Paper Submission to the:
10th International Command and Control Research and Technology Symposium
The Future of C2

Title of Paper:

Intelligent Aided Communication (iaC) in a Command and Control Environment

Suggested Topic / Track:
"Human Factors Engineering" ***or*** **"C4ISR/C2 Architecture"**

Author / Point of Contact:
Ronald A. Moore
ramoore@pacific-science.com
Pacific Science & Engineering Group, Inc.
9180 Brown Deer Road
San Diego, CA 92121
858-535-1661 – office
858-535-1665 – fax

Intelligent Aided Communication (iaC) in a Command and Control Environment

Ronald A. Moore
Pacific Science & Engineering Group, Inc.
9180 Brown Deer Road
San Diego, CA 92121
858-535-1661 – office
ramoore@pacific-science.com

Abstract

During the past several decades many important incremental improvements have been made in command and control (C^2) and decision making theories, practices, and supporting technologies; however, *true innovation has often been lacking*. Major problems remain that hinder revolutionary improvements to military C^2 concepts and practices. Two particularly troublesome problems are information overload and a focus on individuals/small teams versus larger groups within an information environment. To address these and related problems, Pacific Science & Engineering Group (PSE) is developing a new human-centered concept referred to as – *intelligent aided Communication (iaC)*©. The *iaC* concept facilitates more efficient and effective communication and collaboration among users and systems by selectively employing context-aware user profiles (e.g., profiles based on C^2 roles and responsibilities, information requirements, user preferences, etc.) and software agents to manage many of the mundane tasks associated with information exchange and alerting that warfighters perform manually today. Similarly, other *iaC* agents use this same context awareness and user profiles approach to tailor information organization and presentation for the individual warfighter. This paper and presentation will describe the *iaC* concept in more detail and outline how *iaC* can form the foundation for more sophisticated, larger-scale efforts to develop intelligent command centers and technologies.

1. Introduction and Background

To be effective, modern military command and control (C^2) decision making requires an enormous amount of coordinated communication and collaboration among the various forces, services, and coalition partners involved in military operations. Unfortunately, many of the information technologies intended to assist users in acquiring, filtering, managing, and integrating information have instead added to their information burden. A prime reason that these technologies are unable to assist decision makers is that they are not able to understand human users' knowledge[1] requirements. Consequently, much of the information these technologies provide is not tailored to meet the requirements of the tasks being performed. The sheer volume

[1] Knowledge, for purposes of this paper, is defined as domain-specific information, facts, principles, and theories that form the basis for an individual's understanding of a situation.

of information – much of it irrelevant to the decision or task at hand – slows or prohibits the process of information assimilation, understanding, and decision making.

Although many important incremental improvements have been made in command and control and decision making theories, practices, and supporting technologies over the past several decades, true innovation has been lacking. Three major human-related problems exist that preclude revolutionary progress in military command and control:

- *Information overload.* The first major problem is information overload. Military command and control is constantly changing and is far more complex than it has ever been. Military command and control personnel – from the most junior equipment operator to the most senior commander – now have more data and information available to them, more options to consider, and more decisions to make. Often, the decision maker is faced with simply too much information, and too many choices to consider. The sheer volume of available information – much of it irrelevant to the decision or action at hand – slows the process of information assimilation and response. Dynamic environments, where information changes faster than people can process it, greatly exacerbate this problem. In effect, by giving warfighters access to so much information, we turn experts into novices, we make true situation awareness nearly impossible, and we force decision making to be an exercise in laborious, detailed analysis rather than a intuitive, reflexive, near-instant action.

- *Misplaced emphasis on information analysis and conscious thought.* The second major problem is that there are troubling gaps in our understanding of human cognition. Many of the recent advances in theory, practice, and technology have for the most part approached information acquisition and analysis, and decision making as conscious actions taken on the part of the decision maker. Even those theories that acknowledge near-instant decision making describe it as a sequential, usually conscious process whereby information is sought and gathered, patterns are recognized, and correct courses of action selected. However, real life is filled with examples of people quickly – even instantly – making complex decisions and taking actions without conscious thought or due consideration. True masters in an area of expertise often rely almost exclusively on "instinct" and intuition – there is really little or no analysis or decision making occurring in the traditional sense. For example, master martial artists do not consciously consider their own or their opponent's moves – they simply act and react. Seasoned fighter pilots in the heat of battle do not plan each and every command given to the aircraft, or update/revise their situation awareness, or consider their options – instead, they "feel" their aircraft almost as if it was a second skin and seemingly act without thinking. These actions occur long before new information can be gathered, patterns recognized, or conscious decisions made. Clearly, in such cases, "cognitive leaps" are occurring based on the decision maker's already-existing understanding of a situation and surrounding environment.

- *Inappropriate focus on individuals/small teams versus larger groups within an environment.* The third major problem is that much of the past research and development to improve information acquisition and analysis, decision making, and course of action selection has been focused on improving the lot of the individual operator or decision maker, or on small teams, without due consideration to the larger organizations or systems that they work within.

Incremental improvements have been made to individuals' workstations, displays, decision aids, as well as training and procedures, however, little research and development has focused on the larger system as a whole, i.e., the symbiotic relationship between the systems and the humans who use them. As a result, information bottlenecks occur between humans, and between humans and their supporting systems. For example, some users have access to information which they must share with others – but they have no efficient, effective way of doing so. Some users require information from others (human or system) to perform their tasks or make decisions – but have no reliable way of getting it. Sometimes, critical information is available somewhere in the system, but users either don't know it exists or can't access it.

To address these and related problems, new concepts, theories, and technologies must be developed. For example, if we can "intelligently" automate the pre-processing and organization of the information flow to decision makers, it would reduce some of their cognitive load and allow decision makers to focus on relevant and timely information. If we can substantially improve multimodal representations of the information and knowledge space, it could improve a warfighter's perception to the point where understanding and decisions become almost instantaneous. And, if we could re-focus command and control and cognitive decision making research at a higher, holistic level, it should allow us to address system-wide information bottlenecks and greatly reduce decision making error.

Pacific Science & Engineering Group (PSE) has recently completed Phase I of a Defense Advanced Research Projects Agency (DARPA)-sponsored Small Business Innovation Research (SBIR) project titled *Knowledge Flow in Command and Control.* The overall objective of this SBIR effort is to design and develop intelligent, aware command center concepts and technologies based on the symbiotic relationship[2] between human users and their technologies. Phase I demonstrated the feasibility of this objective and laid the foundation for continued development in Phase II.

1.1. The iaC Concept

During Phase I of the SBIR research and development effort, PSE successfully developed a *Knowledge Flow in Command and Control* approach based on lessons learned from previous analyses and research findings in the cognitive, social, organizational and engineering sciences that pertain to information and information exchange issues. An initial system architecture was developed to eliminate limitations in existing information- and knowledge-management technologies, infrastructure, and tools. The resulting concept – which we refer to as *Intelligent Aided Communication (iaC)* – and the prototype iaC tool will intelligently facilitate distributed, coordinated information exchange by military decision makers and their support staffs. The iaC tool approaches the information exchange issue from a human- and information-centric perspective, rather then from an individual, task-based, independent point of view.

[2] In this context, a symbiotic relationship is a cooperative relationship between technologies and their human users that facilitates meeting users' information needs and enhances their decision making.

Information managed by the iaC interface is filtered, sorted, and parsed to iaC users through intelligent and aware agents[3], based on established user profiles, user-defined preferences, and patterned knowledge-based behaviors that are recorded by the system. In a "behind the scenes" manner, agents use a database that contains user profiles to filter, sort, and parse incoming and outgoing information to tailor it to the needs and interests of each system user. Agents thus manage the communication flow between people and the systems they are using. In addition, agents also control information presentation and visualization according to user and situation needs. Innovative visualization interfaces are used within the iaC knowledge space and provide the ability for users to intuitively monitor the flow of information across multiple tasks and missions. iaC agents take on the task of receiving, filtering, integrating, and displaying information in a form that makes it useful for users.

1.2. Characteristics of Modern Command and Control

The design and development of the iaC prototype tool was based on a thorough understanding of C^2 characteristics and requirements. Lessons learned from previous analyses and studies related to C^2 environments were leveraged to support the respective strengths of humans and machines while at the same time engineering the weaknesses out of the system.

Specifically, the following characteristics of C^2 environments were considered:

- *Requirements for communication:* Effective C^2 requires rapid communication and collaboration among U.S. (and coalition) forces. Command centers serve as communication "hubs" within a vast network of distributed commands and individuals.
- *Nature of the communication:* Information exchange in C^2 environments is synchronous and asynchronous; tactical, operational, and strategic.
- *Nature of the participants:* The C^2 information exchange process often involves the participation of individuals and groups that are both co-located, and distributed geographically, organizationally, and/or functionally. Often participants have diverse backgrounds / expertise, are focused on a variety of different tasks, with different goals, and are working under different schedules. Additionally, modern U.S. and coalition C^2 information exchange entails groups who are culturally diverse, have different standard operating procedures, use terminology that differs in application or meaning, and use technologies / infrastructures that are not compatible with other commands / organizations.
- *Nature of the work:* The C^2 environment involves high-stakes, time-compressed decision making, dynamically changing information landscapes, and reliance on stove-piped communication, collaboration, situation awareness, and decision support tools.
- *Nature of the policies and procedures:* Due to the speed with which technologies and policies change, there is often a lack of complete and updated policies, procedures, business rules, and doctrine that guide efficient and effective information exchange.

The C^2 environment characteristics outlined above often exhibit significant information exchange issues and obstacles. Frequently, these issues require that decision-making be based on ambiguous or conflicting information, and result in difficulties identifying related, similar, or redundant information exchanges. Many times it is difficult for decision makers to remain aware

[3] Agents are specially designed software applications that act autonomously on behalf of a particular person.

of current or emerging communication that is of critical importance; relate spatially- and non-spatially relevant information; and identify overlapping information sources.

Secondary effects from C^2-related information exchange issues also result. For example, individuals and groups operating in a modern Navy C^2 environment reported that they struggle with deciding who needs to know information, what information to share, what format to the provide the information in, if others can receive the information (i.e., their capabilities, whether bandwidth issues might prevent the exchange of information), what others need to receive, how to alert others to information with high importance, what information can be trusted, and what are others' areas of expertise are (Pester-DeWan, Moore, & Morrison, 2003).

1.3. Factors Influencing Information Exchange

In order to properly consider and address the information exchange issues described in the preceding section, a systematic review of the technical and scientific literature was conducted. The goal of this review was to identify factors that influence the means by which information moves through human–machine systems. Given the breadth of this topic, the literature review covered fields as varied as information and network systems, and cognitive, organizational, and social psychology. The sources for this literature were likewise diverse and included scientific journals, military lessons learned reports, research and development reviews of communication and collaborative methodologies, and technological reviews. Findings from the literature review are summarized below in terms of their relevance to the design and development of the iaC concept and prototype tool.

1.3.1. Context-based knowledge

Context-Based Knowledge, a term developed specifically for this project, is used to highlight the fact that various factors simultaneously impact information exchange among individuals and groups. Although the research areas cited below have been individually reported in the literature, they have been pooled together here to better show how they affect information exchange. Because the research areas conceptually overlap with one another and affect information exchange in mutually dependent ways, the authors propose that it is important to consider all of these areas when addressing the underlying dynamics of information exchange in C^2 decision making.

1.3.1.1. Transactive memory / knowledge of expertise

Transactive memory can be defined as the combination of "the knowledge possessed by individual group members with a shared awareness of who knows what." (Moreland, 1999, p. 5). It includes an understanding by team members of the knowledge distribution within the team (i.e., other team members' expertise, knowledge and resources), so that all members know with whom to share information and from whom to request needed information. Transactive memory systems combine individual knowledge with shared and explicit knowledge about what other group members know.

Wegner (1986) describes the notion of a transactive memory system in a group environment as a system whose individual members rely on external cues from their environment to trigger their memory. Evidence for transactive memory systems has been found in studies of workgroups (Moreland, Argote, & Krishnan, 1996) in which undergraduate student groups that were trained together outperformed groups that were trained individually (Liang, Moreland, & Argote, 1995). Additional research has shown a decrease in performance (Argote, Insko, Yovetich, & Romero, 1995) and work quality (Thompson & Valley, 1997) in workgroups with high membership change or turnover. These results lend support to the transactive memory framework that argues new group members have not had the opportunity to develop transactive memory and as a result, will perform sub-optimally until they develop it.

One way in which a transactive memory system is developed within a group is through previous interaction. When members develop a history of working together through repeated communication, they learn about each others' preferences and work performance—their expertise, previous information products, preferred information sources, etc. (Moreland, 1999). Knowing and understanding the expertise and experience of the provider of information has an important impact on how the recipient learns to trust and, therefore use the information (Smallman, Heacox, & Oonk, 2004). Without such a prior working relationship, which is common in many modern C^2 environments, it is important to consider how to convey expertise and work experience.

1.3.1.2. Situation context / efficient and effective information exchange

The understanding of expertise, knowledge distribution, and team member experience (transactive memory) is a facet of a larger aspect of understanding, referred to as "situation context." Research has demonstrated the importance of displaying situation context – the overall mission and other team member tasks, and information requirements – to information producers in order to facilitate effective and efficient knowledge and information exchange (Oonk, Moore, & Morrison, 2004). Studies of situation context define information exchange as *effective* if producers are creating information and other team members are accessing all the information that they need to perform their tasks. Information exchange is defined as *efficient* if producers are *not* creating information that is extraneous to other team member's tasks. In other words, information exchange should result in the right information, and only the right information, being shared with the right people (Oonk, Moore, & Morrison, 2004).

Situation context allows information producers to understand the information that other team members believe they need to perform their tasks, as well to recognize and share information that is relevant to other team members, where those members may not even be aware they need that information. A failure to understand situation context often results in information producers sharing information that others do not need and not sharing information they do need. At the same time, the lack of such understanding on the part of the individuals who need the information for their tasks prevents them from asking the right questions of the right people to get that information. The importance of a shared understanding of tasks, expertise, team roles and responsibilities, and information requirements of individual team members has also been highlighted in the shared mental model and transactive memory literatures (e.g., Mathieu et al., 2000, Moreland, 1999) and in studies of military supervisory systems and policies (e.g., Shattuck & Woods, 1997).

An important aspect of situation context is information related to *changes to the context*, i.e., changes or new information related to the mission, group member tasking, and group member information requirements. Previous studies indicate that situation context tools should be graphical representations whenever possible and they should include change alerting functionality.

1.3.1.3. Context-Aware Computing

Context-aware computing is a concept, originating within the computing community, which prescribes that the "design of computing artifacts must take into account how people draw on and evolve social contexts to make the artifacts understandable, useful, and meaningful" (Mouran & Dourish, 2001, p. 89). The basic notion underlying the context-aware computing is that technology be "aware" of the user's context and use this awareness to support the user. Context-aware functions include: (a) presenting the user with information and services appropriate to the context, (b) executing services (e.g., commands or system reconfigurations) for the user based on context, and (c) capturing, tagging and attaching context information for later use (Dey, Abowd, & Salber, 2001).

Within the computing literature, the definition of context focuses on the physical environment within which the technology and user are embedded, including geographical location, user or group identity, and the status of physical objects and spaces (Dey et al., 2001). For the purposes of this project, we extend this definition to include other physical characteristics (such as network status or bandwidth access) and situation context variables – user's mission, tasks, and information requirements, and the expertise, tasks, and requirements of other team members – that we have identified as important in previous studies of information exchange environments (see Situation Context section above; Oonk, Moore, & Morrison, 2004). In other words, context also includes aspects of the user's mission and tasks, as well as the information and human resources necessary to support them in the mission.

1.3.1.4. Information visualization

Problems in information exchange arise when users are unable to extract the important information that is available to them from a larger body of information. This problem is often exacerbated by the nature of the teams exchanging the information, which are characterized by functionally distributed and multi-echelon staffs, working under dynamic conditions. Interestingly, this problem is often at least partly caused by new collaborative technologies designed to support information exchange, which allow the transfer of large amounts of information quickly and easily to almost any location. However, this information is often not the right information for the user (see Situation Context section above) and if it is, it is often presented in a difficult-to-extract, difficult-to-use format. Additionally, "stove-piped" communication, collaboration, and knowledge management systems typically in use today are not "aware" of one another and of the needs of the humans using them. Therefore, these technologies cannot merge relevant information into a meaningful representation for the information recipient.

Information visualization is the application of graphical aids and displays to support human cognitive processes and perception in dealing with various forms of information; in other words, "using vision to think" (Bertin, 1977, as cited in Card, Mackinlay, & Schneiderman, 1999). These visual tools provide a formality to information exchange and bring together the numerous and diverse relevant data sets.

Advances in computer and information display technologies have led to a boom in this multi-disciplinary endeavour, with the introduction of thousands of visualizations that apply our understanding of human factors, cognitive psychology, human perception, and computer science (see Card et al., 1999; Tufte, 1990 for some good examples). It is important to review and assess these emerging information displays, understand their attributes, and determine which is best for which purpose, which will vary across users, tasks, and operational contexts.

1.3.1.5. Trust

With the rapid development of collaborative technologies, group members' skills, knowledge, and expertise can be shared and coalesced to create a transactive memory system; however, information exchange is often predicated on the group's ability to trust one another and the source of the information. Simon's concept of bounded rationality (as cited in Simon, 1982) may help to explain a part of the trust issue. Bounded rationality states that no single individual can ever know all of the options in a particular situation; given that no single individual can possess identical knowledge banks. These knowledge banks are an outgrowth of experience; however, persons with vast amounts of experience (also called expertise) know more than they can actually communicate (Polanyi, 1966). Therefore, this human limitation leads to people doubting if they can trust information from another that is not fully expressed or justified. The trust issue is confounded when the recipient of the information has never before interacted with the source of the information, be it human or machine.

The transfer of trust in expertise can be achieved through a concept that is emerging from situational learning research – the idea that learning is constituted through the sharing of purposeful, patterned activity (Lave & Wenger, 1991). Trust in others' expertise and the information they distribute therefore can be learned and developed through interaction in a social unity that shares a stake in a common situation. It can be seen as a practical capability for the recognition of expertise in group related tasks. The emphasis is not on the behaviors that each individual in the group display; instead, it is on the behaviors that each in the relationship or social exchange framework display. Social Exchange theory allows researchers to examine the social exchanges and relationships between individuals involved in large groups or macro-structures (Emerson, 1981). Likewise, it allowed for the examination of "why" people are involved in an exchange instead of "what kind" of exchange they were involved in. Most social exchange models share the following basic assumptions: (a) social behavior is a series of exchanges; (b) individuals attempt to maximize their rewards and minimize their costs; and (c) when individuals receive rewards from others, they feel obligated to respond.

2. Developing the iaC Tool

The overall objective of this SBIR project is to design and develop intelligent, aware command center concepts and technologies that are based on the symbiotic relationship[4] between human users and their technologies. Phase I work included establishing the conceptual foundation for the *Intelligent Aided Communication (iaC)* tool and delineating its primary features. The iaC tool is designed specifically to aid C^2 decision makers in filtering, integrating, interpreting, and acting upon the types of information typically found in operational settings (i.e., complex, dynamic, ambiguous, conflicting, uncertain). Prototype iaC storyboards and notional functionality were developed and revised in Phase I of the project.

2.1. Conceptual Foundation

The findings of the reviewed technical literature and the previous lessons learned served as a foundation for the design of the iaC features and attributes necessary to support intelligent aided communication. Specifically, the iaC is designed to:

- Help users rapidly develop shared mental models to improve situation awareness among distributed users,
- Allow users working in distributed information spaces to coordinate and collaborate with one another,
- Promote collaborative discussion and analysis of uncertain, ambiguous, or conflicting data,
- Reduce the cognitive load and allow users to focus on relevant, timely information and knowledge,
- Represent knowledge assets, along with their attributes and availability, and
- Filter, organize, and simplify complex information sets without taking away available resources and capabilities required by the warfighter.

The iaC tool is a shell application running on top of the host operating system (e.g., MS Windows) that fully integrates and re-faces existing applications. It is intended to function as a means for all information exchange activities required by a command center and its support groups. The integrative information space within the iaC tool features an information-centric design, support for transactive memory, understanding of situation-context, facilitation of trust among group members and information provided, and alerting capabilities.

Underlying the behavior and display of information for every iaC user is an intelligent "personal agent" that is aware of the user's personal information – their tasking, expertise, experience, current display capabilities, and information preferences, etc. The agent manages the information presented to a user "behind the scenes" by filtering, sorting, and parsing information according to the data contained in evolving user "profiles" These profiles are based on probabilistic needs based on patterned work behaviors, personal information, and user-specified information preferences. The agent is further context-aware in that it understands the overall mission and tasking (situation context) and expertise (transactive memory) of other iaC users within the organization via a shared database. The database is used by the iaC system and all user agents to

---

[4] In this context, a symbiotic relationship is a cooperative relationship between technologies and their human users that facilitates meeting users' information needs and enhances their decision making.

store, use, and disseminate information about users of the tool. With this awareness, the agent automatically manages communication flow between users and systems, as well as information presentation and visualization. iaC agents will be designed to *adapt information flow and presentation* based on users' changing needs, settings, technologies, priorities. It is important to note that a fundamental iaC design principal is that human users will *always* be able to control, modify, and/or override iaC agents, and they will always be able to modify their personal profile as they deem necessary.

Innovative interfaces will be used within the iaC knowledge space to provide the ability for users to intuitively visualize large data sets, and monitor the flow of filtered information and knowledge. As with all aspects of the iaC tool, specific visualizations used at any point in time are determined by the user's personal agent, based on the situation, user tasking, display capabilities, and user personal preference.

2.2. iaC Features and Attributes

The iaC interface consists of a set of integrated features for collecting, filtering, parsing, and displaying information that can be used collaboratively by team members as they perform their tasks. Each of these features was developed to specifically overcome the information exchange issues identified in the literature review. Each of the interfaces described below are housed within an iaC "container" or shell application, which provides a consistent look and feel throughout the system. The iaC interface also provides access to underlying information agents and integrated functions, help systems, and software tools.

2.2.1. Communication module

All communications will be routed through and displayed by the iaC-managed communications interface. The iaC Communication Module interface will use a full complement of communication media. The iaC Communication Module features:

- *A graphical display* (common operational picture, maps, satellite images, drawings, whiteboards, etc.), tailored to the situation and user.
- *Collaboration/communication capabilities* (e-mail, chat, shared documents, voice/audio etc.), also tailored to the situation and user. The optimal or user-preferred format of the information is presented. In Figure 1, the information is translated to the user from speech to text.
- *Situation information,* to support knowledge of situation context including keywords and information urgency.

2.2.2. Agent communications manager

The iaC Agent Communications Manager interface allows the user to see the expertise, capabilities, and connection speeds of other potential collaborators (selected by the personal agent), and can initiate communication with them. Information displayed by the iaC Agent Communications Manager interface includes:

- *Collaborator personal information.* This includes such information as name, rank, organization, and expertise. Expertise is presented in terms of how relevant it is to the user's current problem/situation/needs. Using this information, the user can decide with whom they should share information, from whom they should request information, and whom they should involve in a collaborative session.

- *Collaborator availability and connection speed.* This allows the user to see how easy it to contact other collaborators. Connection speed gives the user an indication of what sort of information others can receive (in terms of file size). Messages sent to collaborators with low connection speeds may be "stripped" of information, potentially reducing their usefulness. Note that iaC users may have to take both personal information and availability into account when deciding with whom to collaborate. In time-critical situations, they may choose to contact an available individual with lower expertise rather than wait for a more expert individual to become available.
- *Collaborator capabilities.* This includes information about what types of display capabilities other system users have access to, including Chat, VTC, Whiteboard, audio/voice, etc.

2.2.3. iaC Module

The multi-purpose iaC Module includes features such as:

- An *Agent Asset Manager,* which allows the user to create and annotate graphics using other images, maps, weather information, etc.
- *Agent Communication Manager,* described in the previous section.
- *Information annotation*, using "pushpins" to symbolize relevant available information. By selecting a geographical location on the map, the user can initiate a download of other information about that location that can be shared with others. This capability supports efficient and effective information exchange by allowing the user to have access to and quickly share *relevant* information about the situation with others.

2.2.4. Dynamic Adaptable Display

One of the major features envisioned for the iaC tool interface is a dynamic display space that adapts to the changing information focus of each user. Figure 1 shows how the display of the iaC will be able to adapt to changing situation and user requirements. Users (or their agents) select which visualization is most appropriate for the situation and their own preferences. In this example, display options include a map, a tree diagram, and a fisheye view.

- The map is a familiar representation to users, allowing them to view information that is optimally presented geospatially. Locations on the map can be linked to amplifying information, highlighted using overlays, etc. The specific map view (topographic, roads, etc) can be changed according to the needs of a particular situation.
- Tree diagrams are an innovative way of supporting information management, displaying inter-related information and putting it into context. Branches of the tree represent categories of information. The location and relative size of the text for a give item of information within the tree structure indicates its current relevance to the user and its relationship with other information items within the tree.
- In the fisheye view, pointing to particular element will enlarge that element so that it can be more easily viewed. At the same time, the other elements in the display space will become smaller so that more room is available for the element of interest. These de-emphasized elements do not disappear from the display, however, but remain visible in case the user

desires to inspect one of them. In that case, pointing to that element will cause it to become the dominant screen object. This fisheye approach to viewing display contents is a good compromise of the competing needs to remain aware of all display content while also being able to view an element of interest in more detail.

Each of these views is augmented by alerting and highlighting, which can be used to draw a user's attention to new or changed information relevant to their current tasking.

Figure 1. Various situation-relevant iaC visualizations.

3. Summary

The iaC tool represents a new way of receiving, processing, organizing, and displaying information under demanding operational conditions. To be effective, it will require ongoing development of advanced features designed to facilitate the transmission, filtering, organization, display, and use of complex, dynamic, and probabilistic information from multiple sources. Phase I of this SBIR established that a human-centric approach to designing an intelligent aware communication aid can improve information exchange among distributed groups of military C^2 decision makers. Accurate, real-time information exchange is a key requirement for effective C^2. Phase I identified the required iaC functionality, features, and user requirements, evaluated off-the-shelf supporting technologies and infrastructures, and developed metrics to measure the operational impact of the iaC tool. The Phase I effort established these requirements to pave the way for the development of a fully functional iaC tool in Phase II of the SBIR project.

The proposed iaC tool will greatly benefit the military by improving communication, coordination, and collaboration among C^2 decision makers, and thereby dramatically improve shared situational awareness and decision-making. However, fast-paced, dynamic information management and decision-making environments characterized by complex and uncertain data, high-stakes decisions, and distributed, decentralized command structures are not unique to the military. Many government and private organizations operate in similar environments on a daily basis and therefore could be expected to benefit from this technology.

References

Argote, L., Insko, C. A., Yoveovetich, & Romero, A .A. (1995). Group learning curves: The effects of turnover and task complexity on group performance. *Journal of Applied Social Psychology, 25,* 512–529.

Card, S. K., Mackinlay, J. D., & Schneiderman (1999). *Readings in information visualization: Using vision to think.* San Francisco, CA: Morgan Kaufmann Publishers, Inc.

Dey, A. K., Abowd, G. D., & Salber, D. (2001). A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. *Human-Computer Interaction*, *16*, 97–166.

Emerson, R. (1981). Social exchange. In M. Rosenberg & R. Turner (Eds.), *Social psychology: Sociological perspectives* (pp. 30–65). New York: Basic Books.

Lave, J., & Wegner, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge, UK: Cambridge University Press.

Liang, D. W., Moreland, R. L., & Argote, L. (1995). Group versus individual training and group performance: The mediating role of transactive memory. *Personality and Social Psychology Bulletin, 21(4)*, 384–393.

Mathieu, J. E., Goodwin, G. F., Heffner, T. S., Salas, E., & Cannon-Bowers, J. A. (2000). The influence of shared mental models on team process and performance. *Journal of Applied Psychology, 85,* 273–283.

Moreland, R. (1999). Transactive memory: learning who knows what in work groups and organizations. In L. L. Thompson, J. M. Levine, & D. M. Messick (Eds.), *Shared cognition in organizations: The management of knowledge* (pp. 3–31). Mahwah, N.J: Lawrence Erlbaum Associates.

Moreland, R. L., Argote, L., & Krishnan, R. (1996). Socially Shared Cognition at Work: Transactive Memory and Group Performance. In J. L. Nye & A. M. Brower (Eds.), *What's Social about Social Cognition?*: 285–309. Thousand Oaks, CA: Sage.

Mouran, T. P., & Dourish, P. (2001). Introduction to this special issue on context-aware computing. *Human-Computer Interaction*, *16*, 87–95.

Oonk, H. M., Moore, R. A., & Morrison, J. M. (2004). Communication of context in multi-echelon information exchange environments. In *Proceedings of the 2004 Command and Control Research and Technology Symposium*. San Diego, CA.

Pester-DeWan, J., Moore, R. A., & Morrison, J. G. (2003). *Knowledge Engineering for Command and Control Transformation at United States European Command (USEUCOM).* (Technical Report). San Diego, CA: Pacific Science & Engineering Group.

Polanyi, M. (1966). *The Tacit Dimension*. Garden City, NY: Doubleday.

Shattuck, L. G., & Woods, D. D. (1997). Communication of intent in distributed supervisory control systems. *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*. Santa Monica, CA: Human Factors Ergonomic Society.

Simon, H. (1982). Theories of Bounded Rationality. In, Herbert Simon (Ed.), *Models of Bounded Rationality. Behavioral Economics and Business Organization* (Vol. 2, pp. 408–423). Cambridge: MIT Press.

Smallman, H. S., Heacox, N. J., & Oonk, H. M. (in press). *Shared Intelligence VisualizEr (SIEVE): Web-based threat assessment for cross cultural intelligence analysis*. (Technical Report). San Diego, CA: Pacific Science & Engineering Group.

Thompson, T. A., & Valley, K. L. (1997). *Changing Formal and Informal Structure to Enhance Organizational Knowledge.* Working Paper 98-060. Harvard University, Cambridge, MA.

Tufte, E. R. (1990). *Envisioning information*. Cheshire, CT: Graphics Press.

Wegner, D. M. (1986). Transactive memory: A contemporary analysis of the group mind. In B. Mullen & G. R. Goethals (Eds.), *Theories of group behavior* (pp. 185–208). New York: Springer-Verlag.