Measuring, Monitoring, and Managing Knowledge in Command and Control Organizations

Jared Freeman, Ph.D., Shawn A. Weil, Ph.D., Kathleen P. Hess, Ph.D.
Aptima, Inc., 1726 M Street, NW, Suite 900
Washington, DC 20036
UNITED STATES

freeman@aptima.com, www.aptima.com

ABSTRACT

Virtual environments for command and control typically represent spatial information about entities, such as the location of friendly and enemy forces. Iconography and interaction standards for such displays are well defined. Less attention has been paid to representing non-geographical information, such as information about the state of knowledge and decision making in a command staff. We report here on two technologies designed to enable commanders to measure, monitor, and manage knowledge and decision making. The IMAGES tool (now under development) exploits communication and language analysis technologies as well as network visualization techniques to help commanders explore the distribution of knowledge in written communications (e.g., chat and email). The CENTER tool (now implemented) exploits a theory of collaborative critical thinking for representing the state of decision making within distributed teams. Here, we describe challenge, requirements, and two solutions for measuring, monitoring, and managing knowledge using virtual environments in command and control operations.

INTRODUCTION

Modern Command and Control (C2) systems harness geographical databases, imagery, other sensor data, and standardized symbology to represent critical information spatially for C2 operations (e.g., MCS, CPoF, and FBCB2)[1]. Miller (2005) has noted that computerized maps are necessary for C2, but are inevitably deceptive; unambiguous symbology masks identification errors, severe latencies, and systematic omission of data. He explains that, “There is often an assumption that the symbology or data on a map is completely accurate. A map’s symbology must distort the data in an effort to present a coherent informative picture… [and] the data behind that visual representation is distorted as well.” Curiously, mapping systems offer little support for identifying and resolving problematic data. For example, maps do not point to the people with knowledge about the data, its flaws, and its impact on decisions. Information systems, in sum, are not well integrated with the social system of cartographers, geologists, multi-source analysts, correlation analysts, and others who interpret data and diagnose data problems for decision makers.

Our objective is to integrate data systems with social systems. To do this, we are developing tools that help leaders to measure, monitor, and manage the knowledge of team members.

[1] Maneuver Control System, the Command Post of the Future, and Force XXI Battle Command, Brigade-and-Below.

Freeman, J.; Weil, S.A.; Hess, K.P. (2006) Measuring, Monitoring, and Managing Knowledge in Command and Control Organizations. In *Virtual Media for Military Applications* (pp. 2-1 – 2-10). Meeting Proceedings RTO-MP-HFM-136, Paper 2. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

We are concerned with two aspects of knowledge: (1) the distribution of information across the team or organization and (2) team judgments about the quality of information and decision making based on it. Technology that addresses these aspects of knowledge well would create a Common Operational Picture of Team Knowledge (COP^{TK}). Such technology is not common; we are not aware of any extant example of a COP^{TK}. Such technology is technologically feasible. Knowledge and judgments on knowledge and decisions are correctly viewed as cognitive states; and from this perspective they are difficult to assess. Laboratory measurement of cognition involves highly artificial tasks and intrusive instrumentation (e.g., eye tracking, neuroimaging). However, knowledge and judgments are also products of collaboration that emerge in the natural course of communication, and that can be efficiently expressed in response to concise survey items. Thus, it is possible to measure collaborative cognition, visualize these measures so that commanders can monitor team state, and give leaders the capability to manage cognitive collaboration.

We are addressing the challenge of measuring, monitoring, and managing cognitive collaboration with two technologies that we are developing under the Collaborative Knowledge Management program of the Office of Naval Research. (1) The Instrument for Measuring and Advancing Group Environmental Situational awareness (IMAGES) captures communications, analyzes them, and presents data concerning ***the distribution of knowledge*** across an organization. (2) Collaboration for ENhanced TEam Reasoning (CENTER) captures brief responses to survey items, analyzes them, and presents data concerning staff ***judgments about the state of knowledge and decision making***. We describe these technologies in detail, below.

Function	**State of Knowledge**	**State of Judgments & Decisions**
Measure		
Monitor	***IMAGES***	***CENTER***
Manage		

IMAGES

IMAGES is a software tool designed to improve the distribution of knowledge within organizations. IMAGES consists of a repository of written communications (e.g., chat, email) among members of a potentially distributed organization, modular (or swappable) tools that compute measures of the distribution of knowledge represented by those communications, and a visualization system that enables commanders to easily monitor the organization's knowledge state. Components of IMAGES are variously in design, development, or are largely completed.

Measuring Knowledge

The product, when fully developed, will support three forms of communication measurement: Network Text Analysis, Dynamic Network Analysis, and Flow Analysis.

Network Text Analysis: IMAGES formats communications data for semantic analysis by AutoMap (Diesner and Carley 2004; 2005), developed by our partners at Carnegie Mellon University. Automap standardizes terms using a mission-specific thesaurus, filters out terms, cross-indexes terms, and computes counts of the frequency and co-occurrence of terms. These counts, which represent the knowledge in a communication, can then be compared between teams. For example, we can measure the knowledge that is held in common between two individuals or teams by computing the proportion of knowledge they both express (the intersection of knowledge) to the knowledge that either expresses (the union; see Figure 1). Preliminary, experimental research has validated this measurement strategy in a small team setting (Weil, Carley, Diesner, Freeman, & Cooke, 2006).

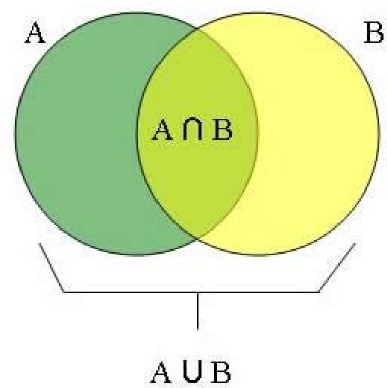

Figure 1: Knowledge held in common as a proportion of all knowledge: A∩B / A∪B.

Dynamic Network Analysis Metrics: A second class of metrics leverages the science of dynamic network analysis developed at CMU and the associated meta-matrix approach to relational data (Carley 2003; Carley and Reminga 2004). The meta-matrix specifies several classes of data that exist in communications, specifically data about people, knowledge, resources, tasks, and organizations. Crossing these data types produces useful input for network analyses. For example, connections derived from personnel data alone generate a social network ("Who talks to whom"). Crossing personnel and knowledge data generates a knowledge state network ("Who knows what"). Crossing knowledge data produces an information network ("What is relevant to what"). These are the networks of primary interest in IMAGES at the present time. We can apply the range of graph theoretic social network metrics to these networks to discern, for example, which people or concepts are central to an organization's discourse, and which are gateways to different clusters to other groups or concepts.

Flow analysis metrics: Patterns in the occurrence, sequence, and timing of communications can be identified and assessed using measures developed by our partners at Arizona State University (Cooke, Salas, Cannon-Bowers & Stout 2000; Cooke 2005), and referred to as FAUCET (Flow Analysis of Utterance Communication Events in Teams). These are content-independent measures, and – though they assess only who communicates, when, and in what order – scores on these measures have been experimentally shown to be strongly correlated with effective team performance and team situational awareness in domains such as UAV operations.

Monitoring Knowledge

The conceptual design for data visualization in IMAGES (see Figure 2) illustrates functionality with which users will configure communications analyses, explore analysis results, and review diagnoses and recommended actions. A sub-set of the illustrated features is currently being implemented.

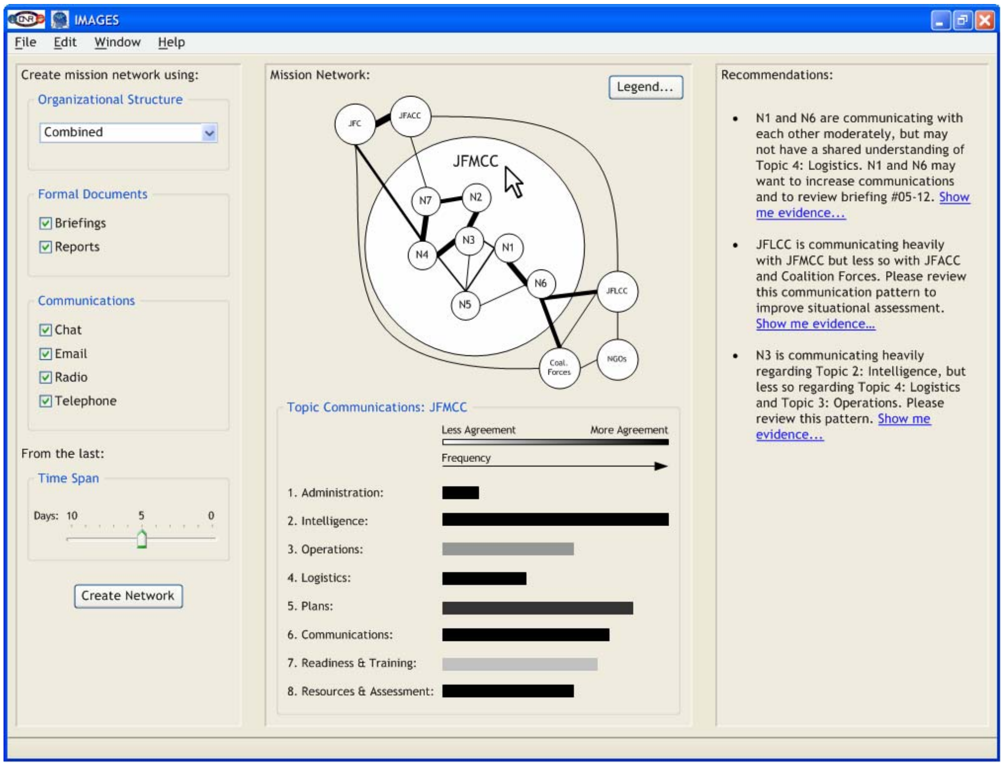

Figure 2: The IMAGES concept interface provides controls for the analysis of communications (left pane), a visualization of communications frequency (top center) and topics (bottom center), and action recommendations.

In the left hand pane of Figure 2, the operator is able to configure the tool, specify the types of data sources with which to create a semantic network, and set the timeframe for analysis. Both formal (reports and briefs) and informal data sources (chat, e-mail) might be selected for analysis, assuming that these are available in the collaborative environment. These parameters determine how communications is measured in IMAGES. The top-center pane presents a network. In this case, the nodes – various Joint Forces components, Coalition Forces, and Non-Governmental Organizations – represent organizations involved in a Coalition relief effort. The connections between nodes indicate communications volume; the absence of an arc between nodes indicates there was no direct communication, while a thin line indicates limited communication. In the bottom center of the panes, a graph indicates the topics being discussed (e.g., administration, operations, logistics), based on several generic thesauri. In this case, the topics correlate with the assignments of major staff organizations in a typical military organization.

Using IMAGES, an operator could monitor whether the appropriate organizations are:

1. Talking to each other, by noting the connections between nodes;
2. Talking about the appropriate topics, by checking the topic profile ;
3. Talking about them in the same contexts, by observing the darkness of the bar.

The ability to manipulate the time frames involved, the communication mediums used, and the level of detail desired could afford greater flexibility to the operator in a future implementation of IMAGES.

Managing Knowledge

The right hand pane of Figure 2 illustrates one notion for a management aid within IMAGES. It presents an automated diagnosis of a knowledge state (e.g., “Units A and C are not communicating at all. Units A and B are not discussing enemy position"). This diagnosis is computed by comparing the structure and content of an observed knowledge state to that of a model or normative knowledge state. The normative knowledge state might be defined directly by specifying the anticipated topics of communication between team members. Alternatively, it might be inferred from a computational model of the task assignments of team members and the information and communication requirements between tasks (e.g., "The executor of Task A must pass weather data to the executor of Task B"). In addition to diagnosis, the interface presents a remedy, such as ordering team members to review some aspect of a mission which should be – but has not yet been – a topic of discussion.

CENTER

CENTER is a software system designed to improve *collaborative critical thinking* by teams about knowledge and decisions. The CENTER tool (1) enables a leader to query members of the organization concerning the state of mission knowledge and decisions, (2) elicits brief responses and summarizes them statistically, and (3) presents these measures to leaders with guidance concerning the issues on which leaders should focus their attention and that of members. In short, CENTER helps leaders to measure, monitor, and manage collaborative critical thinking about team knowledge and decisions. CENTER is a fully implemented software package that runs on networked Windows and Linux platforms.

Measuring Knowledge

Collaborative critical thinking involves interaction between team members to reveal uncertainty concerning knowledge or decisions, identify its sources, and devise ways to diminish it or accommodate it. These collaborative activities may help team members improve estimates of risk and refine plans to accomplish missions in the face of risk.

Our definition of this collaborative activity derives from the literature on individual critical thinking, specifically the work of Cohen, et al. (1998; 1997), which empirically validated that individuals who engage in several specific critical thinking behaviors outperform others on tactical assessment, planning, and decision making tasks Collaborative critical thinking leverages this set of behaviors in its definition and measures. CCT consists of (1) monitoring interactions that alert other team members to the existence of uncertainty, (2) assessment interactions in which team members evaluate the opportunity (e.g., available time) and need (e.g., priority or stakes) to resolve the uncertainty, (3) critiquing interactions in which team members identify the source of uncertainty (specifically: gaps in knowledge, conflicting interpretations, and untested assumptions), and (4) action planning and execution activities that resolve problems with knowledge or decisions, or that compensate for irresolvable uncertainty.

Collaborative Critical Thinking is frequently applied to two objects. A focus on the mission involves critiquing assessments (e.g., of enemy intent, or the state of own forces) and plans (as is done in Course of Action development and assessment). A focus on the team's process involves a critique of goals, the plans (or strategies) for achieving those goals, and the state of tasks that constitute the plan.

We have crossed these two dimensions – the collaborative activities that constitute critical thinking, and the objects to which it is applied – to define the space of behavior that must be measured (see Table 1).

Table 1: CENTER measures critical thinking activities applied to team products and processes.

	Objects of CCT				
	Team products		Team processes		
CCT Behavior	**Assessment**	**COA/Plan**	**Goals**	**Plans**	**Tasks**
Monitoring	*A1*				*T1*
Assessment		*C2*			
Critiquing for gaps					*T3*
Critiquing for assumptions				*P4*	
Critiquing for ambiguity					*T5*
Action	*A6*		*G6*		

We have defined measures within this space that are ratings of agreement (strongly disagree to strongly agree) with assertions (below) that can be customized (in the bracketed, cloze fields) for a given mission. For example, probes relevant to the marked cells in Table 1 are:

A1: The team's assessment [of _____] is correct.
A6: The team is taking actions to resolve problems with the assessment [concerning _____].
C2: The team has time to critique and refine the plan [regarding _____].
P4: The team has identified key assumptions that have yet to be tested concerning its strategy [for _____].
G6: The actions of team members are consistent with the mission goals [concerning _____].
T1: Team members seek feedback on their tasks [concerning _____].
T3: The team is completing all tasks [concerning _____].
T5: Team members seek to resolve ambiguity in task assignments.

CENTER allows a leader or facilitator to select a subset of probes appropriate to the mission at hand, and customize them or use them in their generic form. The facilitator can then trigger the delivery of each probe to networked members of the team. Each probe appears in a small window in a member's workspace (see Figure 3) with a rating scale and two buttons: one to add textual comments and one to send the response back to the facilitator. Each window disappears after a specified period, and a countdown reminds the team member of this.

In experimental research conducted with our colleague Michael Coovert, Ph.D., at the University of South Florida, participants found these probes to be useful in a teamwork exercise executed, and non-disruptive of taskwork if they occurred at least three minutes apart.

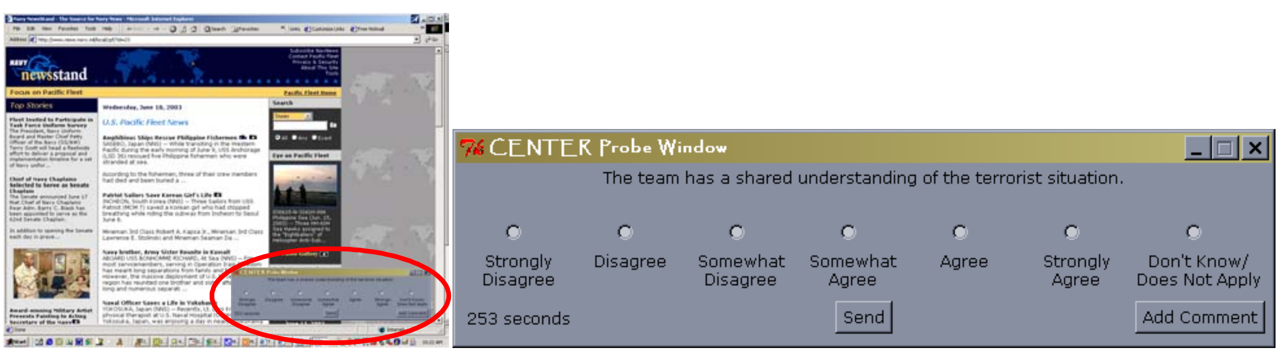

Figure 3: CENTER probes are simple, unobtrusive, and rapidly addressed.

Monitoring Knowledge

CENTER converts responses to each probe into numeric values, and summarizes them as a mean and range (see Figure 4). Leaders or facilitators can view the numeric responses to all probes, or drill down to inspect the responses – both ratings and comments – to any one probe. In this way, leaders can monitor the organization's state of collaborative critical thinking with respect to mission-specific issues.

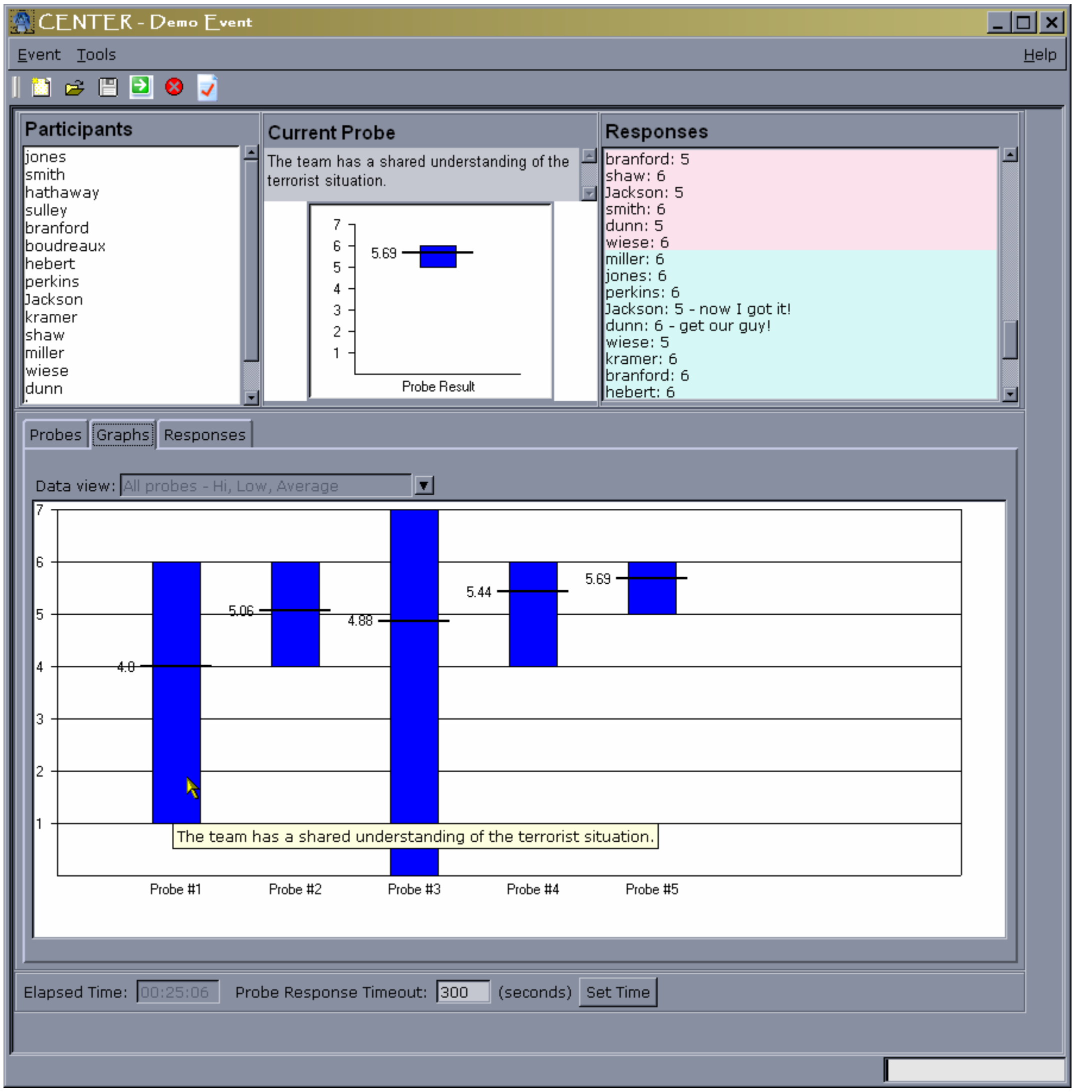

Figure 4: Responses to CENTER probes are summarized as means and range.

Managing Knowledge

CENTER helps leaders to interpret measures of collaborative critical thinking and take action to improve it. It does so by analyzing distribution patterns in each response and presenting guidance to the leader. For example, assume that this probe – "The team has the information it needs to plan." – is administered to the team well into a long, mission planning task. The distribution of responses across the team may have a high (positive) mean and low variance, indicating that there is near unanimous agreement with the probe statement. In this case, CENTER advises the leader as follows:

The team members believe that they have the information they need to plan. Suggest that they move on. If there is a large team then probe for lone dissenters, if found, engage them, for example: "Would you like to add anything?"

If the responses across the team exhibit an average mean and high variance (indicating that some people agree with the probe while others disagree), CENTER returns the following guidance:

The team members do not agree whether the team has the information it needs to plan. Seek to understand why there is so little consensus. Tell those who disagreed with the probe: "Share your concerns regarding insufficient information needed for planning with the other team members. Tell them what information seems to be missing. See if they have that information." Tell the team members who agreed with the probe "Not all team members believe that there is enough information to plan. Find out what information is missing." Help the team quickly get the information it needs.

The leader can then send messages to the team members, or the leader can engage all or a subset of team members in an instant message session (see Figure 5) to facilitate more complete knowledge management.

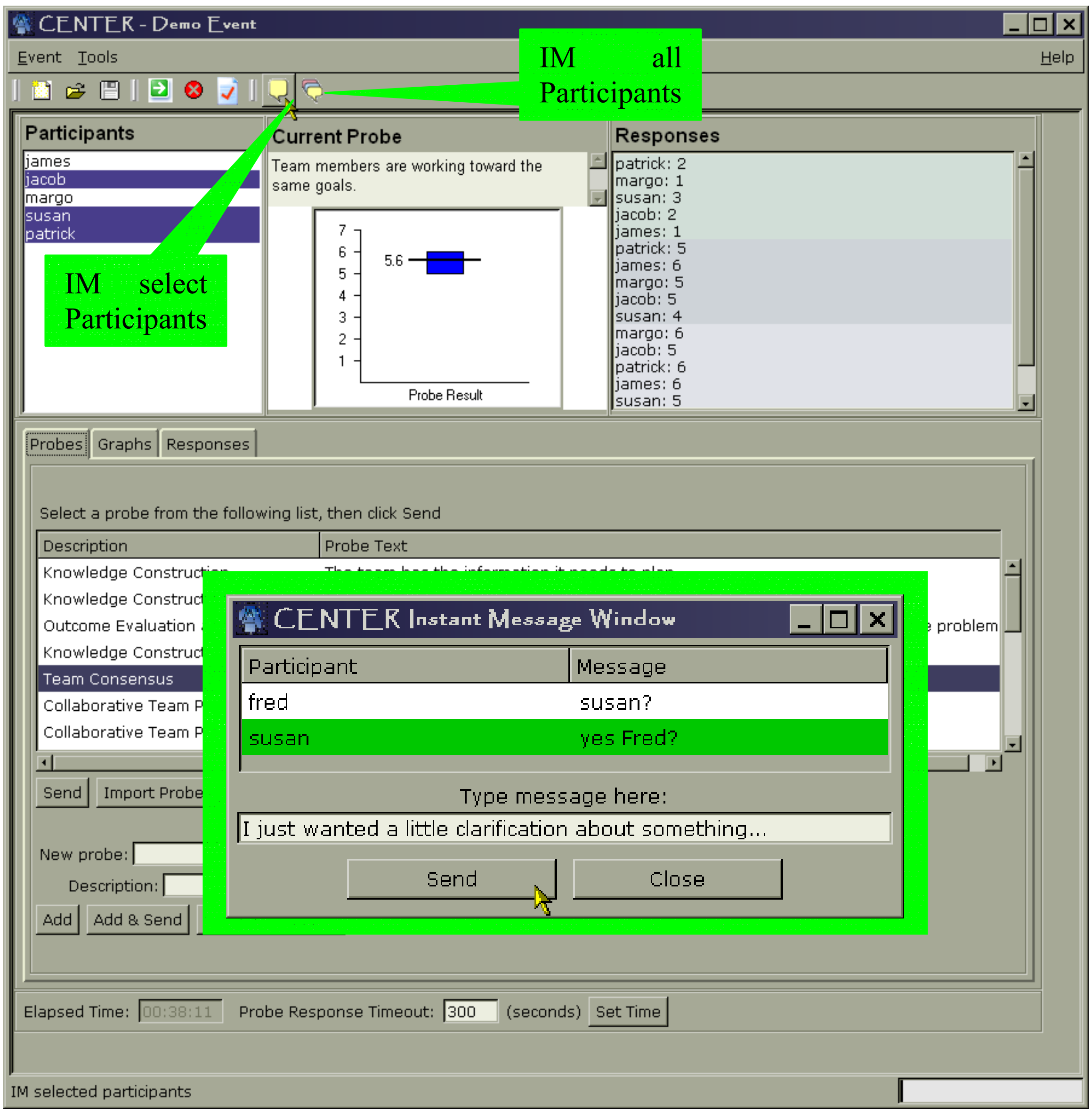

Figure 5: CENTER's Instant Message capability

CONCLUSION

IMAGES and CENTER are designed to make the social system of knowledge more accessible to leaders. These technologies ***measure*** the state of knowledge within teams as well as team judgments about knowledge and decision making, and they enable leaders to ***monitor and manage*** such knowledge. These capabilities are important to help leaders leverage the capabilities of modern information systems, by giving them insights into the use of information from these systems and judgments about it. Thus, CENTER and IMAGES may help to integrate data systems with social systems. Technologies such as this may be particularly important in distributed organizations, and in virtual organizations[2], in which leaders cannot easily observe interactions – such as "buzz" about specific information or arguments over decisions – that convey the state of team knowledge. In these environments, technology is needed to make team knowledge state accessible.

We invite opportunities to transition CENTER and IMAGES (when it is completed) to operational environments and to training environments where they might be used to measure of teamwork competencies and support After Action Reviews.

ACKNOWLEDGMENTS

The authors thank Dr. Michael P. Letsky of the Office of Naval Research for his support of CENTER and IMAGES through ONR's Collaborative Knowledge Management program.

REFERENCES

Carley, K.M. (2003). Dynamic Network Analysis. In R. Breiger, K.M. Carley, and P. Pattison (Eds.), Dynamic Social Network Modeling and Analysis: Workshop Summary and Papers, (pp. 133-145). Committee on Human Factors, National Research Council, National Research Council.

Carley, Kathleen M. and Jeff Reminga, 2004. ORA: Organization Risk Analyzer. Carnegie Mellon University, School of Computer Science, Institute for Software Research International, Technical Report CMU-ISRI-04-101.

Cohen, M.S., Freeman, J. and Thompson, B.T. (1998). Critical Thinking Skills in Tactical Decision Making: A Model and a Training Method. (Canon-Bowers, J. and E. Salas, eds.), *Decision-Making Under Stress: Implications for Training & Simulation*. Washington, DC: American Psychological Association Publications.

Cohen, M.S. & Freeman, J. (1997). Improving critical thinking. In Flin, R., Salas, E., Strub, M., & Martin, L. (Eds.), *Decision Making Under Stress: Emerging Themes and Applications*. Ashgate.

Cooke, N. J., Salas, E., Cannon-Bowers, J. A., & Stout, R. J. (2000). Measuring Team Knowledge. Human Factors, Vol 42,1 (pp. 151-174).

Cooke, N.J. (2005). Communication in Team Cognition. Proceedings of the Collaboration and Knowledge Management Workshop 2005. San Diego, CA.

Diesner, J., and Carley, K.M. (2004). AutoMap1.2 - Extract, analyze, represent, and compare mental models from texts. Carnegie Mellon University, School of Computer Science, Institute for Software Research International, Technical Report CMU-ISRI-04-100.

Diesner, J., and Carley, K.M. (2005). Revealing Social Structure from Texts: Meta-Matrix Test Analysis as a novel method for Network Text Analysis. In V.K. Naravanan and D.J. Armstrong (Eds.), Causal Mapping for Information Systems and Technology Research: Approaches, Advances, and Illustrations, (Chapter 4). Harrisburg, PA: Idea Group Publishing.

[2] Virtual organizations are ad hoc alliances or opportunistic, temporary alliances of individuals from different formal organizations.

Kiekel, P.A., Gorman, J. C., & Cooke, N. J. (2004). Measuring speech flow of co-located and distributed command and control teams during a communication channel glitch. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*.

Miller, Craig S. (2005). A New Perspective for the Military: Looking at Maps Within Centralized Command and Control Systems. *Air & Space Power Chronicles*. (http://www.airpower.maxwell.af.mil/airchronicles/cc/miller.html)

Weil, S. A., Carley, K. M., Diesner, J., Freeman, J., & Cooke, N. J. (2006). Measuring Situational Awareness through Analysis of Communications: A Preliminary Exercise. Paper submitted to the Command and Control Research and Technology Symposium, San Diego, CA.

AUTHORS

Jared Freeman, Ph.D. is Vice President for Research at Aptima. Dr. Freeman's work concerns problem solving and decision making in real-world settings and the design of decision aids and training systems to support these activities. He served as principal investigator on projects to define and support collaborative critical thinking; automate the analysis of voice communications; automate the analysis of written usability documents; and model the fit between human cognitive abilities, decision support systems, and mission requirements. Dr. Freeman holds a Ph.D. in Cognitive Psychology from Columbia University and a M.A. in Educational Technology from Teachers College, Columbia University.

Shawn A.Weil, Ph.D., is a Cognitive Psychologist in the Human Performance Division at Aptima. Dr. Weil's work addresses the selection and application of natural language processing techniques to assess aspects of individual and team performance, and the investigation of organizational adaptation through iterative model-driven experimentation. He is also a primary contributor to the design of systems that effectively manage diverse game-based experiential training. Dr. Weil received Ph.D. and M.A. in Cognitive/Experimental Psychology from The Ohio State University with a dual-specialization in psycholinguistics and cognitive engineering, and a B.A. in Psychology/Music from Binghamton University (SUNY).

Kathleen P. Hess, Ph.D., is a Senior Industrial/Organizational Psychologist and Lead for the Leadership and Culture Development Team. Dr. Hess provides expertise in training, leadership development, and cultural issues. She applies this expertise to the development and validation of training programs and selection tests in areas including computer skills, information management, collaboration, and leadership skills. Dr. Hess develops traditional, instructor-led training programs and pencil-and-paper selection tests, as well as computer-based programs, including web-based self-development programs, simulation-based selection test beds, and network-based tools to improve team collaboration. Dr. Hess received a Ph.D. and M.S. in Industrial and Organizational Psychology from Pennsylvania State University.