Approach

Rather than throw the baby out with the bathwater, a more reasonable approach is the emphasis on the morphology and how it relates to both external and internal representations in the proposed ontology. When analyzing human behavior in more moderate forms of activity theory, the role of the environment is considered as being as important as the role of the human; however, known limitations, including short-term working memory, are still taken into account. In other words, the unit of analysis should involve both human and environment. In contrast, Figure III-2, illustrating the Model Human Processor, is a diagram of a push-button device and a finger pushing the button, but the resulting model only addresses button-pushing from the perspective of mental structures. In activity theory, descriptions involve the device and the human. From the perspective of the proposed ontology, the design of the device (as an external representation), the makeup of the human (as the morphology) and the internal processes (as internal representations) have equal footing.

Further refining this analysis, the principal design attributes pertaining to the warfighter or soldier are presented in the columns of Table III-2. A row in the table reflects an instance of these design attributes. The totality of the columns and rows constitute the "ontology"—the soldier's *being*—to underscore a soldier-centered design philosophy. This ontology is far from complete, and, ideally, one row should not be considered in isolation from another. These interdependencies will ultimately come about from the evolving composition of the ontology as it unfolds during future phases of the effort. The ontology should not be confused with the model, which is presented in the next section. The ontology is a way of looking at soldiers, their requirements, their composition, capabilities, and the relationship between the soldiers and the environments.

Columns in Table III-2 are partitioned into three groups: (1) external representations and events, (2) morphology, and (3) internal representation and processes. These three categories underscore the dynamic relationships among stimuli in the environment that are identified or constructed as external representations; how the morphology of the human interacts or interfaces with these representations; and how they are sensed, perceived, transformed, maintained, and acted upon by the human as internal representations and processes—more specifically, in terms of memory and cognition. *External representation* follows its received interpretation in the literature[6]. Among the leading examples are problem isomorphs (Kotovsky et al., 1985; Zhang, 1991, 1997; Zhang and Norman, 1994; Norman, 1993), distributed cognition (Zhang, 1991, 1997; Zhang and Norman, 1994; Norman, 1993; Hutchins, 1990, 1995; Flor and Hutchins, 1992), diagram understanding (Larkin and Simon, 1987; Barwise and Etchemendy, 1994), and decision framing, (Tversky and Kahneman, 1984; Kahneman and Tversky, 1979) *Morphology* is simply a general term referring to the various human organs, limbs, and physiological subsystems that are actively engaged when interacting with a dynamic (externally

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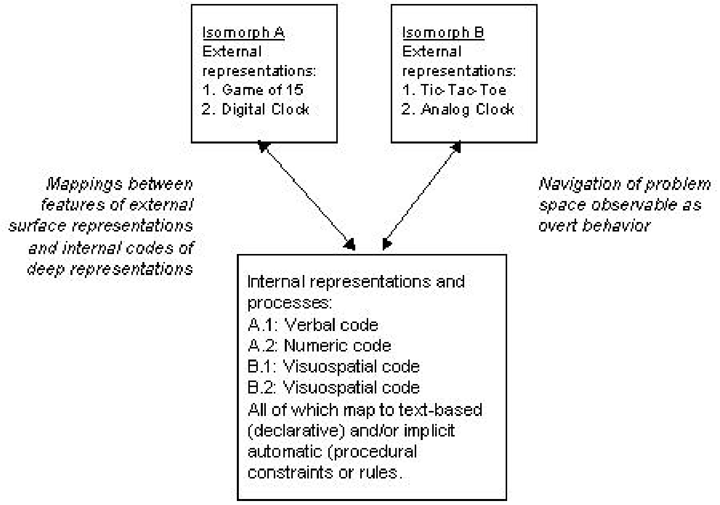
[6] The concept of external representation was first introduced as "external memory" by Newell while proposing the Blackboard architecture. This architecture suggested tools, artifacts, and procedures that are maintained in the environment to assist human limitations and the ephemeral properties of internal working and long-term memory. Norman and his students, however, later refined the concept by proposing external features that map (most efficiently according to design principles and known human capailities such as automaticity) to these various internal processes (Norman, 1993).

Table III-2. Example of Soldier-Centered Ontology—Mapping External to Internal Representations via Morphology

External Representation		Morphology	Internal Representation			
Stimulus	Example		Modality		Structure	Processes
			Channel	Code		
Orthographic–Alphanumeric	“FIRE”	Eye	Visual	Verbal	Verbal	Linguistic: lexical LTM: procedural, semantic
Orthographic–Dysfluent language	e-mail	Eye	Visual	Verbal	Verbal	Linguistic: lexical, syntactic, semantic, conceptual, situation model STWM: articulatory rehearsal loop LTM: declarative, procedural, semantic, episodic
Diagram	Computer display with terrain and symbology	Eye	Visual	Visuospatial Verbal	Visual/ Verbal	Semantic memory, visual memory
Utterance	“FIRE”	Ear	Auditory	Verbal	Verbal	Linguistic: lexical, syntactic, semantic, conceptual, situation model STWM: articulatory rehearsal loop LTM: declarative, procedural, semantic, episodic
Speech act	Command	Ear	Auditory	Verbal	Verbal	
Dysfluent language	Point-to-point conversation	Ear	Auditory	Verbal	Verbal	
Orientation of limbs	Orientation in seat of vehicle Orientation on ground	Limbs	Proprioceptive	Visuospatial Spatial	Visual/ Verbal	Perception: Proprioception–Orientation LTM: procedural Situated action
Stressor, insult, performance enhancing drug, nuclear, biological, chemical agent, mission-oriented protective posture (MOPP) gear	Amphetamines or “Go” pills Low dose of Sarin 4 mg atropine sulfate Fatigue, hunger, fear, anxiety	Muscle Cardiovascular Respiratory Physiology	Visual Verbal Haptic Proprioceptive	Mixed: visual, verbal, haptic, physiological	Mixed	Speed-accuracy tradeoff ROC Yerkes-Dodson law of arousal Signal-detection theory Regression models of performance Degradation Multiple resource theory Sternberg model ARI Integrated stress model Janis-Mann coping levels

represented) world and internal features of human memory and cognition. *Internal representation* refers to the various internal structures, processes, and models that have been identified and validated over the past century of research through observational studies, practice, computational models, or working systems. The notion of *channel* is derived verbatim from the "attention" literature and addresses the human capability to sense, perceive, and filter different types of external stimuli as different internal *codes* along various channels. The maintenance and selection of codes on these channels can occur in their early (sensory), middle (perceptual), or late (conceptual) forms. The combined sense of channel and code and how they become activated by external representations in a bottom-up sense or by internal representations in a top-down sense is what many typically think of as a *modality*. Figure III-3 elaborates further on these relationships.



Game of 15 is more difficult to solve than Tic-Tac-Toe although they are the same game. Numeric external representation of time in digital clock affords accurate telling of time but with longer response times owing to numerals, whereas analog clock takes less time, owing to rapid perception of visuospatial representation, but at the expense of accuracy.

Figure III-3. Problem Isomorphs or the Mapping Between Internal Representations and Different External Representations

Restated, the relevance to human factors and the SMI is identifying as many parallel channels as possible that can maintain as many of these different types of codes on each channel (according to battlespace complexity) and the warfighter's echelon (according to the soldier's task).

Consider the last row of Table III-2, for example, pertaining to environmental and physiological stressors. The first column, **External Representation**, summarizes some of the better known stressors including hunger, fatigue, performance enhancing drugs, and

NBC agents. This entry might be somewhat misleading since the representation in this case is actually a combination of stressor and features of a task performed by a human in a certain context. However, for this example, the emphasis is on the stressor. Sometimes referred to as “performance moderators” or “behavior moderators,” a significant amount of research has resulted in some well-known models, some of which are summarized in the last column, **Processes**.

Also consider soldier fatigue, a performance-enhancing drug, and the Yerkes-Dodson Law. According to this law, which assumes the shape of an inverted U, performance is optimal at the top of the inverted U, when the human is at a moderate level of arousal, perhaps because of a low-to-moderate dose of an amphetamine. A fatigued soldier with no drug is probably on the left-hand portion of the U. In this fatigued state of nominal arousal, performance will suffer. Likewise, if the soldier takes too much amphetamine and becomes over-aroused, performance will also suffer. The analysis does not have to end here since the effects of certain classes of drugs, including amphetamines, have also been examined with respect to the speed-accuracy tradeoff and cognitive performance. Naylor, Callaway, and Halliday (1992) and Dellinger, Taylor, and Richardson (1986), for instance, have isolated the effects of certain drugs on different phases of cognitive processing according to the Sternberg model—some affecting speed, others affecting accuracy, yet others affecting both speed and accuracy, depending on the processing phase affected by the drug [(1) stimulus encoding, (2) maintenance of the stimulus in short-term working memory (STWM) and search of long-term memory (LTM), (3) selection of the appropriate response, and (4) execution of the response]. As such, receiver operating characteristics (ROCs) of different soldiers, performing a given task, with a given dose of amphetamine, can also be determined. Some may be fast and accurate, others may be fast and sloppy, and so forth. As programmatic details and requirements emerge during Phase II, given what is known about Yerkes-Dodson, Speed-Accuracy Tradeoff, and the Sternberg model, to name a few, how will the specification and development of appropriate artifacts and processes unfold according to this broader view? This example does not even begin to address the kinds of equipment that might be appropriate for the SMI, but the point is that different theoretical outlooks will need to be organized within this proposed ontology, that salient characteristics of different approaches to design will have to be addressed, and that the user should assist in the definition of the SMI program during Phase II.

3. Informational Equivalence

Another tenet of this model focuses on the notion of "informational equivalence," (i.e., generating different surface representations—text vs. graphics, different graphical forms, one wording vs. an alternate wording, and so forth—that represent or stand in for a canonical or uniform deep representation]. For example, tic-tac-toe and the game 15 are graphics-based visuospatial and text-based versions—problem isomorphs—of the same problem (see Figure III-3.) The deep representation is usually cast in terms of the problem space, and the constituents of the deep representation are mapped to the different surface constituents of each kind of representation. In tic-tac-toe, the constituents of the visuospatial surface representation are the three rows and columns of the grid and the Xs and Os that occupy each cell in the grid. In the game 15, the constituents are text and numeric, and a running total is maintained as each player tries to generate moves that total 15.

Research since the 1950s, in particular, has underscored the relevance of phases of processing and the effects of types and composition of stimuli—text, graphics, problem representation, wording—on solution times and errors, response bias, ease of recognition or recall, and understandability. Some important principles that have emerged are the choice between consistent and varied mapping of stimuli, semantic congruity, mapping of text-based rules to external visuospatial constraints; reduction of "chart junk," "feature bloat," "visual clutter," and "color pollution" (Tufte, 1983); wording of scenarios on response bias or heuristics; and limited domain knowledge, to name a few. As a result, the tax on memory, processing efficiency, and problem semantics are recurring themes. In general, this research has focused on combinations on stimuli that address visual and verbal processing. The FCS-SMI approach, in contrast, will require the consideration of many different kinds of stimuli and morphologies owing to the demands on the soldier's capabilities. The model presented in Section III.B underscores the need for nonvisual and nonverbal stimuli when these two channels of processing are either inundated by battlespace complexity or become irrelevant according to the soldier's situation or echelon. In comparison to disembodied attempts at unification (Newell 1990), the unifying theme in this ontology is intended to be "ecumenical" and seeks to integrate features from any and all models, techniques, or processes that have demonstrated efficacy. In the literature, for example, situated action and symbolic cognition appear to be at odds—the former addressing deficits in the latter, the latter arguing for informational equivalence with the former. In FCS-SMI, *both* situated action *and* symbolic cognition are considered approaches that have known benefits and acknowledged deficits, yet the exclusion of either could yield significant gaps in the proposed ontology. FCS-SMI does not have the time or patience for this kind of academic infighting.

C. THE DESIGN MODEL

The proposed model is based on the interrelationships among four sets of variables: (1) operational, (2) battlespace, (3) sensor modalities, and (4) echelon. In its simplest form, the model can be depicted as bivariate relationship between situational complexity and information processing requirements (see Figure III-4). The curve represents the "appropriate" match between situational complexity and human information-processing capabilities. The relation is thought to be monotonic and increasing, but the exact shape is unknown (i.e., the relationship in Figure III-4 is notional).

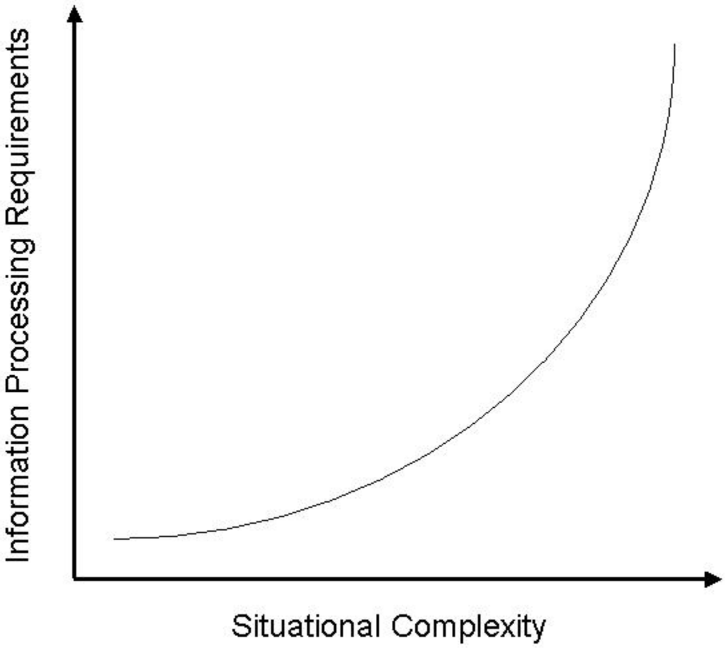


Figure III-4. General Form of the Design Model

To make the model more relevant, the abstract axes must be translated into dimensions that are more operationally significant. In the first example, let's substitute echelon (from individual soldier to UA commander) for complexity. The rationale is that, compared with lower echelons, high echelon missions are larger in scope and involve a greater number and variety of operational systems. While generally increasing in complexity, we acknowledge that some aspects of performance at higher echelons are actually easier (e.g., while higher echelon performers face more large and more complex situations, they generally have more time available to respond than do their lower echelon counterparts. Thus, while echelon is, in actuality, a multidimensional concept, it is a reasonable surrogate for complexity.

The Y-axis can be similarly translated to more meaningful dimensions. For instance, the requirements can be translated into matching processing modality capabilities. Modalities can be ordered in their evolutionary status. The chemical senses (taste and smell) represent relatively primitive sensory modalities that appeared early in evolutionary development of mammals, Vision, in contrast, is the most sophisticated modality and appeared relatively late in evolution. The underlying continuum from the least to the most complex modalities is also multidimensional in nature. More complex modalities have greater processing bandwidths (an advantage to performance), but they also require greater processing time and resources (a disadvantage).

Figure III-5 provides a specific instantiation of the model that displays appropriate processing modality capabilities as a function of echelon. Again, the exact shape of the curve is unknown, but it indicates generally that, whereas the more sophisticated processing modalities (audition and vision) are appropriate for higher echelons, the more primitive modalities (chemical and haptic senses) are appropriate for lower echelons. Further, this particular relationship depicts a discontinuity corresponding to the marked differences between the operating environments of mounted and dismounted soldiers: Mounted soldiers operate in a relatively benign environment, with limited or indirect visual access to external world. Dismounted soldiers, in contrast, are completely immersed in the external world. The dismounted soldier has to use all available senses and should not be distracted by augmented visual or auditory presentations that could distract him from this rich and rapidly changing environment. Thus, the primitive modalities are particularly appropriate for the "eyes busy/ears busy" environment of the dismount.

The relationship depicted in Figure III-5 has two specific implications for FCS interface design. First, it supports the current vision-centric approach to designing C4ISR interfaces for the commander and staff. Second, it suggests that these standard approaches are not appropriate for lower echelons—particularly, the dismounted soldier.

Situational complexity can also be operationally defined by the two discrete phases of battle: planning and execution. Compared with planning, execution is more complex on several dimensions: greater unpredictability, severity of environmental

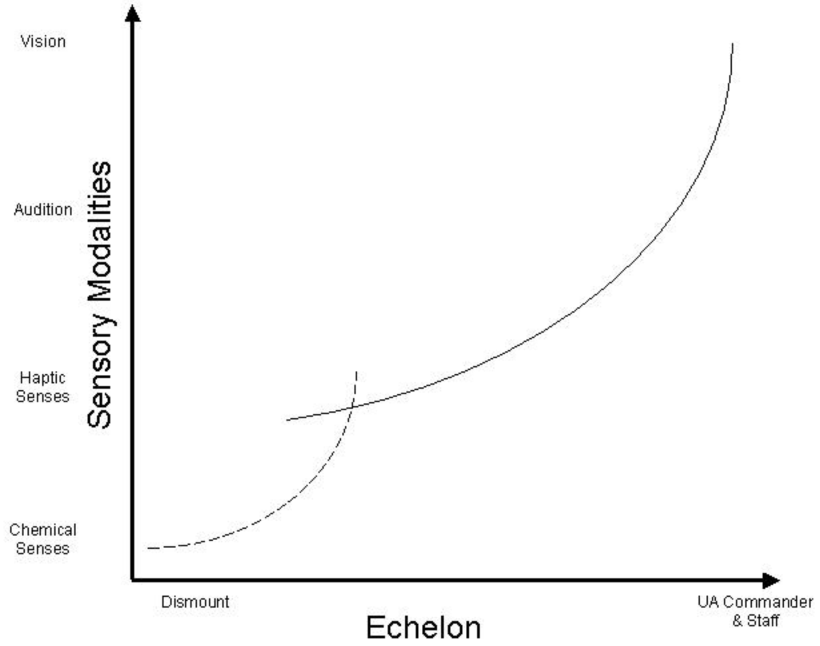


Figure III-5. Relationship Between Processing Modality and Echelon

conditions, individual stress, and so forth. Figure III-6 displays the resulting relationship between sensory modalities and phase of battle. This figure depicts an interactive relationship within the echelon, where the previous relationship between echelon and modality applies to execution but not for planning. The rationale is that the "eyes/ears-busy" environment of the dismount does not apply to planning. Thus, this second example illustrates that, for planning purposes, the visual mode may be appropriate to all echelons.

It should also be pointed out that actual processing modalities are not a single point along a processing continuum, as indicated in Figures III-5 and III-6. For example, auditory processing varies greatly in complexity, from the resource-intensive processing required to understand complex oral instructions to the automated response to a warning buzzer. Thus, the modalities address a distribution of processing requirements and capabilities with the relative positions indicative of the central tendencies of those distributions. These concepts are illustrated by the notional triangular distributions depicted in Figure III-7.

The overlapping distributions in Figure III-7 also suggest that the choice of modality is not a mutually exclusive one: Just as some level of visual interface processing is appropriate for the lowest echelon, some level of chemical and haptic processing is

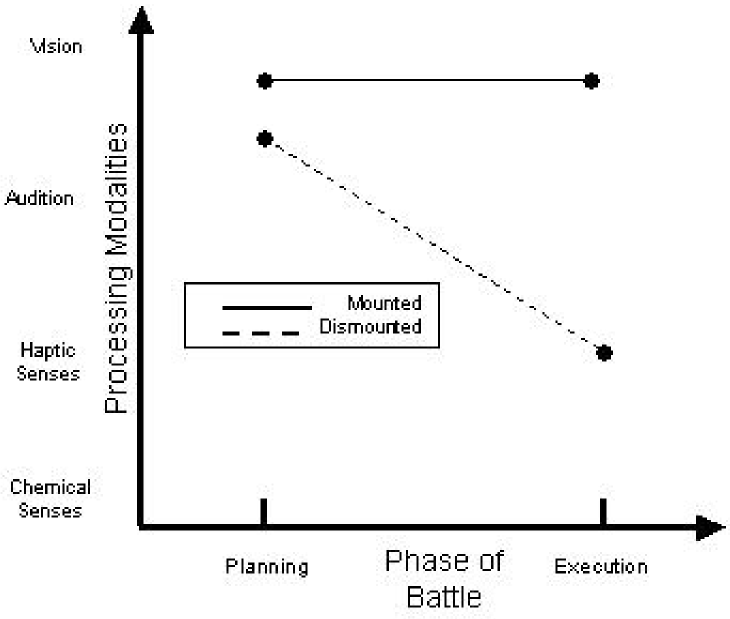


Figure III-6. Relationship Between Processing Modality and Phase of Battle

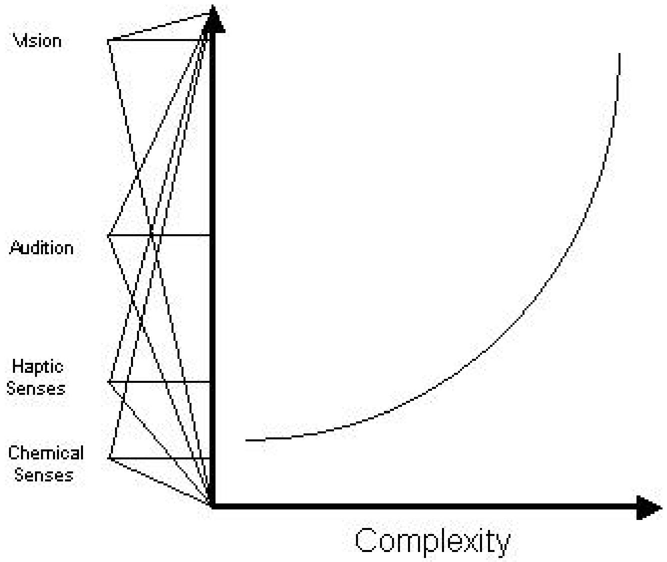


Figure III-7. Spread of Capabilities Within Each of the Modalities

suitable for the highest echelon. In other words, the difference among echelons is one of the relative importance of processing modalities. Also, the auditory modality was located near the midpoint of the spectrum to suggest that this modality is important to all echelon levels. This implies that auditory-based representations may provide the common representation for all echelons of the UA. Although this could be considered a justification for traditional radio communications, it remains to be seen whether this representation should be based on analogue frequency modulation (FM) or some other advanced technology.

D. PRELIMINARY GUIDELINES

The design model is tentative and abstract at this point in its development. Nevertheless, it provides several concrete guidelines for the design of the FCS interface.

- Critical information may often need to be recoded to facilitate communication among echelons. For instance, information pushed down from higher echelons must be recoded into auditory or haptic forms to augment the detailed terrain information available to the individual soldier. Similarly, tactile and auditory information pushed up from lower echelons should be recoded into visual forms that can be used to augment graphic tactical displays.
- Differences among echelons in information-processing capabilities are greatest during the execution phase of battle. In contrast, during the planning phase, the amount of time available increases so that visual processing becomes appropriate for all echelons.
- The auditory modality provides a connecting link for mounted and dismounted forces. Audition provides a practical lingua franca for all elements of the UA in that information does not require extensive coding or decoding to be pushed up or down the echelon.
- The model can be used to derive recommended modalities of interface representations. Table III-3 summarizes several implications that we have discussed: (1) visual displays are appropriate for planning for all echelons, (2) nonvisual processing (tactile, aural) are appropriate for individual/small unit dismounts during execution, and (3) auditory processing is the common link across echelons (and phases).

Table III-3. Recommended Primary, Secondary, and Tertiary Representation Modalities for Echelon and Phase of Battle

	Phase of Battle	
Echelon	**Plan**	**Execute**
UA	Visual/Auditory	Visual/Auditory
Battalion	Visual/Auditory	Visual/Auditory
Company	Visual/Auditory	Auditory/Visual
Platoon	Auditory/Visual	Auditory/Tactile/Visual
Individual	Auditory/Visual	Tactile/Olfactory/Auditory

REFERENCES

Alberts, D.S., Garstka, J.J., and Stein, F.P. (1999). *Network centric warfare: Developing and leveraging information superiority*. Washington, DC: C4ISR Cooperative Research Program, Office of the Assistant Secretary of Defense (C3I).

Avery, L.W., and Bowser, S.E. (1992). *Human factors design guidelines for the Army Tactical Command and Control System (ATCCS) Soldier-Machine Interface*. (AES-R-002). Fort Lewis, WA: Army Tactical Command and Control System.

Barwise, J. and Etchemendy, J. (1994). *Hyperproof*. Stanford: CSLI Lecture Notes. New York: Cambridge University Press.

Baumgardner, N. (2002). C4ISR On-the-move demonstrations to feature wide-array of technologies. *DDN C4ISR News*. Retrieved December 30, 2002 from the Defense Daily Network Web site: http://www.defensedaily.com.

Bowers, P. (2002). The TRW Tactical Systems Division builds the next generation of tactical Army operations systems. *Crosstalk, 15*, 14–15.

Boyd, M. (n.d.). *FCS CTD WMI Architecture*. [Briefing]. Arlington, VA: Defense Advanced Research Projects Agency.

Card, S.K., Moran, T.P., and Newell, A. (1983). *The psychology of human-computer interaction*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Carroll, J.M., and McKendree, J. (1987). Interface design issues for advice-giving expert systems. *Communications of the ACM, 30 (1),* 14–31.

Carroll, J.M. (Ed.) (1991). *Designing interaction: Psychology at the human-computer interface*. Cambridge, UK: Cambridge University Press.

Chairman, Joint Chiefs of Staff (2000). *Joint Vision 2020*. Washington, DC: U.S. Government Printing Office.

Chao, B.P. (1986). *Design guidelines for human-computer dialogues*. (SAND86-0259). Sandia National Laboratories, Albuquerque, New Mexico.

Collins, J.M. (1998). *Military geography for professionals and the public*. Washington, DC: National Defense University Press.

Commander's Support Environment (CSE) User's Guide. (2002).

Crew Integration and Automation Testbed (CAT), Soldier-Machine Interface (SMI), Integrated Product Team (IPT) Members (n.d.). Detroit, MI: U.S. Army Tank-Automotive & Armaments Command (TACOM), RD&E Center (TARDEC), Vetronics Technology Area.

Crew-integration and Automation Testbed (CAT) advanced technology demonstrator (2002). [Briefing] Retrieved December 30, 2002, from the Tank-automotive and Armament Command Research, Development, and Engineering Center (TACOM-TARDEC) Web site: http://www.tacom.army.mil/tardec/vetronics/catatd.htm.

Csikszentmihalyi, M. (1990) *Flow: The psychology of optimal experience*. New York: Harper and Row.

Deatz, R.C., Greene, K.A., Holden, W.T., Jr., Throne, M.H., and Lickteig, C.W. (2000). *Refinement of prototype staff training methods for future forces*. (ARI Research Report 1763). Alexandria, VA: U.S. Army Research Institute for the Social and Behavioral Sciences.

Defense Advanced Research Project Agency (DARPA) (2002). *DARPA fact file: A compendium of DARPA programs*. Retrieved January 29, 2003, from the DARPA Web site: http://www.darpa.mil/body/NewsItems/pdf/DARPAfactfile.pdf.

Dellinger, J.A., Taylor, H.A., and Richardson, B.C. (1986). Comparison of the effects of atropine sulfate and ethanol on performance, *Aviation, space, and environmental medicine, Dec. 1986,* 1185–1188.

Department of Defense (1997). *Department of Defense design criteria standard: Aircrew alerting systems* (MIL-STD-411F). Washington, DC: Author.

Department of Defense (1998). *Department of Defense design criteria standard: Human engineering* (MIL-STD-1472F). Washington, DC: Author.

Department of Defense (1999). *Department of Defense interface standard: Common warfighting symbology* (MIL-STD-2525B). Washington, DC: Author.

Department of Defense (2001). *Department of Defense interface standard: Aircraft display symbology* (MIL-STD-1787C). Washington, DC: Author.

Dierksmeier, F.E., Johnston, J.C., Winsch, B.J., Leibrecht, B.C., Sawyer, A.R., and Quinkert, K.A. (1999). *Structured simulation-based training program for a digitized force: Approach, design, and functional requirements, Volume 1* (ARI Research Report 1737). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Dondis, D.A. (1973). *A primer of visual literacy*. Cambridge, MA: Massachusetts Institute of Technology.

FBCB2 full-rate production stalled. (March 1, 2002). *Jane's Defence Weekly*.

Flach, J.M., and Dominguez, C.O. (1995). Use-centered design: Integrating the user, instrument, and goal. *Ergonomics in Design, 3 (3),* 19–24.

Flor, N.V. and Hutchins, E. (1992) Analyzing distributed cognition in software teams: A case study of collaborative programming during adaptive software maintenance. In J. Koenemann-Belliveau, T. Moher, and S. Robertson, (Eds.), *Empirical Studies of Programmers: Fourth Workshop*. Norwood, NJ: Ablex Publishing.

Funk, H.B., and Miller, C.A. (1997). "Context sensitive" interface design. In *Proceedings of the International and Interdisciplinary Conference on Modeling and Using Context (CONTEXT-97)*, Rio de Janeiro, Brazil: Federal University of Rio de Janeiro.

Galitz, W.O. (1993). *User-interface screen design*. New York, NY: John Wiley and Sons.

Goudeseune, C., and Kaczmarski, H. (2001). Composing outdoor augmented-reality sound environments. In *Proceedings of 2001 International Computer Music Conference,* Havana.

Gourley, S. (September 25, 2002). *U.S. Army expands battlefield digitization*. Retrieved April 16, 2003, from the Jane's Defence Weekly Web site: http://www.janes.com.

Gumbert, J., Cranford, T.C., Lyles, T.B., and Redding, D.S. (2003). DARPA's future combat system command and control. *Military Review,* May–June. 79–84.

Headquarters, Department of the Army (1995, July). *Operator's manual (Volumes 1 and 2) for tank, combat, full-tracked: 120-mm gun, M1A2, General Abrams*. (Technical Manual TM 9-2350-288-10-1/2). Washington, DC: Author.

Headquarters, Department of the Army (1996, April). *Tank platoon* (Field Manual FM 17-15). Washington, DC: Author.

Howard, E., and Less, M.C. (2002). *WMI procurement specification kick-off meeting*. [Briefing]. Arlington, VA: Defense Advanced Research Projects Agency.

Hromadka, T.V. (2001). Lessons learned in developing human-computer interfaces for infantry wearable computer systems. In *Usability evaluation and interface design: cognitive engineering, intelligent agents, and virtual reality, Volume 1*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Hutchins, E. (1990). The Technology of Team Navigation. In J. Galegher., R.E. Kraut, and C. Edigo, (Eds.), *Intellectual Teamwork*. Hillsdale, N.J.: LEA.

Hutchins, E. (1995). How a cockpit remembers its speed. *Cognitive Science, 19,* 265–288.

Information Exploitation Office, DARPA (n.d.). *Command Post of the Future (CPOF).* Retrieved December 31, 2002, from the DARPA Web site: http://dtsn.darpa.mil/ixo/cpof.asp.

Jarboe, J., Ritter, P., Hale, T., Lewis, J. and Poikonen (2002). *Battle Lab Experiment Final Report (BLEFR) for Future Combat Command and Control (FCC2), Concept Experimentation Program* (CEP #01-1701). Fort Knox, KY: Mounted Warfare Testbed, Mounted Maneuver Battle Laboratory.

Joint Robotics Program (2001). *Joint Robotics Program Master Plan 2001*. Washington, DC: Author.

Jordan, P.W. (2000). *Designing pleasurable products*. Philadelphia, PA: Taylor and Francis, Inc.

Kahneman, K., and A. Tversky. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47*, 263–291.

Kelley, J.F. (1984). An iterative design methodology for user-friendly natural language office information applications. *ACM Transactions on Office Information Systems, 1 (2)*, 26–41.

Kelly, K. (1998). *New rules for the new economy: Ten radical strategies for a connected world*. New York: Viking Press.

Kotovsky, K., Hayes, J.R., and Simon, H.A. (1985). Why are some problems hard? Evidence from tower of Hanoi. *Cognitive Psychology*, 17, 248–294.

Kroemer, K.H.E., Kroemer, H.B., and Kroemer-Elbert, K.E. (1994). *Ergonomics: How to design for ease and efficiency*. Englewood Cliffs, NJ: Prentice Hall.

Larkin, J. and Simon, H.A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*(1), 65–99.

Laurel, B. (Ed.) (1990). *The art of human-computer interface design.* New York, NY: Addison-Wesley Publishing Company, Inc.

Lewis, H.V., and Fallesen, J.J. (1989). *Human factors guidelines for command and control systems: Battlefield and decision graphics guidelines.* (Research Project 89-01). U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA.

Lickteig, C.W., Sanders, W.R., Lussier, J.W., and Sauer, G. (2003). A focus on battle command: Future command systems human systems integration. In *Proceedings of the 2003 Interservice/Industry Training, Simulation, and Education Conference.* Arlington, VA: National Training Systems Association.

Lickteig, C.W., and Throne, M.H. (1999). *Applying digital technologies to training: A focus on pictorial communication* (Technical Report 1097). Alexandria, VA: U.S. Army Research Institute for the Social and Behavioral Sciences.

Maslow, A. H. (1970). *Motivation and personality* (2nd Edition). New York: Harper and Row.

Miller, C.A., and Funk, H.B. (2001, March). Associates with etiquette: Meta-communication to make human-automation interaction more natural, productive and polite. In *Proceedings of the 8th European Conference on Cognitive Science Approaches to Process Control*. Munich, Germany: European Association of Cognitive Ergonomics.

Miller, C.A., and Hannen, M.D. (1999, January). User acceptance of an intelligent user interface: A rotorcraft pilot's associate example. In *Proceedings of 1999 International Conference on Intelligent User Interfaces* (pp. 109–116). Redondo Beach, CA: Association of Computing Machinery.

Mounted Maneuver Battle Laboratory (2002). *UA Concept Experimentation Program (CEP), Battle Lab Experimentation Final Report* (BLEFR). Fort Knox, KY: Author.

Nardi, B.A. (Ed.) (1996). *Context and consciousness: Activity theory and human-computer interaction.* Cambridge, MA: The MIT Press.

National Research Council (1997). Panel on human factors in the design of tactical display systems for the individual soldier. *Tactical displays for soldiers: Human-factors considerations*. Washington, DC: National Academy Press.

North Atlantic Treaty Organization (1990). Military symbols for land-based systems (STANAG 2019). Brussels, Belgium: Author.

Naylor, H., Callaway, E., and Halliday, R. (1992). Biochemical correlated to human information processing. In P.A. Vernon (Ed.), *Biological approaches to the study of human intelligence* (333–373). Norwood, NJ: Ablex Publishing

Newell, A. (1990). *Unified theories of cognition.* Cambridge, MA: Harvard University Press.

Nielsen, J. (1995). *Usability engineering*. New York: Academic Press.

Norman, D.A. (1993). *Things that make us smart: Defending human attributes in the age of the machine*. New York, NY: Addison-Wesley Publishing Company, Inc.

Norman, D.A., and Draper, S.W. (Eds.) (1986). *User-centered system design: New perspectives on human-computer interaction.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Norman, K.L. (1991). *The psychology of menu selection: Designing cognitive control at the human/computer interface*. Norwood, NJ: Ablex Publishing Corporation.

Page, W. (n.d.). *Command post of the future*. [Briefing]. Washington, DC: Information Exploitation Office, DARPA.

Patterson, M. (2002). *Wireless Tactical Voice Activation System/Helmet-Mounted Display (TVAS/HMD) program.* [Briefing]. Sterling Heights, MI: General Dynamics Land Systems.

Program Executive Office – Aviation, Aviation Electronic Systems (2001). *Preliminary Software Requirements Specification (SRS) for the Common Army Aviation Situational Awareness (SA) Soldier Machine Interface (SMI)* (Coordinating Draft). Redstone Arsenal, AL: Author.

Ray, D. (2000, November). *Final report: Battle Command Reengineering 4*. Fort Knox, KY: Mounted Maneuver Battle Laboratory.

Scerbo, M.W., Freeman, F.G., Mikulka, P.J., Parasuraman, R., Di Nocero, F., and Prinzel, L.J. III (2001, June). *The efficacy of psychophysiological measures for implementing adaptive technology* (NASA/TP-2001-211018). Hampton, VA: National Aeronautics and Space Administration.

Shepard, A.P. (1991). *Report of results of ATCCS Contingency Force Experiment-Light (ACFE-L) Group B, Soldier-Machine Interface (SMI) Assessment* (AES-91-02). Fort Lewis, WA: Army Tactical Command and Control System.

Tank-automotive and Armament Command Research, Development, and Engineering Center (TACOM-TARDEC) (2002, September). *Crew Integration and Automation*

Testbed (CAT) Advanced Technology Demonstration. Retrieved December 30, 2002, from the TACOM-TARDEC Web site: http://www.tacom.army.mil/tardec/vetronics/catatd.htm

Toth, J., Hooton, S., and Graesser A. (in preparation). *A proposed model for mixed-mode communication design standards via cognitive readiness in advanced distributed learning* (Draft IDA Document). Alexandria, VA: Institute for Defense Analyses.

Tufte, E.R. (1983). *The visual display of quantitative information*. Cheshire, CT: Graphics Press.

Tullis, T.S. (1988). Screen design. In M. Helander (Ed.), *Handbook of human-computer interaction*. North-Holland: Elsevier Science Publishers B.V.

Tversky, A. & Kahneman, D. (1984). Choices, values, and frames. *American Psychologist, 39,* 341–350

Vygotsky, L.S. (1962). *Thought and language*. Cambridge, MA: The MIT Press.

Waisel, L B. (2002). DARPA's Command Post of the Future (CPOF) program. In *Proceedings of the 2002 Conference of Scuola Superiore G. Reiss Romoli (SSGRR-2002)*. L'Aquila, Italy: Telecom Italia Group.

Waldrop, M.M. (2002). *Cutting through the fog of war*. Retrieved December 31, 2002, from the Business 2.0 Web site: http://www.business2.com/articles/mag/0,1640,36729,FF.html.

Weintraub, D.J., and Ensing, M. (1992). *Human-factors issues in head-up display design: The book of HUD*. (CSERIAC Report Number 20 92-2). Wright-Patterson Air Force Base, OH: Armstrong Medical Research Laboratory.

White, A. (2000). *Digital battle staff training deficiencies and mission essential task list mapping* (IAT.R 0222). Austin, TX: Institute for Advanced Technology, University of Texas at Austin.

Wickens, C.D., and Andre, A.D. (1990). Proximity, compatibility, and information display: Effects of color, space, and objectness of information integration. *Human Factors, 32*, 61–77.

Wright, S. (2002). The M1A2 and the IVIS. *News from the Front* [On-line publication], Mar-Apr¸ 33–34. Retrieved December 23, 2002 from Center from Army Lessons Learned Web site: http://call.army.mil/products/pdf/nftf/marapr02/marapr02bk.pdf.

Zhang, J., and Norman, D.A. (1994). Representations in distributed cognitive tasks. *Cognitive Science, 18,* 87–122.

Zhang, J. (1997). The nature of external representations in problem solving, *Cognitive Science, 21,* 179–217.

Zhang, J. (1991). The interaction of internal external representations in a problem solving task. In *Proceedings of the 13th Annual Conference of the Cognitive Science Society, Chicago, IL,* 954–958. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

GLOSSARY

2-D	two-dimensional
3-D	three-dimensional
4-D	four-dimensional
ACFE-L	ATCCS Contingency Force Experiment-Light
ACM	Association for Computing Machinery
ADA	Air Defense Artillery
AES	ATCCS Experimentation Site
AFATDS	Advanced Field Artillery Tactical Data System
AFV	Armoured Fighting Vehicle
AI	artificial intelligence
AIAA	American Institute of Aeronautics and Astronautics
AMPS	Aviation Mission Planning System
APA	American Psychological Association
API	application protocol interface
ARI	U.S Army Research Institute for Behavioral and Social Sciences
ARL	Army Research Laboratory
ASAS	All Source Analysis System
ATCCS	Army Tactical Command and Control System
ATD	Advanced Technology Demonstration Advanced Technology Demonstrator
AVN	Aviation
BCR	Battle Command Reengineering
BDI	Balkan Digitization Initiative
BFA	battlefield functional area
BLEFR	Battle Lab Experimentation Final Report
BLUFOR	Blue Forces
BMS	Battle Management Systems

C2	command and control
C3	command, control, and communications
C3I	command, control, communications, and computers
C4I	command, control, communications, computers, and intelligence
C4ISR	command, control, communications, computer, intelligence, surveillance, and reconnaissance
CAT	Crew-integration and Automation Testbed
CBT	computer-based training
CCD	Command and Control Display
CDAS	Cognitive Decision Aiding System
CDY/CEU	Commander’s Display Unit/Commander’s Electronic Unit
CEL	Cognitive Engineering Laboratory (University of Toronto)
CEP	Concept Experimentation Program
CHI	Computer-Human Interaction
CID	Commander’s Integrated Display
CIM	Cockpit Information Management
CITV	Commander’s Independent Thermal Viewer
CJCS	Chairman of the Joint Chiefs of Staff
CMU	Carnegie Mellon University
COA	course of action
COC	combat operations center
ColOP	Collaborative Operating Picture
COMSEC	communications security
CONOPS	concept of operations
COP	Common Operating Picture
CPOF	Command Post of the Future
CSE	Commander’s Support Environment
CSERIAC	Crew System Ergonomic Information Analysis Center
CSLI	Center for the Study of Language and Information (Stanford University)
CSS	combat service support
CSSCS	Combat Service Support Computer System

CTD	Concept and Technology Demonstration
CU	Cornell University
CVC	combat vehicle crewman
DARPA	Defense Advanced Research Project Agency
DCIEM	Defence and Civil Institute of Environmental Medicine
DDN	Defense Daily Network
DISA	Defense Information Systems Agency
DIVA	Data IntensiVe Architecture
DoD	Department of Defense
DOT	Department of Transportation
DOT&E	Director for Operational Test and Evaluation
DTIC	Defense Technical Information Center
EPLARS	Enhanced Position Location and Reporting System
FAA	Federal Aviation Administration
FAADC3I	Forward Area Air Defense Command, Control, Computers, and Intelligence
FBCB2	Force XXI Battle Command Brigade and Below
FCS C2	FCS Command and Control
FCS	Future Combat Systems
FFRDC	Federally Funded Research and Development Center
FM	Field Manual frequency modulation
FMTV	Family of Medium Tactical Vehicles
FOV	field of view
FRP	full-rate production
FY	fiscal year
GDI	Gulf Digitization Initiative
GOMS	Goals, Operators, Methods, and Selection (rules)
GPS	Global Positioning System
GUI	graphic user interface
HCI	Human-Computer Interface
HFCS	Human Factors of Command Systems

HFES	Human Factors and Ergonomics Society
HIRL	Haptic Interface Research Laboratory (Purdue University)
HITL	human-in-the-loop
HMD	helmet-mounted display
HMMWV	High-Mobility, Multipurpose Wheeled Vehicle
HUD	heads-up display
I/O	input/output
IAT	Institute for Advanced Technology, University of Texas at Austin
ICA	International Conference on Auditory Display
ICAT	Intelligent Computer-Aided Training
IDA	Institute for Defense Analyses
IEA	International Ergonomics Association
IFAC	International Federation of Automatic Control
IFIP	International Federation for Information Processing
IFORS	International Federation of Operational Research Societies
IITRI	Illinois Institute of Technology Research Institute
IMS	Intelligent Munitions System
IMW	Integrated Mounted Warrior
IOT&E	Initial Operational Test and Evaluation
IPB	intelligence preparation of the battlefield
ISR	intelligence, surveillance, and reconnaissance
ISWC	International Symposium on Wearable Computers
ITA	Interface Technology Analyses
IVIS	InterVehicular Information System
IXO	Information Exploitation Office
JV	Joint Vision
JVMF	Joint Variable Message Format
LAN	local area network
LOS	line of sight
LRIP	low-rate initial production
LSI	Lead Systems Integrator

LTM	long-term memory
LUT	Limited User Test
MC2	Mobile Command and Control
MCRP	Marine Corps Reference Publication
MCS	Maneuver Control System
MEP	Mission Equipment Package
METT-T	mission, enemy, terrain, troops, and time
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
MIT	Massachusetts Institute of Technology
MMBL	Mounted Maneuver Battle Laboratory
ModSAF	Modular Semi-Autonomous Forces
MOPP	mission-oriented protective posture
MSIS	Man-Systems Integration Standards
n.d.	no date
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBC	nuclear, biological, and chemical
NCW	Network Centric Warfare
NLOS	Non Line of Sight
NPRDC	Navy Personnel Research and Development Center
NTC	National Training Center
OPFOR	opposing force
OPORD	operations order
Ops	operations
OT&E	operational test and evaluation
PC	personal computer
PCIS	Portable Common Interface Set
plc	Public Limited Company (United Kingdom)
PM	Program Manager
PNL	Pacific Northwest Laboratory
POC	Point of Contact

POSNAV	Position Navigation
PPA	Product Personality Assignment
PVD	Plan View Display
R&D	research and development
RDT&E	research, development, test, and evaluation
RFI	request for information
RIE	Righi Interface Engineering, Inc.
ROC	receiver operating characteristic
RPA	Rotorcraft Pilot's Associate
S&T	Science and Technology
SA	situational awareness
SAIC	Science Applications International Corporation
SC4	Surrogate digital Command, Control, Communications, and Computer
SCO	Santa Cruz Operation
SEP	System Enhancement Program
SEQUAM	Sensorial Quality Assessment
SIGSOFT	Special Interest Group on Software Engineering (ACM)
SINCGARS	Single-Channel Ground and Airborne Radio System
SME	subject matter expert
SMI	soldier-machine interface
SRS	software requirements specification
SPAWAR	Space & Naval Warfare Systems Command (U.S. Navy)
SRS	Software Requirements Specification
SSGRR	(Conference of) Scuola Superiore G. Reiss Romoli
STANAG	Standardization Agreement (NATO)
STWM	short-term working memory
T&E	test and evaluation
TACOM	U.S. Army Tank-automotive and Armaments Command
TARDEC	Tank-Automotive Research, Development, and Engineering Center
TBM	Theater Battle Management

TLX	Task Load Index (NASA)
TM	Technical Manual
TOCHI	Transactions on Computer-Human Interaction
TR	Technical Report
TTO	Tactical Technology Office (DARPA)
TTP	tactics, techniques, and procedures
TVAS/HMD	Tactical Voice Activation System/Helmet-Mounted Display
UA	Unit of Action
UA	unit of action (U.S. Army)
UAV	unattended air vehicle unmanned aerial vehicle
UE	unit of employment (U.S. Army)
UIST	User Interface Software and Technology
UGV	unmanned ground vehicle
UPA	Usability Professionals' Association
USC	University of Southern California
VBAP	Voice-Band Audio Processor
VCR	videocassette recorder
VTC	video teleconferencing
VTT	Vehicle Technology Testbed
WMD	weapons of mass destruction
WMI	Warfighter-Machine Interface
WWW	World Wide Web

APPENDIX A
METHODS FOR UNDERSTANDING USERS

APPENDIX A
METHODS FOR UNDERSTANDING USERS

Table A-1. Summary of Methods for Understanding Users[1]
(In Table A-1, *P* means "participant, *I* means "investigator," and *Q* means "questionnaire.")

Method	Description	Advantages	Disadvantages
Private Camera Conversation Vries, Hartevelt, and Oosterholt (1996)	In a private booth, room, or location, participant *(P)* provides a prompted or unprompted discussion of prior experience with product.	*P* is less inhibited owing to privacy and absence of investigator *(I)*, especially when emotional or hedonic topics might be discussed. Ps typically enjoy being video taped.	*I* has little control over session; *P* directs monologue. If *P* says something vague, *I* cannot clarify what he/she meant.
Co-Discovery Kemp and Gelderen (1996)	Two *P*s (a dyad), who know each other, work together to explore product or concept. *I* may or may not be present.	Discussion between two *P*s elicits more knowledge and ideas; more spontaneous; keeping each other in check. Better certainty that *P*s may isolate various themes (e.g., aesthetics vs. function).	*I* loses control of session if not present. If present, *I* may unduly influence the session.
Focus Groups Morgan (1993); O'Donnell, Scobie, and Baxter (1991)	Small group of people (5–15) gather to discuss an issue, product, or concept, guided by discussion leader (*DL*). Discussion is loosely structured, but *DL* may employ prompts to raise topics concerning *I* or to generate discussion if session languishes.	Group dynamics provide even more information than co-discovery dyad. Issue raised by one member can stimulate ideas by the other members.	*DL* has to be careful not to lead the witness (e.g., *Do the tactile properties of the remote control give it a high-quality feel* vs. *When you hold the remote, does it feel of a low or high quality, and why?*) Dominant or long-winded personalities may take over the discussion, but an experienced *DL* can mediate by redirecting discussion to other members.
Think-Aloud Protocols Kerr and Jordan (1994); Virzi (1992)	*P* is asked to verbalize thoughts and emotions while performing task or interacting with artifact. *I* may prompt *P* with general questions (e.g., *What are you thinking now?*) or specific questions (e.g., *How do the graphics affect the overall appearance of quality?*)	*I* might understand how and why *P* reacts in a session; great source of prescriptive data, leading to rectification of design flaw(s). Some consider this the most powerful method of extracting maximum prescriptive or diagnostic information.	*P* may rationalize thoughts and/or *I* may influence protocol with prompts. See also Schooler, Ohlsson, and Brooks (1993), who doubt the validity of verbal reports describing visual information. *I* may use prompting level that is too general or specific.

Note 1 for Table A-1: *Methods involve both participant(s) (P) and investigator (I), who may be a designer, scientist, or engineer. Advantages and disadvantages listed are not necessarily limited to a given method. For instance, any method involving groups is susceptible to group dynamics, and any method involving presence of investigator is susceptible to bias and/or demand characteristics.*

Table A-1. Summary of Methods for Understanding Users[1] (Continued)

Method	Description	Advantages	Disadvantages
Experience Diaries Zimmerman and Wieder (1977) Nielsen (1993)	Mini-questionnaire so that *P* can note experiences with product over time. *Ps* may be asked weekly to record how they feel, likes-dislikes, problems, general impressions of product.	Requires little time and effort for *I* and few materials or facilities. Data are captured longitudinally, seeing how *Ps* experiences change over time (e.g., initial excitement about new product fades, revealing good or bad characteristics). Unexpected rare, quirky problems can be captured.	Since *I* is not present, *P* may lose interest if too much detail is required. *P* may also misunderstand how the diary should be completed and/or provide too little detail. Usually possible only with finished products or mature prototypes, providing better benefits for future product lines. Iterative software prototypes are the exception.
Reaction Checklists Edgerton (1996) Johnson (1996)	*P* checks a list of +/– reactions they have with the product. Property list may comprise Jordan's levels, physio, psycho, socio, and ideo, or other features such as functional, aesthetic, interaction style. Property is a phrase or sentence, e.g., *The buttons feel good to the touch,* or a photo/diagram, checking highlighted +/– properties.	Cheap and effective, requiring few materials or facilities. *I* can identify links between properties and underlying design aspects of artifact—functional, aesthetic, interaction style, etc.—using statistical cluster analysis.	Evaluation is only as effective as wording of the property lists. *I* may not understand why *P* checked a list; i.e., information more surface than deep, compared with other methods. Not considered as effective with prototypes and partial products; software, again, a possible exception.
Field Observations	*I* watches *P* in “natural’” setting where product is used *in situ*. *I* may or may not provide directions. Assumption is that influence/presence of *I* should be held to an absolute minimum.	Greater degree of ecological validity vs. controlled study, for example. However, if *Ps* are aware of recording equipment, they eventually begin to ignore it and return to quasi-naturalistic behavior, as exemplified in “reality TV.”	Presence of *I* in the form of questions, prompts can affect *Ps* behavior and validity. However, *P* can be recorded without knowledge of recording equipment presence, but this raises ethical issues. Data can be significant if study occurs over the course of days, weeks, or months.
Questionnaires *(Q)* Wilson (2001)	*P* responds to printed lists of questions. • In **fixed-response**, *P* selects item from a scale (e.g., response to *Display is easy to understand* can range from *strongly disagree* to *strongly agree*.) Examples include Task Load Index (Hart and Staveland, 1988); System Usability Scale (Brooke, 1996); Software Usability Measurement Inventory (Kirakowski, 1996); and Computer User Satisfaction Inventory (Kirakowski and Corbett, 1988). • In **open-ended** response, *P* provides written response to question (e.g., *What are the best aspects of this product?*) Analysis is more qualitative in nature.	Once checked for validity and reliability, *Q* can be copied and issued to many others at little cost. If *I* is not present, *Ps* will be less inhibited. Statistical analysis is also possible.	If administered remotely, only 25% are usually completed, and they are self-selecting. Those that are completed reflect a sample of the population that is not representative. Possibility of misinterpreting *Ps* responses can also occur. Also may be difficult to isolate major themes. Piloting is required.

Table A-1. Summary of Methods for Understanding Users[1] (Continued)

Method	Description	Advantages	Disadvantages
Interviews	*I* asks *P* a series of questions (three types): • **Unstructured**. Open-ended questions. Allows *P* to steer conversation. Useful when *I* has limited knowledge of issues pertinent to product. • **Semi-Structured.** *I* has a clearer idea of issues, so discussion is more constrained (e.g., *P* is prompted by *I* on topics or properties central to the design). • **Structured.** *I* guides discussion, soliciting fixed responses (e.g., on a scale, or property lists) to pre-determined questions, also allowing for elaboration and quantitative analysis.	Versatile, like a face-to-face *Q*, with elaboration. Unlike *Q*, less chance of misunderstanding questions and allows for clarifications. Less preparation and piloting required than with a *Q,* since *I* can drill-down a topic or investigate an emergent topic. Self-selection problems endemic to *Q* technique not an issue, since *I* is present at session.	Requires significant time for *I* with added risk of bias and demand characteristics (e.g., *P* may want to please *I* and might also be more inhibited). Also requires more time to evaluate responses from *P.*
Immersion	*I* is the *P* who also experiences and evaluates the product. **This is the predominant method in many realms of Department of Defense (DoD) human-factors research.**	Convenient; preserves confidentiality. *I* gains first-hand experience and insights with product rather than depending on the third-person perspective of *P*. *I's* analysis is integrated with intimate knowledge of design goals and constraints only understandable after years of experience. Can be a powerful technique.	Investigator *bias* is the predominant problem. *I* is not representative of a typical *P.* In particular, if *I* also happens to be an engineer, or scientist, or investigator, the design process may succumb to the self-fulfilling prophecy. Cognitive dissonance and lack of objectivity are also potential problems. **Many developers and investigators are ill-equipped in human factors but adhere to this technique. Inferior products are the result.** User-centered design iterations involving other *Ps* could be interleaved with this method.
Laddering Reynolds (1998)	*I* asks *P* to mention +/– of product feature, *P* responds and then *I* asks why. *P* responds, and *I* asks why again. Cycle repeats until *P* no longer responds. At this point, *I* has isolated a fundamental value or benefit. Process continues with other features of interest to *I.* For example, one-calorie drink laddering leads to value of being thin and beautiful, thus promoting an enjoyable life. Product theme has been isolated.	Allows *I* to gather information about (1) formal and experiential properties, (2) desired benefits, and (3) characteristics about the target user and the relationships between these three aspects. Properties thus linked to benefits, which are then linked to target group. Appropriate for prototypes or final products.	Can be time consuming for *I* and *P.* Constant iteration of "why?" may place *P* under pressure. *P* may rationalize (i.e., rationalization about answer instead of gaining insight into their true feelings) when he/she feels that the question is irrelevant, thus giving *I* incorrect information about the design.

Table A-1. Summary of Methods for Understanding Users[1] (Continued)

Method	Description	Advantages	Disadvantages
Participative Creation Hartevelt and van Vianen (1994)	Group of *Ps* are gathered with designers and human-factors specialists to discuss issues relating to product design. Topics include requirements, aesthetics, functional, and interactional properties. This method differs from focus group because *Ps* are involved in a hands-on way regarding product design, not issues.	Direct human interaction between designers and human-factors specialists and the target users vs. indirect methods.	Significant time commitment required for *Ps.* Also, *Ps* are not professional designers and can cloud or misdirect the design process. *Ps* may also be intimidated by designer's expertise and thus be inhibited to share ideas vs. an indirect approach, where *I* is not present.
Controlled Observation	**The workhorse of DoD human-factors research.** Independent and dependent variables are identified, and the method is strictly controlled. Not unlike the American Psychological Association (APA) Format. Counterbalancing, proper *P* selection, internal-external-ecological validity are intrinsic to process.	Data gathered from study are "pure" and more reliable. Statistical tests are possible, and statistical significance can be ascertained. Great precision in identification of variables, interactions, and main effects.	Controlled environment is too sterile and artificial. External-ecological validity and generalizability to actual situations are major issues. Context is by and large absent vs. field study. (See Carroll, 1991; Nardi, 1996; and Norman, 1993.)
Expert Appraisal Kerr and Jordan (1994)	One or more subject matter experts (SMEs)—but people who are not the designer or *I*—assume the role of *P.* The SME *P*, compared with the novice *P*, can articulate factors pertaining to content, requirements, aesthetics, function, interaction, and so forth. SME may be a domain expert (content) or even a human-factors expert (design process).	Good method for providing diagnostic, prescriptive analysis. Objective, specialized knowledge (contrasted with immersion) can lead to rapid, more focused solutions.	SME is not representative of the user population and could miss vital features. Novice may have a mental model that is completely different from expert's mental model (i.e., shallow vs. deep domain knowledge). (See Chi, Feltovich, and Glaser, 1981; Chase and Simon, 1973.)
Property Checklists Ravden and Johnson (1989); Johnson (1996)	List of design properties, or design elements, that affect whether a product is usable. Two or more kinds of properties are • **High-level.** Consistency, compatibility, good feedback, and so forth • **Mid-level.** Task-specific use • **Low-level.** Font-size, position of displays and controls, and so forth. *I* determines whether design conforms to properties on the list. These lists help *I* to assess anticipated contributions to product success, defined by its benefits (e.g., control, power, safety). Product elements in list can include form, color, materials/finishings, graphics, sound, functionality, interaction design. *I* determines if each element emphasizes the benefits (e.g., *Does the interaction design emphasize control?*)	*Ps* are not required, since *I* does the evaluation. High-level and low-level checklists can also be applied to each phase of the process: requirements, design, implementation, test and evaluation (T&E), and release/maintenance.	Quality of evaluation depends on accuracy of expert's (i.e., *I*) personal judgment. Some items on list are derived from years of human-factors research, such as the appropriate font-size viewable from a given distance. Other items, however, are subjective and ephemeral and will vary no matter how objective *I* tries to be [e.g., masculine vs. feminine interpretation of product; see (Kirkham, 1996)]. Without a representative sample of *Ps,* it is also difficult to determine a range of acceptable variations (i.e., on a normal distribution) to account for individual differences. This could be mitigated by engaging *Ps* with a less technical form of the checklist (e.g., re-cast *I's* conception of 12 pt vs. 9 pt font for *P* as "large" and "small," respectively).

Table A-1. Summary of Methods for Understanding Users[1] (Continued)

Method	Description	Advantages	Disadvantages
Kansei Engineering Nagamachi (1995); Nagamachi 1997); S. Ishihara et al. (1997)	Helps *I* understand (1) relationship between formal and experiential properties of a product, or (2) insight into benefits users wish to gain from products, and the properties that realize these benefits. Two techniques, depending on direction of "flow"" are • **Flow from design to diagnosis.** Manipulating individual characteristics product and then determining user responses. For example, users rated product characteristics based on how they fit with 86 descriptor adjectives/ experiential properties (*showy, calm, masculine, feminine, soft, high grade, and so forth*) on a 5-point scale. Cluster analysis establish links between formal (*I's* perspective) and experiential (*Ps'* perspective). • **Flow from context to design.** Analyzing scenarios and contexts of product us. Establishes link between formal properties of design and benefits of the product. Similar to field study, but metrics include benefits and emotions about product. For example, visits to homes with refrigerators to observe *in situ* use of product. Physical issues arose: bumping head on shelf, heights, and so forth.	Method is thorough. It relies on statistical analyses to establish links between (1) formal properties, (2) experiential properties, and (3) benefits of product. Appears to be most reliable and valid technique for linking product properties to product benefits. Potential benefit for DoD soldier-machine interface (SMI) engineering, particularly with nonvisual and nonauditory interfaces being proposed, which could include clothing, new weapons, augmented reality devices, and so forth.	Given all the dimensions of analysis (e.g., 72 concepts on 86 descriptors for different coffee cans yielding 6,192 responses per *P;* 59 different steering wheels; 500 women evaluated bra design), two important benefits emerged: *beautiful* and *graceful.* Needless to say, the process can be unwieldy. Design elements implicitly based on assumption that product is sum of various features being analyzed, which is contrary to a Gestalt view, where sum is not equivalent to sum of the parts. Gestalt-oriented analysis might be more qualitative in nature but will lack statistical validity.

Table A-1. Summary of Methods for Understanding Users[1] (Continued)

Method	Description	Advantages	Disadvantages
Sensorial Quality Assessment (SEQUAM) Bonapace (1999); Bandini-Buti, Bonapace, and Tarzia (1997)	Analyzing product or prototype in terms of formal properties of aesthetic elements. Using structured interviews, properties are linked with product benefits. Like Kansei engineering but correlation, rather than cluster analysis, is established between properties and benefits. • **Phase 1.** *Is* investigated 14 different door handles, and derived 14 properties— length, thickness, sound, angle of grasp, wrist rotation, and so forth—evaluated by *Ps* (9 M, 9 F). • **Phase 2.** *Is* designed 13 prototype handles. Same *Ps* evaluated handles (performing prescribed tasks) and rated handles on a 10-point scale (proprietary scales—not divulged by authors).	Like Kansei, this method is extremely thorough. Requires fewer features (minimum of 7) since correlation analysis, rather than cluster analysis, is performed. The two-phase approach can be extrapolated to iterative prototyping based on desired requirements, properties, and benefits. Potential benefit for DoD SMI engineering, particularly with nonvisual and nonauditory interfaces being proposed, which could include clothing, new weapons, augmented reality devices, and so forth.	Potential problem is interaction effects (e.g., drinking glass, *narrowness* and *lightness* correlated with each other and correlated with benefit of a feeling of *elegance* while drinking from and holding glass). *I* may not be able to ascertain which property, *narrowness* or *lightness,* contributes to the feeling of *elegance.* In Kansei cluster analysis, more samples would test prototypes that are *narrow* and *heavy* vs. *narrow* and *light.* Also difficult to keep all properties on scale-like continuum, such as weight, height vs. color and shape, which may or may not be expressible on a scale.
Product Personality Assignment Jordan (1997); Jordan and Servaes (1995); Norman (1992)	"Personality" is seen as experiential property of product. It may appear frivolous, but it pushes human-factors engineer to consider full suite and range of thoughts and emotions associated with product (e.g., soldiers best friends are their guns). Using Briggs-Myers (Briggs-Myers and Myers, 1980), different *Ps* assign different personalities to products (i.e., anthropomorphize the product). *Ps* completed questionnaires and then participated in focus groups to discuss results. Some significant extrinsic personality characteristic emerged for a product, and a strong correlation existed between a *Ps* personality type and the image that *P* projected on to the product (e.g., "introvert" and "extrovert." *Ps* assigned "introvert" and "extrovert" properties, respectively, to same product.)	Given enough *Ps* with different types of personalities, if a predominant personality emerges (e.g., 65% aggressive soldiers vs. 35% aggressive soldiers), that feature should be designed into product. Big cross-cultural advantage for DoD to convey clear appropriate perception of threat to the enemy. Facilitates perception of higher levels in Maslow hierarchy. Geometrically designed products rated "sensible," "trustworthy." Organic products were "friendly," "intuitive," and even "cute." Light colors "extroverted." Dark colors were "introverted."	Risk that the *wrong* personality type might emerge from the product and convey the *wrong* personality. For instance, consider cultural effects: In America, the color red conveys 'fatality" and "danger," but in China, the color red conveys "friendly."

Table A-1. Summary of Methods for Understanding Users[1] (Continued)

Method	Description	Advantages	Disadvantages
Mental Mapping Gross (described in Hine, 1995)	*P* oftentimes make conceptual links between a design and a people or well-known public figures. Association or mapping caused by product's formal capabilities. For example, a focus group associated detergent packaging with Sylvester Stallone as "get the job done." Less positive result when group identified toothpaste package with Arnold Schwarzenegger. *Ps* are asked to make up stories about product or are even hypnotized to get at archetypes in implicit memory.	*Ps* reasons for product identification are irrational and conflict with most rational theories of user preferences. Gross has had great success with this technique, however, and is widely respected and used throughout industry.	Strong case that *Ps* perceptions are simply rationalizations or Festinger's notion of cognitive dissonance (see Banynard and Hayes, 1994), especially when a strong emotional attachment to product exists. True feelings of product are in implicit memory and are difficult to identify with most of the techniques described herein. *Ps* may key in on archetypal characteristics of product that are inappropriate. Each corporation keeps method for successful product proprietary.
Expert Case Studies Macdonald (1998)	Examine successful products and determine the link between product benefits and formal/experiential properties. *I* uses professional judgment as a designer to analyze properties that make products appealing to users. This method is a form of expert appraisal.	See Jordan (2000, pp. 192–197) for summary of successful case studies: kitchen utensils, electric razor, pens, handles, control panels, auto exhaust. For the latter, a less costly Mazda exhaust system was engineered to sound like an expensive classic British sports car. Adding wheels to any sized suitcase was another significant design success. For a given DoD requirement, a survey of related products in industry would be a plus.	Appraisal from only one *I* may be too biased. Better to attain appraisals from a panel of *Is* or SMEs. Difficult to understand how generalizable analysis of a pre-existing product may be to a product under development.
Experiential Case Studies Jordan (1999)	Complimentary to Macdonald (1998), but users are the basis for the evaluation. Purpose is to understand why users associate particular product properties with product benefits and successes. General product properties—technical, functional, aesthetic. Passive semi-structured interview technique.	Direct insight into why users find particular products pleasurable. Relies on fewer assumptions vs. Macdonald (1998) since users, not experts, are performing the assessment.	Method relies on unprompted articulation of issues and product characteristics important to them. Like Gross, *P* may not be able to articulate exactly what he/she likes about the product. Method may lead to "lowest common denominator" in the design. Nothing new might be gained vs. Macdonald's approach, and recruiting *Ps* can be difficult and costly.

REFERENCES FOR APPENDIX A

Bandini-Buti, L., Bonapace, L. and Tarzia, A. (1997). Sensorial quality assessment: A method to incorporate perceived user sensations in product design. Applications in the field of automobiles. In *Proceeding of IEA '97* (pp. 186–189). Helsinki: Finnish Institute of Occupational Health.

Banyard, P. and Hayes, N. (1994). *Psychology: Theory and application*. London: Chapman and Hall.

Bonapace, L. (1999). The ergonomics of pleasure. In W.S. Green and P.W. Jordan (Eds.), *Human factors in product design: Current practice and future trends* (pp. 234–248). London: Taylor & Francis.

Briggs-Myers, I. and Myers, P. (1980). *Gifts differing*. California: Consulting Psychologists Press.

Brooke, J. (1996). SUS — A quick and dirty usability scale. In P.W. Jordan, B. Thomas, B.A. Weerdmeester, and I.L. McClelland (Eds.), *Usability evaluation in industry* (pp. 189-194). London: Taylor & Francis.

Carroll, J. (Ed.) (1991). *Designing interaction: The psychology at the human computer interface*. Cambridge: Cambridge University Press.

Chase, W.G. and Simon, H.A. (1973). Perception in chess. *Cognitive Psychology*, *4*, 55–81.

Chi, M.T.H., Feltovich, P.J., and Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, *5*, 121–152.

de Vries, G., Hartevelt, M. and Oosterholt, R. (1996). Private camera conversation method. In P.W. Jordan, B. Thomas, B.A. Weerdmeester, and I.L. McClelland (Eds.), *Usability evaluation in industry*. London: Taylor & Francis.

Edgerton, E.A. (1996). Feature checklists: A cost effective method for "in the field" usability evaluation. In P.W. Jordan, B. Thomas, B.A. Weerdmeester, and I.L. McClelland (Eds.), *Usability evaluation in industry*. London: Taylor & Francis.

Hart, S.G. and Staveland, L.E. (1988). Development of the NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P.A. Hancock and N. Meshkati (Eds.), *Human mental workload* (pp. 139–183). North Holland: Elsevier Science Publishers B.V.

Hartevelt, M.A. and van Vianen, E.P.G. (1994). User interfaces for different cultures: A case study. In *Proceedings of the Human Factors and Ergonomics Society Conference* (pp. 370–373). Santa Monica, CA: Human Factors and Ergonomics Society (HFES).

Hine, T. (1995). *The total package*. Boston: Little, Brown and Company.

Ishihara, S., Ishihara, K., Tsuchiya, T., Nagamachi, M. and Matsubara, Y. (1997). Neural networks approach to Kansei analysis on canned coffee design. In *Proceedings IEA '97* (pp. 211–213). Helsinki: Finnish Institute of Occupational Health.

Johnson, G.I. (1996). The usability checklist approach revisited. In P.W. Jordan, B. Thomas, B.A. Weerdmeester, and I.L. McClelland (Eds.), *Usability evaluation in industry* (pp. 179–188). London: Taylor & Francis.

Jordan, P.W. (1999). Pleasure with products: Human factors for body, mind, and soul. In W.S. Green and P.W. Jordan (Eds.), *Human factors in product design: Current practice and future trends* (pp. 206–217). London: Taylor & Francis.

Jordan, P.W. and Servaes, M. (1995). Pleasure in product use: Beyond usability. In S. Robertson (Ed.), *Contemporary ergonomics*. London: Taylor & Francis.

Jordan, P.W. (1997). Products as personalities. In M.A. Hanson (Ed.), *Contemporary ergonomics*. London: Taylor & Francis.

Jordan, P.W. (2000). *Designing pleasurable products: The new human factors*. New York: Taylor and Francis.

Kemp, J.A.M. and van Gelderen, T. (1996). Co-discovery exploring: An informal method for iteratively designing consumer products. In P.W. Jordan, B. Thomas, B.A. Weerdmeester, and I.L. McClelland (Eds.), *Usability evaluation in industry* (pp. 139–146). London: Taylor & Francis.

Kerr, K.C. and Jordan, P.W. (1994). Evaluating functional grouping in a multi-functional telephone using think-aloud protocols. In S.A. Robertson (Ed.), *Contemporary Ergonomics 1994*. London: Taylor & Francis.

Kirakowski, J. (1996). The software usability measurement inventory: Background and usage. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, and I. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 169-177). London: Taylor & Francis.

Kirakowski, J. and Corbett, M. (1988). Measuring user satisfaction. In D.M. Jones and R. Winder (Eds.), *People and computer IV* (pp. 329–338). Cambridge: Cambridge University Press.

Kirkham, P. (1996). *The gendered object*. Manchester: Manchester University Press.

Macdonald, A.S. (1998). Developing a qualitative sense. In N. Stanton (Ed.), *Human factors in product design and evaluation*. London: Taylor & Francis.

Morgan D.L. (1993). *Successful focus groups*. London: Sage Publications.

Nagamachi, M. (1995). *The story of Kansei engineering*. Tokyo: Kaibundo Publishing.

Nagamachi, M. (1997). Requirement identification of consumers' needs in product design. In *Proceedings of IEA '97* (pp. 231–233). Helsinki: Finnish Institute of Occupational Health.

Nardi, B. (1996). *Context and consciousness*. Cambridge, MA: MIT Press.

Nielsen, J. (1993). *Usability engineering*. Cambridge, MA: Academic Press.

Norman, D.A. (1992). *Turn signals are the facial expressions of automobiles*. Reading, MA: Addison-Wesley.

Norman, D.A. (1993). *Things that make us smart: Defending human attributes in the age of the machine*. New York: Addison-Wesley.

O'Donnell, P.J., Scobie, G. and Baxter, I. (1991). The user of focus groups as an evaluation technique in HCI. In D. Diaper and N. Hammond (Eds.), *People and computers VI* (pp. 211–224). Cambridge: Cambridge University Press.

Ravden, S.J. and Johnson G.I. (1989). *Evaluating usability of human-computer interfaces: A practical method*. Chichester: Ellis Horwood Limited.

Reynolds, T.J. (1998). Laddering theory, method, analysis, and evaluation. *Journal of Advertising Research, 28* (1), 11–31.

Schooler, J.W., Ohlsson, S., and Brooks, K. (1993). Thoughts beyond words: When language overshadows insight. *Journal of Experimental Psychology: General*, *122* (2), 166–183.

Virzi, R.A. (1992). Refining the test phase of usability evaluation: How many subjects is enough? *Human Factors, 34,* 457–468.

Wilson, C.E. (2001). *Usability, user interface design, and HCI bibliography*. Retrieved January 14, 2003, from the Human Factors International Web site: http://www.humanfactors.com/downloads/bibliography.asp.

Zimmerman D., and Wieder D. (1977) The diary: diary-interview method. *Urban Life 5* (4), 479–498.

APPENDIX B
BIBLIOGRAPHY OF REFERENCES IN DATABASE

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BIBLIOGRAPHY OF REFERENCES IN DATABASE

Alberts, D.S., Garstka, J.J., and Stein, F.P. (1999). *Network centric warfare: Developing and leveraging information superiority*. Washington, DC: C4ISR Cooperative Research Program, Office of the Assistant Secretary of Defense (C3I).

Al-Moky, T. (1997). *Determining effectiveness of visual disability guidelines presented on a multimedia workbench*. Retrieved April 14, 2003, from the Virginia Tech Human Computer Interaction Laboratory Web site: http://hci.ise.vt.edu/research/%20HCI_SN4.html.

Angel, H., Brooks, J., Greenley, M., and Kumagi, J. (1999). *Human factors integration requirements for Armoured Fighting Vehicles (AFVs)*. (DCIEM No. CR-2000-075). Ontario, Canada: Defence and Civil Institute of Environmental Medicine.

Anzai, Y., Ogawa, K., and Mori, H. (1995). Vol. 20B: Symbiosis of human and artifact: Human and social aspects of human-computer interaction. In G. Salvendy (Ed.), *Advances in Human Factors/Ergonomics* series. New York, NY: Elsevier Science Publishing Company, Inc.

Auer, Jr., E.T., Bernstein, L.E., and Coulter, D.C. (1998). Temporal and spatio-temporal vibrotactile displays for voice fundamental frequency: An initial evaluation of a new vibrotactile speech perception aid with normal-hearing and hearing-impaired individuals. *Journal of the Acoustical Society of America*, *104 (4),* 2477–2489.

Avery, L.W., Badalamente, R.V., Bowser, S.E., O'Mara, P.A., and Reynolds, S.E. (1990). *Human factors design guidelines for the Army Tactical Command and Control System (ATCCS) soldier-machine interface, Version 1.0*. Fort Lewis, WA: Pacific Northwest Laboratory (PNL) for the U.S. Army Tactical Command and Control System (ATCCS) Experimentation Site (AES).

Avery, L.W., and Bowser, S.E. (1992). *Human factors design guidelines for the Army Tactical Command and Control System (ATCCS) Soldier-Machine Interface*. (AES-R-002). Fort Lewis, WA: Army Tactical Command and Control System.

Avery, L.W., Sanquist, T.F., O'Mara, P.A., Shepard, A.P., and Donohoo, D.T. (1999). *U.S. Army weapon systems human-computer interface style guide*. Richland, WA: The Pacific Northwest National Laboratory.

Bach-y-Rita, P., Kaczmarek, K.A., Tyler, M.E., and Garcia-Lara, J. (1998). Form perception with a 49-point electrotactile stimulus array on the tongue: A technical note. *Journal of Rehabilitation Research and Development, 35 (4),* 427–430.

Baker, C.C. (1988). *Text-editing performance as a function of screen size: A pilot study*. (612716.H7000700011). U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland.

Barfield, W., and Furness, III, T.A. (Eds.) (1995). *Virtual environments and advanced interface design*. New York, NY: Oxford University Press, Inc.

Barrett, E. (Ed.) (1992). *Sociomedia: Multimedia, hypermedia, and the social construction of knowledge*. Cambridge, MA: The MIT Press.

Baumann, M.R., Sniezek, J.A., and Buerkle, C.A. (2001). Self-evaluation, stress, and performance: A model of decision making under acute stress. In E. Salas and G.A. Klein (Eds.), *Linking expertise and naturalistic decision-making*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Baumgardner, N. (2002). C4ISR On-the-move demonstrations to feature wide-array of technologies. *DDN C4ISR News*. Retrieved December 30, 2002 from the Defense Daily Network Web site: http://www.defensedaily.com.

Bennett, C.T., O'Donnell, K.A., and Johnson, W.W. (1988). Dynamic perspective displays and the control of tilt-rotor aircraft in simulated flight. In *Proceedings of the American Helicopter Society*. Washington, DC.

Biberman, L.M., and Tsou, B. (1991). *Image display technology and problems, with emphasis on airborne systems*. Technical Report No. AD-B1157 161. Defense Technical Information Center, Alexandria, VA.

Biggs, S.J., and Srinivasan, M.A. (2001). Haptic interfaces. In K.M. Stanney (Ed.), *Handbook of virtual environment technology*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Biggs, S.J., and Srinivasan, M.A. (2002). Tangential versus normal displacements of skin: Relative effectiveness for producing tactile sensations. In *Proceedings of 10th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, Orlando, FL.

Blackwood, W.O., Anderson, T.R., Bennett, C.T., Corson, J.R., Endsley, M.R., Hancock, P.A., Hochberg, J., Hoffman, J.E., and Kruk, R.V. (1997). *Tactical displays for soldiers: Human factors considerations*. Washington, DC: National Academy Press.

Blattner, M.M., and Dannenberg, R.B. (Eds.) (1992). *Multimedia interface design*. New York: ACM Press.

Boff, K.R., and Lincoln, J.E. (Eds.) (1988). *Engineering data compendium*. Wright-Patterson Air Force Base, OH: Armstrong Medical Research Laboratory.

Boose, J.H., and Gaines, B.R. (Eds.) (1990). *The foundations of knowledge acquisition: Knowledge-based systems* (Volume 4). Academic Press: San Diego, CA.

Bowen, C.D. (1998, October). *Theater Battle Management (TBM) Human Computer Interface (HCI) specification, Version 1.1*. Retrieved April 14, 2003, from the MITRE Web site: http://www.mitre.org/pubs/tbm/TBMHCI.html.

Bowers, P. (2002). The TRW Tactical Systems Division builds the next generation of tactical Army operations systems. *Crosstalk, 15*, 14–15.

Boyd, M. (n.d.). *FCS CTD WMI Architecture*. [Briefing]. Arlington, VA: Defense Advanced Research Projects Agency.

Brewster, S. (2001). The impact of haptic 'touching' technology on cultural applications. Proceedings of *EVA 2001,* Scotland.

Brewster, S.A. (1999, January). *Welcome to the earcons and multimodal interaction group home page!* Retrieved April 14, 2003, from the Glasgow Multimodal Interaction Group Home Page: http://www.dcs.gla.ac.uk/~stephen.

Brewster, S.A. (2002). Chapter 12: Non-speech auditory output. In J. Jacko and A. Sears (Eds.), *The human computer interaction handbook*. Lawrence Erlbaum Associates, Inc.

Brewster, S.A. (2002). Visualization tools for blind people using multiple modalities. *Disability and Rehabilitation Technology, 24 (11–12),* 613–621.

Brewster, S.A., Lumsden, J., Bell, M., Hall, M. and Tasker, S. (2003). Multimodal 'Eyes-Free' interaction techniques for wearable devices. To appear in *Proceedings of ACM CHI 2003*, Fort Lauderdale, FL: ACM Press.

Brewster, S., and Murray-Smith, R. (Eds.) (2000). Haptic human-computer interaction. In *Proceedings of the First International Workshop*, Glasgow.

Brickner, M.S. (1989). *Helicopter flights with night vision goggles: Human factors aspects*. NASA Technical Memorandum 101039.

Brignull, H.A. (2000). *An evaluation on the effect of screen size on users' execution of web-based information retrieval tasks*. Unpublished doctoral dissertation: The University of Sussex, Falmer, Brighton, UK

Bullinger, H.-J. (1991). Vol. 18A: Human aspects in computing: Design and use of interactive systems and work with terminals. In Salvendy, G. (Ed.), *Advances in human factors/ergonomics* series. New York, NY: Elsevier Science Publishing Company, Inc.

Burke, M. (1992). *Applied ergonomics handbook*. Chelsea, MI: Lewis Publishers, Inc.

Burns, C.M. (2000). Putting it all together: Improving integration in ecological displays. *Human Factors, 42*, 226–241.

Burns, C.M., Vicente, K.J., Christoffersen, K. and Pawlak, W.S. (1998). Towards viable, useful, and usable human factors design guidance. *Applied Ergonomics, 33*, 311–322.

Campbell, C.H., Deatz, R.C., and Quinkert, K.A. (2000). Performance analysis and training for digital command staff: Training for the battle command reengineering III. In *Proceedings of the Command and Control Research and Technology Symposium*, Monterey, CA.

Carroll, J.M., and McKendree, J. (1987). Interface design issues for advice-giving expert systems. *Communications of the ACM, 30 (1),* 14–31.

Chairman, Joint Chiefs of Staff (2000). *Joint Vision 2020*. Washington, DC: U.S. Government Printing Office.

Chang, A., O'Modhrain, S., Jacob, R., Gunther, E., and Ishii, H. (2002). ComTouch: Design of a vibrotactile communication device. In *Proceedings of Designing Interactive Systems Conference: Processes, Practices, Methods, and Techniques*, London, England: ACM Press.

Chao, B.P. (1986). *Design guidelines for human-computer dialogues*. (SAND86-0259). Sandia National Laboratories, Albuquerque, New Mexico.

Chin, J.P., Diehl, V.A., and Norman, K.L. (1988). Development of an instrument measuring user satisfaction of the human-computer interface. In *Proceedings of SIGCHI´88 Conference: Human Factors in Computing Systems*, New York: Association for Computing Machinery.

Chipman, S., and Meyrowitz, A.L. (1993). *Foundations of knowledge acquisition: Cognitive models of complex learning*. Boston, MA: Kluwer Academic Publishers.

Collins, J.M. (1998). *Military geography for professionals and the public*. Washington, DC: National Defense University Press.

Concept Evaluation of Build 1: WMI Overview. (n.d.). Future Combat Systems Program Office.

Cooper, A. (1995). *About face: The essentials of user interface design*. Foster City, CA: IDG Books Worldwide, Inc.

Cowen, M. (1991). *A comparison of four types of feedback during computer-based training (CBT)*. (NPRDC-TR-92-2). Navy Personnel Research and Development Center, San Diego, California.

Crepps, D., Foran, M., Engelbert, N., and Kim, Y. (1999, Spring). *Haptics-e: The electronic journal of haptics research*. Retrieved April 16, 2003, from Haptics-e Web site: http://www.haptics-e.org.

Crew Integration and Automation Testbed (CAT), Soldier-Machine Interface (SMI), Integrated Product Team (IPT) Members (n.d.). Detroit, MI: U.S. Army Tank-Automotive & Armaments Command (TACOM), RD&E Center (TARDEC), Vetronics Technology Area.

Crew-integration and Automation Testbed (CAT) advanced technology demonstrator (2002). [Briefing] Retrieved December 30, 2002, from the Tank-automotive and Armament Command Research, Development, and Engineering Center (TACOM-TARDEC) Web site: http://www.tacom.army.mil/tardec/vetronics/catatd.htm.

Crowley, J.S. (1991). *Human factors of night vision devices: Anecdotes from the field concerning visual illusions and other effects*. (Report No. 91-15). Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Cutler, J.R. (2002, April). *Vibrotactile.org: A division of the GW HIVE Lab*. Retrieved April 14, 2003 from the Vibrotactile.org Web site: http://www.vibrotactile.org.

Darnell, M.J. (2002). *Bad human factors designs: A scrapbook of illustrated examples of things that are hard to use because they do not follow human factors principles*. Retrieved April 14, 2003 from Michael J. Darnell's Web site: http://www.baddesigns.com/index.shtml.

Deatherage, B.H. (1972). Auditory and other sensory forms of information presentation. In H.P. van Cott and R.G. Kinkade (Eds.), *Human engineering guide to equipment design*. Washington, DC: Government Printing Office.

Deatz, R.C., Greene, K.A., Holden, W.T., Jr., Throne, M.H., and Lickteig, C.W. (2000). *Refinement of prototype staff training methods for future forces*. (ARI Research Report 1763). Alexandria, VA: U.S. Army Research Institute for the Social and Behavioral Sciences.

Decker, J.J., Dye, C.J., Lloyd, C.J.C., and Snyder, H.L. (1991). *The effects of display failures and symbol rotation on visual search and recognition performance*. (Technical Memorandum 4-91). U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland.

Decker, J.J., Kelly, P.L., Kurokawa, K, and Snyder, H.L. (1991). *The effect of character size, modulation, polarity, and font on reading and search performance in matrix-addressable displays*. (Technical Memorandum 6-91). U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland.

Defense Advanced Research Project Agency (DARPA) (2002). *DARPA fact file: A compendium of DARPA programs*. Retrieved January 29, 2003, from the DARPA Web site: http://www.darpa.mil/body/NewsItems/pdf/DARPAfactfile.pdf.

Defense Information Systems Agency (1996). Human-computer interfaces (Section 5). In *Department of Defense Joint Technical Architecture*. Retrieved April 14, 2003, from the DoD Joint Technical Architecture Web site: http://www-jta.itsi.disa.mil/jta/jta-v1.0/sect5.html.

Defense Information Systems Agency, Center for Standards (1996). DoD Human Computer Interface Style Guide (Volume 8). In *Department of Defense Technical Architecture Framework for Information Management*. Retrieved April 14, 2003, from DISA Web site: http://www-library.itsi.disa.mil/tafim/tafim3.0/pages/volume8/frontmtr.htm.

Department of Defense (1984). *Department of Defense design criteria standard: Human factors engineering design criteria for helicopter cockpit electro-optical display symbology* (MIL-STD-1295AV). Washington, DC: Author.

Department of Defense (1989). *Human engineering guidelines for management information systems* (MIL-HDBK-761A). Washington, DC: Author.

Department of Defense (1991). *Department of Defense design criteria standard: Task performance analysis* (MIL-STD-1478). Washington, DC: Author.

Department of Defense (1991). *Noise measurement report* (DI-HFAC-80938A). Washington, DC: Author.

Department of Defense (1994). *Critical task analysis report* (DI-HFAC-81399). Washington, DC: Author.

Department of Defense (1994). *Human engineering design approach document – Operator* (DI-HFAC-80746A). Washington, DC: Author.

Department of Defense (1994). *Software development and documentation* (MIL-STD-498). Washington, DC.

Department of Defense (1995). *Department of Defense handbook: Human engineering design guidelines* (MIL-HDBK-759C). Washington, DC: Author.

Department of Defense (1997). *Department of Defense design criteria standard: Aircrew alerting systems* (MIL-STD-411F). Washington, DC: Author.

Department of Defense (1997). *Department of Defense design criteria standard: Noise limits* (MIL-STD-1474D). Washington, DC: Author.

Department of Defense (1997). *Department of Defense handbook: Human engineering design guidelines* (MIL-HDBK-759C). Washington, DC: Author.

Department of Defense (1998). *Department of Defense design criteria standard: Human engineering* (MIL-STD-1472F). Washington, DC: Author.

Department of Defense (1998). *Department of Defense handbook: Human engineering design guidelines* (MIL-HDBK-759C). Washington, DC: Author.

Department of Defense (1998). *Human engineering design approach document - Maintainer* (DI-HFAC-80747B). Washington, DC: Author.

Department of Defense (1998). *Human engineering simulation concept* (DI-HFAC-80742B). Washington, DC: Author.

Department of Defense (1999). *Department of Defense handbook: Definitions of human factors terms* (MIL-HDBK-1908B). Washington, DC: Author.

Department of Defense (1999). *Department of Defense handbook: Human engineering program process and procedures* (MIL-HDBK-46855A). Washington, DC: Author.

Department of Defense (1999). *Department of Defense interface standard: Common warfighting symbology* (MIL-STD-2525B). Washington, DC: Author.

Department of Defense (2000). *Human engineering design data digest*. Washington, DC: Department of Defense Human Factors Engineering Technical Advisory Group.

Department of Defense (2001). *Department of Defense interface standard: Aircraft display symbology* (MIL-STD-1787C). Washington, DC: Author.

Department of the Army (1997). *Operational terms and graphics* (FM 101-5-1/MCRP 5-2A). Washington, DC: Author.

Dickey, B., and Rogers, A. (1999). Now for the tactor vest. *Flight Safety Australia*, November-December 1999.

Dierksmeier, F.E., Johnston, J.C., Winsch, B.J., Leibrecht, B.C., Sawyer, A.R., and Quinkert, K.A. (1999). *Structured simulation-based training program for a digitized force: Approach, design, and functional requirements, Volume 1* (ARI Research Report 1737). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Doerrer, C., and Werthschützky, R. (2002). Simulating push-buttons using a haptic display: Requirements on force resolution and force-displacement curve. In *Proceedings of Eurohaptics 2002*, University of Edinburgh, UK

Dominessy, M.E. (1989). *A literature review and assessment of touch interactive devices* (Technical Memorandum 11-89). U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland.

Dondis, D.A. (1973). *A primer of visual literacy*. Cambridge, MA: Massachusetts Institute of Technology.

Dumas, J.S. (1988). *Designing user interfaces for software*. Englewood Cliffs, NJ: Prentice Hall.

Dye, C., and Snyder, H.L. (1991). *The effects of display failures, polarity, and clutter on visual search for symbols on cartographic images* (Technical Memorandum 9-91). U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland.

Edinburgh College of Art (2001). *Welcome on the Tacitus web site*. Retrieved April 14, 2003, from the Tacitus Web site: http://www.eca.ac.uk/tacitus.

Eleventh symposium on haptic interfaces for virtual environment and teleoperator systems. (2003) [Call for papers]. Retrieved April 14, 2003, from the Haptics Symposium Web site: http://www.hapticssymposium.org.

Ellis, S.R. (2000). On the design of perspective displays. In *Proceedings of the 44th Annual Meeting of the Human Factors and Ergonomics Society*, San Diego, CA.

Engineering Acoustics, Inc. (n.d.). *Tactor evaluation system*. Retrieved April 14, 2003, from the Engineering Acoustics, Inc. Web site: http://www.eaiinfo.com/page5.html.

Evans, M. (2001). Fabrizio's choice: Organizational change and the revolution in military affairs debate. *National Security Studies Quarterly, 12 (1),* 1–25.

Flach, J.M., and Dominguez, C.O. (1995). Use-centered design: Integrating the user, instrument, and goal. *Ergonomics in Design, 3 (3),* 19–24.

Foundations in sound and non-speech auditory interfaces. (n.d.). Retrieved April 14, 2003, from the Interaction Design Institute Ivrea Web site: http://people.interaction-ivrea.it/d.pakhare/docsound.htm.

Foyle, D.C., and Kaiser, M.K. (1991). Pilot distance estimation with unaided vision, night-vision goggles and infrared imagery. In *Digest of Technical Papers, SID International Symposium XXII*. Anaheim, CA.

Francis, G. (2000). Designing multifunction displays: An optimization approach. *International Journal of Cognitive Ergonomics, 4 (2),* 107–124.

Funk, H.B., and Miller, C.A. (1997). “Context sensitive” interface design. In *Proceedings of the International and Interdisciplinary Conference on Modeling and Using Context (CONTEXT-97)*, Rio de Janeiro, Brazil: Federal University of Rio de Janeiro.

Galitz, W.O. (1993). *User-interface screen design*. New York, NY: John Wiley and Sons.

Galitz, W.O. (1997). *The essential guide to user interface design: An introduction to GUI design principles and techniques*. New York, NY: John Wiley and Sons.

Geldard, F.A. (1960). Some neglected possibilities of communication. *Science, 131 (3413),* 1583–1588.

Gemperle, F., Ota, N., and Siewiorek, D. (2001). Design of a wearable tactile display. In *Proceedings of Fifth International Symposium on Wearable Computers (ISWC’01),* Zurich, Switzerland.

Gill, K.S. (1996). *Human machine symbiosis: The foundations of human-centered systems design*. London, UK: Springer.

Gorman, P. (1980). *A command post is not a place*. Retrieved April 14, 2003, from the Institute for Defense Analysis, Command Post of the Future Web site: http://www.ida.org/DIVISIONS/sctr/cpof/CPnotPlace.pdf.

Goudeseune, C., and Kaczmarski, H. (2001). Composing outdoor augmented-reality sound environments. In *Proceedings of 2001 International Computer Music Conference,* Havana.

Gourley, S. (September 25, 2002). *U.S. Army expands battlefield digitization*. Retrieved April 16, 2003, from the Jane’s Defence Weekly Web site: http://www.janes.com.

Greene, R. (2001). Tactical situational awareness system (Newsletter 0827). Pensacola, FL: Naval Aerospace Medical Research Laboratory.

Haas, E., and Edworthy, J. (Eds.) (2003). *The ergonomics of sound: Selections from the Human Factors and Ergonomics Society annual meetings, 1985–2000*. Santa Monica, CA: Human Factors and Ergonomics Society.

Haptic Interface Research Laboratory. (n.d.). Retrieved April 14, 2003, from the Purdue University HIRL Web site: http://www.ecn.purdue.edu/HIRL/index.html.

Haptics Community Web Page (2003, March). Retrieved April 14, 2003, from the Northwestern University, Laboratory for Intelligent Mechanical Systems Web site: http://haptic.mech.nwu.edu.

Hart, S.G., and Brickner, M.S. (1987). Helmet-mounted pilot night vision systems: Human factors issues. In S.R. Ellis, M.K. Kaiser, and A. Grundwald (Eds.), *Spatial displays and spatial instruments* (NASA Conference Publication No. 10032). Moffett Field, CA: NASA Ames Research Center.

Headquarters, Department of the Army (1995, July). *Operator’s manual (Volumes 1 and 2) for tank, combat, full-tracked: 120-mm gun, M1A2, General Abrams*. (Technical Manual TM 9-2350-288-10-1/2). Washington, DC: Author.

Headquarters, Department of the Army (1996, April). *Tank platoon* (Field Manual FM 17-15). Washington, DC: Author.

Healy, A.F., and Proctor, R.W. (Eds.) (2003). *Experimental psychology* (Volume 4). In I.B. Weiner (Ed.), *Handbook of psychology*. New York: John Wiley and Sons.

Hedge, A. (2002). *Cornell university ergonomics web*. Retrieved April 14, 2003, from CU Ergo Web site: http://ergo.human.cornell.edu.

Helander, M. (Ed.) (1988). *Handbook of human-computer interaction*. New York, NY: Elsevier Science Publishing Company, Inc.

Hernandez-Rebollar, H.L., Kyriakopoulos, N., and Lindeman, R.L. (2002). The AcceleGlove: A whole-hand input device for virtual reality (technical sketch). In *Conference Abstracts and Applications of SIGGRAPH 2002* (p. 259). New York: Association of Computing Machinery.

Howard, E., and Less, M.C. (2002). *WMI procurement specification kick-off meeting*. [Briefing]. Arlington, VA: Defense Advanced Research Projects Agency.

Hromadka, T.V. (2001). Lessons learned in developing human-computer interfaces for infantry wearable computer systems. In *Usability evaluation and interface design: cognitive engineering, intelligent agents, and virtual reality, Volume 1*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Human Factors of Command Systems (HFCS) (n.d.). *Human factors of command systems (HFCS) website*. Retrieved October 24, 2002, from the Defence Research and Development Canada Web site:
http://www.dciem.dnd.ca/DCIEM/research/hfc_e.html.

Human Factors: Research and Technology (2002, May). Retrieved April 14, 2003, from the Human Factors Research and Technology Division Web site:
http://olias.arc.nasa.gov.

Information Exploitation Office, DARPA (n.d.). *Command Post of the Future (CPOF)*. Retrieved December 31, 2002, from the DARPA Web site:
http://dtsn.darpa.mil/ixo/cpof.asp.

Interface Design and Evaluation (2003, March). Retrieved April 14, 2003, from the Navy Center for Applied Research in Artificial Intelligence Web site:
http://elazar.itd.nrl.navy.mil.

In-Vehicle Information System (IVIS) Project (1997, March). Retrieved April 14, 2003, from the Oak Ridge National Laboratory, IVIS Web site:
http://avalon.epm.ornl.gov/IS/human_factors/ivs.html.

Isys Information Architects, Inc. (1999). *Interface hall of shame, and interface hall of fame*. Retrieved October 16, 2002, from the Isys Web site:
http://www.iarchitect.com/index.htm.

Jarboe, J., Ritter, P., Hale, T., Lewis, J. and Poikonen (2002). *Battle Lab Experiment Final Report (BLEFR) for Future Combat Command and Control (FCC2), Concept Experimentation Program* (CEP #01-1701). Fort Knox, KY: Mounted Warfare Test-bed, Mounted Maneuver Battle Laboratory.

Jarvenpaa, S.L., and Dickson, G.W. (1988). Graphics and managerial decision making: Research based guidelines. *Communications of the ACM, 31 (6),* 764–775.

John, B.E., and Kieras, D.E. (1996). The GOMS family of user interface analysis techniques: comparison and contrast. *ACM Transactions on Computer-Human Interaction (TOCHI), 3,* 320–351. Retrieved April 14, 2003, from Portal, the ACM Digital Library Web site: http://delivery.acm.org/10.1145/240000/236054/p320-john.pdf?key1=236054&key2=5717140501&coll=portal&dl=ACM&CFID=5106077&CFTOKEN=41719906.

John, B.E., and Kieras, D.E. (1996). Using GOMS for user interface design and evaluation: Which technique? *ACM Transactions on Computer-Human Interaction (TOCHI), 3,* 287-319. Retrieved April 14, 2003 from Portal, the ACM Digital Library Web site: http://delivery.acm.org/10.1145/240000/236050/p287-john.pdf?key1=236050&key2=4696140501&coll=portal&dl=ACM&CFID=5106077&CFTOKEN=41719906.

Joint Robotics Program (2001). *Joint Robotics Program Master Plan 2001*. Washington, DC: Author.

Kampis, G. (1991). *Self-modifying systems in biology and cognitive science: A new framework for dynamics, information, and complexity*. Elmsford, NY: Pergamon Press, Inc.

Kelley, J.F. (1984). An iterative design methodology for user-friendly natural language office information applications. *ACM Transactions on Office Information Systems, 1 (2)*, 26–41.

Kelly, K. (1998). *New rules for the new economy: Ten radical strategies for a connected world*. New York: Viking Press.

Klatzky, R.L., and Lederman, S.J. (2002). Touch. In A.F. Healy and R.W. Proctor (Eds.), *Experimental psychology* (pp. 147–176).

Kosslyn, S.M. (1994). *Elements of graph design*. New York, NY: W.H. Freeman and Company.

Krausman, A.S., Crowell III, H.P., and Wilson, R.M. (2002). *The effects of physical exertion on cognitive performance*. (ARL-TR-2844). Aberdeen Proving Ground, Maryland: U.S. Army Research Laboratory.

Kroemer, K.H.E., Kroemer, H.B., and Kroemer-Elbert, K.E. (1994). *Ergonomics: How to design for ease and efficiency*. Englewood Cliffs, NJ: Prentice Hall.

Laurel, B. (Ed.) (1990). *The art of human-computer interface design.* New York, NY: Addison-Wesley Publishing Company, Inc.

Lewis, H.V., and Fallesen, J.J. (1989). *Human factors guidelines for command and control systems: Battlefield and decision graphics guidelines.* (Research Project 89-01). U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA.

Lickteig, C.W. (1986). *User interface requirements for Battlefield Management Systems (BMS).* (Research Product 86-25). U.S. Army Research Institute for the Behavioral and Social Sciences, Fort Knox, KY.

Lickteig, C.W. (1989). *Design guidelines and functional specifications for simulation of the Battlefield Management System's (BMS) user interface.* U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA.

Lickteig, C.W., and Throne, M.H. (1999). *Applying digital technologies to training: A focus on pictorial communication* (Technical Report 1097). Alexandria, VA: U.S. Army Research Institute for the Social and Behavioral Sciences.

Lindeman, R.W., and Yanagida, Y. (2003) Empirical studies for effective near-field haptics in virtual environments. In Proceedings of *IEEE Virtual Reality 2003.*

Main, R.E., and Paulson, D. (1988). *Guidelines for the development of military training decision aids* (NPRDC TR 88-16). Navy Personnel Research and Development Center, San Diego, CA.

Mandel, T. (1997). *The elements of user interface design.* New York, NY: John Wiley and Sons.

Man-Systems Integration Standards (2003, March). *Man-systems integration standards.* Retrieved April 14, 2003, from the MSIS Web site: http://msis.jsc.nasa.gov.

Martin, T.L. (2002). Time and time again: Parallels in the development of the watch and the wearable computer. In *Proceedings of 6th International Symposium on Wearable Computers (ISWC'02),* Seattle, WA.

McCabe, P.T., Hanson, M.A., and Robertson, S.A. (2000). *Contemporary ergonomics 2000.* New York, NY: Taylor and Francis, Inc.

McCann, P.H. (1983). *Methods for improving the user-computer interface* (Report No. NPRDC TR 83-29). San Diego, CA: Navy Personnel Research and Development Center, San Diego.

Meister, D. (1991). Vol. 17: Psychology of system design. In G. Salvendy (Ed.), *Advances in human factors/ergonomics.* New York, NY: Elsevier Science Publishing Company, Inc.

Mejdal, S., McCauley, M.E., and Beringer, D.B. (2001). *Human factors design guidelines for multifunction displays* (DOT/FAA/AM-01/17). Oklahoma City: FAA Civil Aerospace Medical Institute.

Meyrowitz, A.L., and Chipman, S. (Eds.) (1993). *Foundations of knowledge acquisition: Machine learning*. Norwell, Massachusetts: Kluwer Academic Publishers.

Miller, C.A., and Funk, H.B. (2001, March). Associates with etiquette: Meta-communication to make human-automation interaction more natural, productive and polite. In *Proceedings of the 8th European Conference on Cognitive Science Approaches to Process Control*. Munich, Germany: European Association of Cognitive Ergonomics.

Miller, C.A., and Hannen, M.D. (1999, January). User acceptance of an intelligent user interface: A rotorcraft pilot's associate example. In *Proceedings of 1999 International Conference on Intelligent User Interfaces* (pp. 109–116). Redondo Beach, CA: Association of Computing Machinery.

MIT Touch Lab (2002, May). Retrieved April 14, 2003, from the Laboratory for Human and Machine Haptics, Touch Lab Web site: http://touchlab.mit.edu.

Mitchell, D.K., and Kysor, K.P. (1992). *A preliminary evaluation of the prototype tactical computerized interactive display* (Technical Memorandum 2-92). U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland.

Moran, T.P., Card, S.K., and Newell, A. (1983). *The psychology of human-computer interaction*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Mounted Maneuver Battle Laboratory (2002). *UA Concept Experimentation Program (CEP), Battle Lab Experimentation Final Report* (BLEFR). Fort Knox, KY: Author.

Multisensory displays. (2001, April). British Telecommunications plc. Web site: http://more.btexact.com/projects/multisensory.

Murray, S.A. (1995, June). Human-machine interaction with multiple autonomous sensors. In *Proceedings of 6th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design and Evaluation of Man-Machine Systems*. Cambridge, MA. Retrieved April 14, 2003, from the SPAWAR Web site: http://www.spawar.navy.mil/robots/research/hmi/ifac.html.

Myers, B., Malkin, R., Bett, M., Waibel, A., Bostwick, B., Miller, R.C., Yang, J., Denecke, M., Seemann, E., Zhu, J., Peck, C.H., Kong, D., Nichols, J., and Scherlis, B. (2002). Flexi-modal and multi-machine user interfaces. In *Proceedings of Fourth International Conference on Multimodal Interfaces*. Pittsburgh, PA: IEEE.

Mynatt, E.D., Back, M., Want, R. and Frederick, R. (1997, October). Audio aura: Lightweight audio augmented reality. In *Proceedings of UIST '97 User Interface Software and Technology Symposium*. Banff, Canada. Retrieved April 14, 2003, from the Maribeth Back's Web site: http://xenia.media.mit.edu/~mbb/audio-auramb.html.

Nielsen, J. (1995). *Usability engineering*. New York: Academic Press.

Nielsen, J. (2003). *Voice interfaces: Assessing the potential*. Retrieved April 14, 2003, from the Useit.com Alert Box Web site: http://www.useit.com/alertbox/20030127.html.

Norman, D.A. (1993). *Things that make us smart: Defending human attributes in the age of the machine*. New York, NY: Addison-Wesley Publishing Company, Inc.

Norman, D.A., and Draper, S.W. (Eds.) (1986). *User-centered system design: New perspectives on human-computer interaction*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Norman, K.L. (1991). *The psychology of menu selection: Designing cognitive control at the human/computer interface*. Norwood, NJ: Ablex Publishing Corporation.

North Atlantic Treaty Organization (1990). Military symbols for land-based systems (STANAG 2019). Brussels, Belgium: Author.

O'Donnell, K.A., Johnson, W.W., Bennett, C.T., and Phatak, A.V. (1988). The effect of perspective displays on altitude and stability control in simulated rotary wing flight. In *Proceedings of the AIAA Flight Simulation Technologies Conference*. Atlanta, GA.

Oakley, I., McGee, M.R., Brewster, S., and Gray, P. (2000). Putting the feel in 'look and feel'. In *Proceedings of ACM CHI 2000*. The Hague, Netherlands: ACM Press.

O'Brien, T.G., and Charlton, S.G. (Eds.) (1996). *Handbook of human factors testing and evaluation*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Orasanu, J., Martin, L., and Davison, J. (2001). Cognitive and contextual factors in aviation accidents: Decision errors. In E. Salas and G.A. Klein (Eds.), *Linking expertise and naturalistic decision-making*. Mahwah, NJ: Lawrence Earlbaum Associates, Inc..

Overmyer, S.P. (1990). The impact of DOD-STD-2167A on iterative design methodologies: Help or hinder? *ACM SIGSOFT Software Engineering Notes, 15(5),* 50–59. Retrieved April 14, 2003, from the Massey University Albany Web site: http://www.massey.ac.nz/~spovermy/papers/2167a/2167pap.htm.

Page, W. (n.d.). *Command post of the future*. [Briefing]. Washington, DC: Information Exploitation Office, DARPA.

Palpable Machines (n.d.). Retrieved April 14, 2003, from the Palpable Machines Web site: http://www.mle.ie/palpable.

Parrish, R.N., Gates, J.L., and Munger, S.J. (1981). *Design guidelines and criteria for user/operator transactions with Battlefield Automated Systems Volume IV: Provisional guidelines and criteria* (Technical Report 537). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Patterson, M. (2002). *Wireless Tactical Voice Activation System/Helmet-Mounted Display (TVAS/HMD) program*. [Briefing]. Sterling Heights, MI: General Dynamics Land Systems.

Perlman, G. (2003). *Bibliographic databases and annotated bibliographies on HCI*. Retrieved April 14, 2003, from hcibib.org Web site: http://www.hcibib.org/hci-sites/BIBLIOGRAPHY.html.

Perlman, G. (2003). *Design guidelines, principles, standards, rules, …* Retrieved April 14, 2003, from the hcibib.org Web site: http://www.hcibib.org/hci-sites/GUIDELINES.html.

Pew, R.W. (1988). Human factors issues in human systems. In M. Helander (Ed.), *Handbook of human-computer interaction*. North-Holland: Elsevier Science Publishers B.V.

Preece, J. (1994). *Human-computer interaction*. New York, NY: Addison-Wesley Publishing Company, Inc.

Princeton Plasma Physics Laboratory (n.d.). *Motif style guide*. Retrieved April 14, 2003, from the Santa Cruz Operaton (SCO) Web site: http://w3.pppl.gov/misc/motif/MotifStyleGuide/en_US/TOC.html.

Program Executive Office – Aviation, Aviation Electronic Systems (2001). *Preliminary Software Requirements Specification (SRS) for the Common Army Aviation Situational Awareness (SA) Soldier Machine Interface (SMI)* (Coordinating Draft). Redstone Arsenal, AL: Author.

Pulkki, V., and Lokki, T. (1998). Creating auditory displays to multiple loudspeakers using VBAP: A case study with DIVA project. In *Proceedings of International Conference on Auditory Display (ICAD),* Glasgow, Scotland.

Quinkert, K.A. (1988). *Design and functional specifications for the simulation of the Commander's Independent Thermal Viewer (CITV)* (Research Product 88-17). U.S. Army Research Institute for the Behavioral and Social Sciences, Fort Knox, KY.

Ray, D. (2000, November). *Final report: Battle Command Reengineering 4*. Fort Knox, KY: Mounted Maneuver Battle Laboratory.

Redden, E.S. (2002). *Virtual environment study of mission-based critical information requirements* (ARL-TR-2636). Aberdeen Proving Ground, Maryland: U.S. Army Research Laboratory.

Reliable, Accurate, and Wireless Body Monitoring Technologies. (2003). Retrieved April 14, 2003, from the BodyMedia, Inc. Web site: http://www.bodymedia.com/sec01_entry/01B_entry.jsp.

RIE: Righi Interface Engineering, Inc. (2003, January). Retrieved April 14, 2003, from the RIE Web site: http://www.righiinterface.com.

Roby, C.G. (Ed.) (1991). *Proceedings of the Second Portable Common Interface Set (PCIS) workshop: Interface Technology Analyses (ITA2)* (IDA Document D-1047). Alexandria, VA: Institute for Defense Analyses.

Roth, S.F., Chuah, M.C., Kerpedjiev, S., Kolojejchick, J.A., and Luca, P. (1997). Towards an information visualization workspace: Combining multiple means of expression. *Human-Computer Interaction Journal, 12 (1/2),* 131–185.

Roussot, J-M. (2002, March). *Design guidelines*. Retrieved April 14, 2003, from the European Air Traffic Control Authority Web site: http://www.eurocontrol.int/eatmp/hifa/hifa/HIFAdata_tools_designguidelines.html.

Rupert, A. (1997). Which way is down? *Naval Aviation News, 79(3),* 16-17.

Rush, C.E., Verona, R.W., and Crowley, J.S. (1990). *Human factors and safety considerations of night vision systems flight using thermal imaging systems* (Report No. 90-10). Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Salas, E., and Klein, G. (Eds.) (2001). *Linking expertise and naturalistic decision-making*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc..

Sawhney, N., and Schmandt, C. (n.d.). *Nomadic radio: Wearable audio computing*. Retrieved April 14, 2003, from the Speech Interface Group MIT Media Laboratory Web site: http://web.media.mit.edu/~nitin/NomadicRadio.

SC-21/ONR S&T Manning Affordability Initiative (2002, October). Retrieved April 14, 2003, from the SC-21/ONR S&T Manning Affordability Web site: http://www.manningaffordability.com/s&tweb/%20index_main.htm.

Scali, S., Shillito, A.M., and Wright, M. (2002). Thinking in space: Concept physical models and the call for new digital tools. Paper presented at *Crafts in the 20th Century*, Edinburgh, Scotland.

Scerbo, M.W., Freeman, F.G., Mikulka, P.J., Parasuraman, R., Di Nocero, F., and Prinzel, L.J. III (2001, June). *The efficacy of psychophysiological measures for implementing adaptive technology* (NASA/TP-2001-211018). Hampton, VA: National Aeronautics and Space Administration.

Schmorrow, D. (2002). *Welcome to the new Augmented Cognition website!* Retrieved April 14, 2003, from the Augmented Cognition Web site: http://www.augmentedcognition.org.

Schraagen, J.M., Chipman, S.F., and Shalin, V.L. (Eds.) (2000). *Cognitive task analysis*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Shah, P., and Carpenter, P.A. (1995). Conceptual limitations in comprehending line graphs. *Journal of Experimental Psychology: General, 124*, 43–61.

Shepard, A.P. (1991). *Report of results of ATCCS Contingency Force Experiment-Light (ACFE-L) Group B, Soldier-Machine Interface (SMI) Assessment* (AES-91-02). Fort Lewis, WA: Army Tactical Command and Control System.

Shilling, R. (2002, August). *Immersive technologies for data management and virtual environments*. Paper presented at the MOVES Institute Open House 2002. Retrieved April 14, 2003, from the MOVES Web site: www.movesinstitute.org/Openhouse2002/PresentationsOpenhouse2002/shilling_openhouse2002.ppt.

Shilling, R.D., and Shinn-Cunningham, B. (2000). Virtual auditory displays. In K Stanney (Ed.), *Handbook of virtual environment technology*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Shillito, A.M., Paynter, K., Wall, S., and Wright, M. (2001). Tacitus' project: Identifying multi-sensory perceptions in creative 3D practice for the development of a haptic computing system for applied artists. *Digital Creativity Journal, 12 (5),* 195–203.

Shinseki, E. (1999). *The Army vision: Soldiers on point for the nation: Persuasive in peace, invincible in war*. Address at the annual meeting of the Association of the United States Army, Washington, DC.

Shneiderman, B. (1998). *Designing the user interface: strategies for effective human-computer interaction* (3rd Edition). Reading, MA: Addison-Wesley Publishing Company.

Sidorsky, R.C. (1984). *Design guidelines for user transactions with battlefield automated systems: Prototype for a handbook* (DTIC AD-A153 231). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Smith, M.J., and Salvendy, G. (1993). Vol. 19A: Human-computer interaction: Applications and case studies. In G. Salvendy (Ed.), *Advances in Human Factors/Ergonomics*. New York, NY: Elsevier Science Publishing Company, Inc.

Smith, M.J., and Salvendy, G. (1993). Vol. 19B: Human-computer interaction: Software and hardware interfaces. In G. Salvendy (Ed.), *Advances in Human Factors/Ergonomics*. New York, NY: Elsevier Science Publishing Company, Inc.

Smith, M.J., Salvendy, G., Harris, D., and Koubek, R.J. (Eds.) (2001). *Usability evaluation and interface design: Cognitive engineering, intelligent agents and virtual reality – Volume 1*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Smith, S.L., and Mosier, J.N. (1986). *Guidelines for designing user interface software* (ESD-TR-86-278). Bedford, Massachusetts: The MITRE Corp. Retrieved April 14, 2003, from the HCIBIB Web site: http://www.hcibib.org/sam.

Society for Information Display (2000). Retrieved April 14, 2003, from the Society for Information Display Home Page: http://www.sid.org.

Tactile Directional Display. (n.d.). Retrieved April 14, 2003, from the Purdue University HIRL Web site: http://www.ecn.purdue.edu/HIRL/projects_vest.html.

Tan, H., Durlach, N., Reed, C., and Rabinowitz, W. (1999). Information transmission with a multi-finger tactual display. *Perception & Psychophysics, 61(6),* 993-1008.

Tank-automotive and Armament Command Research, Development, and Engineering Center (TACOM-TARDEC) (2002, September). *Crew Integration and Automation Testbed (CAT) Advanced Technology Demonstration*. Retrieved December 30, 2002, from the TACOM-TARDEC Web site: http://www.tacom.army.mil/tardec/vetronics/catatd.htm.

The Boeing Company (2002, October). Warfighter Machine Interface (WMI) Procurement Specification. Los Angeles, CA: Author. (PROPRIETARY)

The MOVES Institute (n.d.). *Immersive Technologies for Data Management and Virtual Environments*. Retrieved April 14, 2003, from the MOVES Web site: http://www.movesinstitute.org.

Thompson, J.A. (1997). Web-based collection of critical incidents for usability evaluation. Retrieved April 14, 2003, from the Virginia Tech Human-Computer Interaction Laboratory Web site: http://hci.ise.vt.edu/research/HCI_UE2.html.

Travis, D. (1991). *Effective color displays*. New York: Academic Press.

Tufte, E.R. (1983). *The visual display of quantitative information*. Cheshire, CT: Graphics Press.

Tullis, T.S. (1988). Screen design. In M. Helander (Ed.), *Handbook of human-computer interaction*. North-Holland: Elsevier Science Publishers B.V.

Unit of Action Maneuver Battle Lab (2002, November). *Operational requirements document for the Future Combat Systems* (Change 1 Final). Fort Knox, KY: Author.

Urban, C.D. (1990). Design and evaluation of a tactical decision aid. In *Proceedings IEEE International Conference on Systems, Man, and Cybernetics*, New York.

Usability Professionals' Association (2003, April). Resources. Retrieved April 14, 2003, from the UPA Web site: http://www.upassoc.org/html/resources.html.

van Veen, H.A.H.C., and van Erp, J.B.F. (2000). Tactile information presentation in the cockpit. In *Proceedings of Haptic Human-Computer Interaction 2000* (pp. 174–181).

Veron, H., Southard, J.R., Leger, J.R., and Conway, J.L. (1990). *3D displays for battle management* (Technical Report No. AD-A223 142). Alexandria, VA: Defense Technical Information Center.

Verplank, W.L. (1988). Graphic challenges in designing object-oriented user interfaces. In M. Helander (Ed.), *Handbook of human-computer interaction*. North-Holland: Elsevier Science Publishers B.V.

Vicente, K.J. (1999). *Cognitive work analysis: Toward safe, productive, and healthy computer-based work*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Vicente, K.J., Burns, C.M. and Pawlak, W.S. (1993). *Egg-sucking, mousetraps, and the tower of babel: Making human factors guidance more accessible to designers* (CEL 93-01). Toronto, CA: Cognitive Engineering Laboratory, University of Toronto.

Wagner, D.A., Birt, J.A., Snyder, M., and Duncanson, J.P. (1996). *Human factors design guide for acquisition of commercial-off-the-shelf subsystems, non-developmental items, and developmental systems* (DOT/FAA/CT-96/1). Atlantic City, NJ: FAA Technical Center.

Waisel, L B. (2002). DARPA's Command Post of the Future (CPOF) program. In *Proceedings of the 2002 Conference of Scuola Superiore G. Reiss Romoli (SSGRR-2002).* L'Aquila, Italy: Telecom Italia Group.

Waldman, S. (2002). *Agile Commander ATD: C2 products & technologies*. [Briefing to the Modeling and Simulation Technical Working Group]. Retrieved December 30, 2002, from the Defense Information Systems Agency, Common Operating Environment Web site:
http://diicoe.disa.mil/coe/aog_twg/twg/mstwg/agile_brief.ppt.

Waldrop, M.M. (2002). *Cutting through the fog of war*. Retrieved December 31, 2002, from the Business 2.0 Web site:
http://www.business2.com/articles/mag/0,1640,36729,FF.html.

Wall, S.A., Paynter, K., Shillito, A.M., Wright, M., and Scali, S. (2002). The effect of haptic feedback and stereo graphics in a 3D target acquisition task. In *Proceedings of Eurohaptics 2002*. University of Edinburgh, UK.

Walrath, J.D. (1989). *Aiding the decision maker: Perceptual and cognitive issues at the human-machine interface* (DTIC No. AD-A217 862). Aberdeen Proving Ground, Maryland: U.S. Army Human Engineering Laboratory.

Wearable Group (2003). Retrieved April 14, 2003, from the Wearable Group at Carnegie Mellon Web site: http://www.wearablegroup.org.

Weimer, J. (1993). *Handbook of ergonomic and human factors tables*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Weinschenk, S., and Yeo, S. (1995). *Guidelines for enterprise-wide GUI design*. New York, NY: John Wiley and Sons.

Weintraub, D.J., and Ensing, M. (1992). *Human-factors issues in head-up display design: The book of HUD*. (CSERIAC Report Number 20 92-2). Wright-Patterson Air Force Base, OH: Armstrong Medical Research Laboratory.

White, A. (2000). *Digital battle staff training deficiencies and mission essential task list mapping* (IAT.R 0222). Austin, TX: Institute for Advanced Technology, University of Texas at Austin.

Wickens, C.D. (1992). *Engineering psychology and human performance* (2nd Edition). Scranton, PA: Harper Collins.

Wickens, C.D., and Andre, A.D. (1990). Proximity, compatibility, and information display: Effects of color, space, and objectness of information integration. *Human Factors, 32*, 61–77.

Wickens, D., and Hollands, J.G. (2000). *Engineering psychology and human performance*. Upper Saddle River, NJ: Prentice-Hall, Inc.

Wright, S. (2002). The M1A2 and the IVIS. *News from the Front* [On-line publication], Mar-Apr¸ 33–34. Retrieved December 23, 2002 from Center from Army Lessons Learned Web site: http://call.army.mil/products/pdf/nftf/marapr02/marapr02bk.pdf.

Zhang, J. (2001). External representations in complex information processing tasks. In A. Kent (Ed.), *Encyclopedia of library and information science*. New York: Marcel Dekker Inc.

Zhang, J., Johnson, T.R., and Lu, G. (2001). The impact of representational format in a dynamic retargeting task. In *Proceedings of the 3rd International Conference of Cognitive Science*. Beijing, China.

Zhang, J., Johnson, K.A., Malin, J.T., and Smith, J.W. (2002). Human-centered information visualization. In *Proceedings of the International Workshop on Dynamic Visualizations and Learning*. Tübingen, Germany: Knowledge Media Research Center.

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John E. Morrison, Stephen H. Konya, Jozsef A. Toth,
Susan S. Turnbaugh, Karl J. Gunzelman, Richard D. Gilson

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14. ABSTRACT

Guidance is needed to ensure that the design of the soldier-machine interface (SMI) for the Future Combat Systems (FCS) is a user-centered process that accommodates a system-of-systems approach to warfighting; includes all soldiers, mounted and dismounted; and is effective across the full spectrum of warfare. To address this need, we first reviewed relevant literature in three domains: contemporary philosophies of design; specific published guidance from military, academic, and industrial sources; and current interface practices for command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) functions. Based on these reviews, an integrative model was devised to describe the interaction among four sets of variables: operational variables, battlespace, sensory modalities, and echelon. The model indicates that as battlespace complexity increases, so does the bandwidth requirement for human information processing. Despite the tentative nature of the model, it can be used for devising FCS design guidelines. For instance, the model suggested that the auditory modality might provide the common link across echelons. The model also suggested that visual displays might be appropriate to all echelons during planning, where all warfighters have increased time available to process data; however, such displays are not appropriate for lower-echelon warfighters during execution phases.

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