Visualization of Communications Data for Enhanced Feedback in Army Staff Training

Kara L. Orvis, Tara A. Brown, Robert McCormack,
Aptima, Inc.
Woburn, MA
korvis@aptima.com, rmccormack@aptima.com, tbrown@aptima.com

Arwen H. DeCostanza
Army Research Laboratory
Aberdeen Proving Ground, MD
arwen.h.decostanza.civ@mail.mil

ABSTRACT

Although the Army recognizes the critical role that effective teamwork plays in supporting mission outcomes, monitoring and providing feedback to staff organizations on teamwork remains challenging. The Army traditionally relies on self-report surveys and the expertise of observer/coach/trainers (OCTs) who mentor team-based organizations throughout collective training exercises and prepare after action reviews (AARs). While OCTs provide invaluable insight into unit strengths and weaknesses, they face multiple challenges, including (1) minimal access to and review of collaboration taking place via digital systems, and (2) reduced numbers of OCTs available for observation and coaching due to resource cuts. To address these challenges, a system was created for OCTs that collects, analyzes, and displays unit communications information from email, chat, and face-to-face interactions. The system dashboard allows OCTs to see how and when unit members are communicating; how events affect their communications (e.g., amount, timing, and content); and how communications vary across groups and time. This paper describes the exploratory use of the tool within the context of a single Army Staff training exercise that took place over 10 days. Observations regarding usability, utility, and validity of the tool were collected, with particular emphasis placed on the display of social network graphs calculated from wearable sensors capturing face-to-face interactions. Overall, OCT feedback indicated that the dashboard was intuitive and useful, and the information provided was consistent with OCT observations. OCTs also referenced the tool for specific time periods and interactions during the exercise. Additionally, social network diagrams were used as "hard data" for individual coaching sessions and the final AAR. This research supports the use of existing communications data for assessment and feedback in training.

ABOUT THE AUTHORS

Kara L. Orvis, PhD is a Principal Scientist and the Performance Assessment and Augmentation Division Director at Aptima. She has over 15 years of experience conducting military R&D with much of that experience being specific to the Army with areas of leadership, teams, assessment, and training. Dr. Orvis holds a Ph.D. and M.A. in Industrial-Organizational Psychology from George Mason University and a B.A. in Psychology from Ohio Wesleyan University.

Arwen H. DeCostanza, PhD is Chief (A) of the Real-World Soldier Quantification Branch at the Army Research Laboratory (ARL), Human Research and Engineering Directorate. Dr. DeCostanza has expertise in the areas of team and organizational performance, leading a program of research focused on enhancing performance in complex, networked teams. Dr. DeCostanza received her Ph.D. in Industrial and Organizational Psychology from The George Washington University and her B.A. in Psychology from Wake Forest University.

Tara A. (Rench) Brown, PhD is a Scientist in the Advanced Cognitive Training Systems Division at Aptima. She has expertise in the areas of training, unobtrusive measurement, team and multiteam systems, and leadership. Dr. Brown received a Ph.D. and M.A. in Industrial-Organizational Psychology from Michigan State University and a B.S. in Psychology from Wright State University.

Robert McCormack is a Principal Mathematician and Lead for the Organizational Performance Assessment Capability at Aptima. He has expertise in the areas of computational linguistics (NLP), machine learning, epidemiological modeling, and human sociocultural modeling and analysis. Dr. McCormack received a Ph.D. and M.S. in Mathematics from Texas Tech University, and a B.A. in Mathematics and Computer Science from Austin College.

Visualization of Communications Data for Enhanced Feedback in Army Staff Training

Kara L. Orvis, Tara A. Brown, Robert McCormack,
Aptima, Inc.
Woburn, MA
korvis@aptima.com, rmccormack@aptima.com, tbrown@aptima.com

Arwen H. DeCostanza
Army Research Laboratory
Aberdeen Proving Ground, MD
arwen.h.decostanza.civ@mail.mil

INTRODUCTION

Detailed assessment of organizational behavior over sustained periods of time has remained a challenge due to the subjectivity, cost, impracticality, and obtrusiveness of human observers and self-reporting via surveys (Waber, Olguín, Kim, & Pentland, 2008). Due to technological advancements, human behavior critical to organizational performance is increasingly more "observable," with computer-mediated communications, mobile technologies, and wearable data sensors in the workplace. Assessments rooted on this readily available systems-based data offer a number of advantages over observer and self-report assessments. First, system-based assessments are extremely efficient as they can reliably and continuously collect a wealth of information about individual and team processes and performance, without succumbing to the limitations of trained observers (e.g., fatigue, distraction, missed observations). Second, feedback based on system-based data tends to be well-received by the participants, because the results are perceived as "objective"; they are not subject to rating errors, such as the "halo effect" (Murphy & Balzer, 1989). Finally, system-based assessments can be captured unobtrusively, requiring no pause in or distractions from ongoing work activities and necessitating no time or effort from participants or observers.

In the last decade, the military has produced an exponentially growing amount of continuous data due to the rising use of Mission Command systems and other communication technology (e.g., sensors). Much of this data is communications based (email, phone, chat, document sharing) and offers up valuable digital traces that can be utilized to better understand how military teams are performing. Since 2009, the Army Research Institute (ARI), Defense Advanced Research Projects Agency (DARPA), and the Army Research Laboratory (ARL) have supported research aimed at utilizing existing communications based data in an effort to unobtrusively assess team performance. One set of research activities has focused on exploring the value of various visualizations of communications data for the purpose of team monitoring and assessment.

Most workplace communications data provides information about who is interacting with whom, for how long, across time, via some medium. Even simple data like that can be represented in visualizations that provide valuable insight into team member interactions. Figure 1 represents a simple social network display where the letters (nodes) represent members of a team, the lines and arrows represent the directional connections among the team members, and the numbers by the lines represent the amount of communications. Now consider that Person A was a key member of the team. This data may concern the leader of that team given there is a lot of communication with member B but no communication from B to the rest of the team. Images such as this have long provided meaningful insight into social data (Freeman, 2000). The purpose of this paper is to present the research on the use of social network diagrams in providing meaningful information to Observer/Coach Trainers (OCTs) for coaching and formal After Action Review (AAR) within the context of Army staff training exercises.

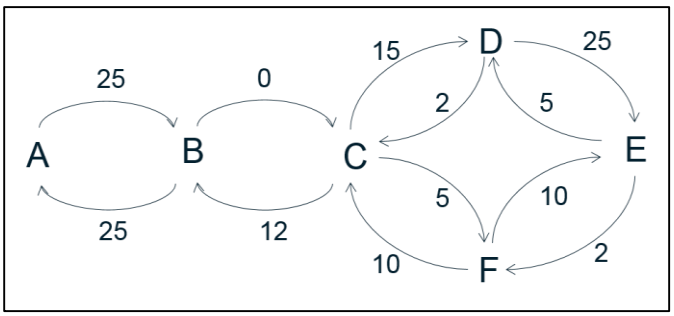

Figure 1: Example Social Network Diagram

Army Staff Training

The Army trains staff organizations at the Battalion level and above in Army Doctrine, Mission Command, and the Operations Process during realistic exercises that run 24 hours a day for ten days. These exercises assist the training unit in preparing for full spectrum operations in both decisive action and stability scenarios. The exercises generally consist of two phases: planning and execution. During the planning phase, units gather information about enemy forces, civilians, and terrain and determine a course of action using the Military Decision Making Process (MDMP). The execution phase often includes concurrent planning activities). Team coordination and states related to Mission Command, such as trust, cohesion, and shared mental models, are critical to the functioning on the staff organizations. The Army recognizes the critical role that effective teamwork plays in supporting mission outcomes and traditionally relies on the expertise of OCTs to assess how well the team is working together to accomplish the mission. OCTs relay this feedback to the units through individual coaching sessions, as well as mid and final AARs.

To properly coach Mission Command concepts, OCTs need to be aware of the synchronization of the staff and communications taking place within the training unit. While OCTs provide invaluable insight into strengths and weaknesses of units, monitoring and providing feedback to staff organizations on teamwork remains challenging. First, OCTs cannot easily access or review collaboration taking place via digital systems. While they can observe some of the face-to-face interactions occurring, most of the communications are hidden from view via radio channels, in digital streams like email, chat, videoconferencing, and VoIP, or in face-to-face interactions in other locations. In addition, resource reductions have resulted in fewer OCTs available for observation and coaching. Moreover, the teams performing in these environments are extremely large and complex, making it challenging for OCTs to gather a representative understanding of performance even when present to observe the unit.

ACCRUE Software Suite

This research program utilizes a software suite called the Automated Collaboration Collection and Relationship Understanding Environment (ACCRUE). The ACCRUE technology captures communications data via multiple sensors, codes and stores data for more complex analytics including network and content analyses, and visualizes the processed data in meaningful ways for specific training and/or operational needs. More specifically, within Mission Command training exercises, ACCRUE is used to 1) collect and organize communications data including email, chat, and face-to-face interactions using sociometric badges; 2) analyze this data for indicators of team states; and 3) display the levels of valid indicators in real-time (see Figure 2). The ultimate goal of ACCRUE is to provide leaders and trainers with a tool that automatically collects systems-based data and provides real-time assessments as to how members of a unit are working together as a team through their communications, allowing for appropriate and timely organizational interventions.

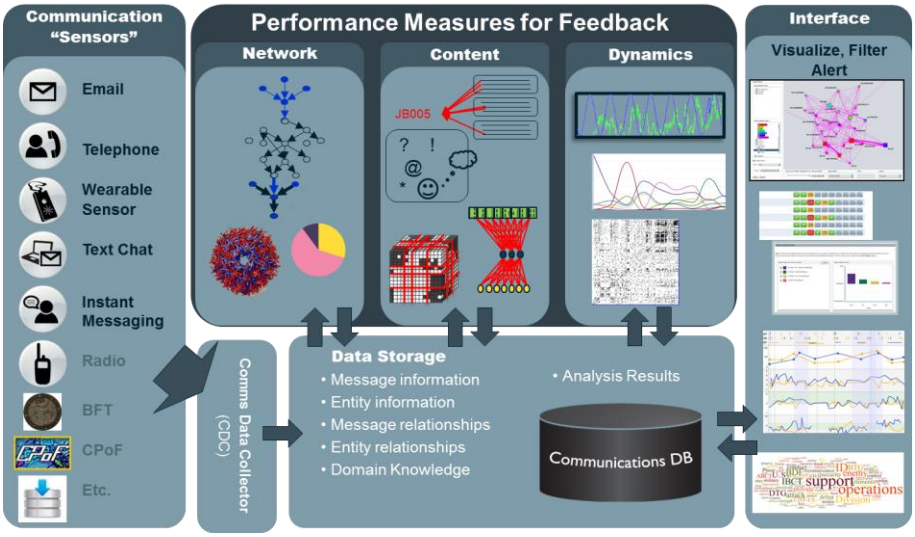

Figure 2: Overview of the Automated Collaboration Collection and Relationship Understanding Environment-(ACCRUE)

The Command Operations Dashboard

The Command Operations Dashboard (COD) is a user-interface within the ACCRUE software suite, which was developed specifically to allow OCTs[1] to see what and when unit members are communicating; how events affect their communications (e.g., amount, timing, and content); and how communications vary across groups and time. The version of the COD (Figure 3) used in the training exercise presented in this paper had four components: a Filter component (left of screen), a Timeline view (top of screen), a Social Network view (center of screen), and a Terms view (right of screen). The *Filter* components allow users to select and deselect messages based on the groups of individuals involved and the type of communication medium (e.g., email, chat). The People panel updates as the filters change to show a list of currently selected individuals by role, rank, and name. As these filters update, the other views will reflect only data based on the current selection parameters. The *Timeline* view shows a line graph of the overall volume (number of) communications over time as well as a "swim lanes" visualization of exercise events. Intervals are depicted as bars, while events are shown as tick marks below them. Users can also use the sliding bars to select a specific timeframe down to a 15 minute interval. The *Network* view shows all the currently selected individuals as nodes, while the lines, or edges, connecting two nodes represent the communications between pairs of individuals for the selected timeframe. The thickness and strength of an edge reflects the number of communications shared between the pair. The graph uses a force-directed layout so that people who communicate more frequently will be drawn closer together, while those that are more isolated will fall on the outside of the graph. Additionally, if a user hovers over a person node they can view the amount of communications taking place via the medium selected. Finally, the *Terms* view shows a sorted list of the most frequently used terms in communications that match the current filter settings.

Within the context of training, the COD and underlying ACCRUE software is presented on a standalone system (laptop) and placed in a location accessible by OCTs. Communications data, to include face-to-face, chat, and email, are running real-time (email and chat) or downloaded daily (in the case of face-to-face data). OCTs are able to interact with the user interface and explore the data at will to look for patterns that support their training feedback or to explore the working relationships among staff members.

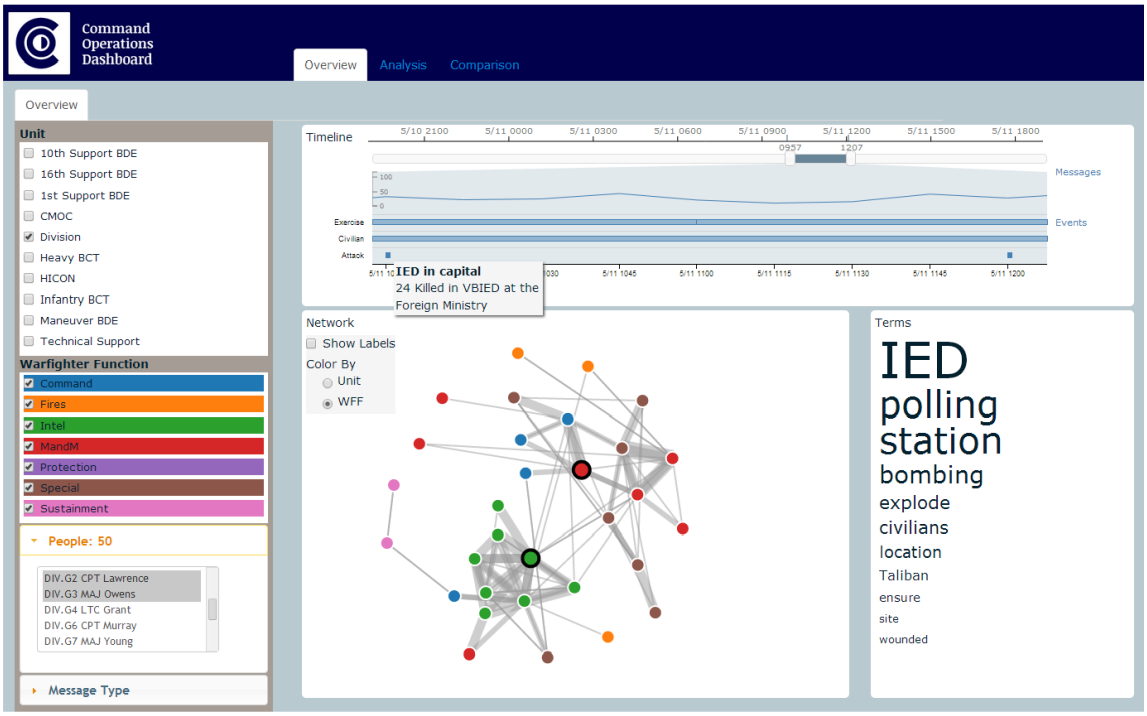

Figure 3. The COD User Interface

[1] A paper presented at International Command and Control Research and Technology Symposium describes the ACCRUE technology method by which the requirements for the COD were collected and vetted (Duchon, et al., 2014).

METHOD

Participants and Procedure

The COD and supporting ACCRUE technologies were deployed at a ten-day, 24/7 brigade-level training exercise that included a brigade staff and six battalion staffs. Prior to the exercise, the researchers obtained permission from the training organization and the training unit to deploy the ACCRUE technology. The computer running the COD interface was located in the room next to the OCT working space, which OCTs used when not observing the unit. Researchers introduced the tool to OCTs upon request and kept notes associated with perceived face-validity of the data, usability of the COD, and the utility of the social network displays in individual coaching and AAR activities.

Email and chat communications data were collected unobtrusively from all staff members (Brigade and support Battalions staff members) continuously over the course of the exercise. In addition, sixty-five participants representing key roles in the brigade and battalion staffs (confirmed by the OCTs) wore Sociometric Badges (Olguín et al., 2009), to capture face-to-face communications. Due to the classification level of the chat and email, only the face-to-face communications data for those sixty-five key staff members are presented in this paper.

Sociometric Badges are sensors approximately the size of a deck of playing cards and are worn on a lanyard around the neck or are clipped to an individual's shirt or vest. The badges contain several commonly available sensors in a single enclosure. The primary data stream used for the visualization of face-to-face networks was infrared (IR). The badges are designed to send a directional IR signal at a frequency of one "ping" per second (the time is adjustable). The IR pings sent from one badge can be received by another badge that is oriented toward the sending badge within a 30-degree cone at a maximum distance of eight feet. A time stamp is recorded by the receiving badge when the signal is received. A string of sequential IR pings separated by less than six seconds was operationalized as a face-to-face interaction, or conversation. The Sociometric Badges are not officially part of the ACCRUE tool (neither were the email and chat programs), but rather the selected data source for capturing face-to-face interactions. ACCRUE is agnostic of where the communications data comes from.

While IR sensors capture signals between any two badges that are facing each other, they do not collect information about the nature of the interaction (e.g. mission-related issues or social issues). More importantly, perhaps, are the false negatives that can occur when two roles are interacting but not facing each other or have their badges obstructed (e.g. in this exercise the Battle NCO and Battle Captain were often facing their Command Post of the Future (CPOF) stations and were talking with others to their backs). Finally, due to the battery life limitations (they needed to be charged each night), face-to-face data was collected during the hours of 0600 to 1800. All results should be interpreted with those limitations in mind. However, even with these limitations, the sensor captures the bulk of interactions and provides unique insight into the interaction patterns among staff members.

RESULTS

Providing visualizations of social network diagrams via communications data networks for the purpose of assisting OCTs in assessing military teams is a novel approach within the context of Army training organizations. As an initial evaluation effort, the research team collected feedback from OCTs and made several observations about the validity of the network data, the usability of the COD, and the utility of the network diagrams.

Validity

In order for the COD to be adopted by OCTs, it is critical that the data presented in the network visualizations are perceived as face-valid. OCTs (and unit members) need to have confidence that the data presented are representative enough of what is actually happening. As mentioned previously, although the bulk of interactions are captured by the badges, there is some error in the data collected via the IR signals. As an initial assessment of face-validity, we asked OCTs on a regular basis if the network data was accurate based on their observations of the unit within the same time periods. Aside from a couple of roles in which the participants were constantly at their computers (e.g. the Battle NCO), OCTs generally felt that the network visualizations were "face-valid" and represented the staff interactions they were observing. Another indication of face-validity was that several OCTs used the tool to explore how the personnel they were observing were interacting with others. They also used printouts of the network visualizations to show to the training unit. The OCTs use of the visualizations as a training and coaching tool provides strong support

of its face validity; if they doubted its validity, they would not have been comfortable using it as a training tool with the unit.

Usability

There were two groups of OCTs using the COD. One group was familiar with the user interface as they had participated in prior development efforts, while the other group had not previously been exposed to the tool. Our usability observations focused on the group of OCTs that were not familiar with the tool. Generally speaking, all OCTs who were not familiar with the COD were hesitant to use it. Upon first glance, OCTs felt the network diagrams were unfamiliar and looked complicated. After talking with OCTs more familiar with the tool, a few of the newer OCTs were willing to sit down with the researchers and sit through a 5-10 minute orientation. As the training exercise went on, more OCTs came by to be introduced to the tool, and in all cases, OCTs were able understand the display, how it operated, and how to read the network diagrams. They were able to apply their expertise and identify when relationships looked "right" or "wrong."

Although the OCTs found the tool to be intuitive after a quick training session, they preferred to have the researchers run the tool. Some of the OCTs would stop by the desk where the COD was sitting and ask the researchers to look at communications among specific people at specific time periods and print a picture out for them. Other OCTs would sit down at the desk with the researcher and tell the researcher how to explore the data. Based on the researchers' observations, this was similar to how OCTs interacted with analysts supporting the unit for other data analytic systems.

Utility

The final purpose of this research was to gather some initial data as to whether the network visualizations provided utility to OCTs and the training unit. Given that the requirements were gathered by prior OCT observation and interviews (Duchon et al, 2014), it was anticipated that the tool would be useful to OCTs. However, this was the first time testing it live at an exercise. Three notable observations regarding the utility of the network data are presented below.

The Brigade Commander Indicated Enthusiastic Support for the Visualization of the Data

As part of this research, we requested permission from the Brigade Commander for their unit to participate in the study. The Brigade Commander for this unit was rather wary of the badges and although he agreed to have his unit participate, he was not sure how this "research" would be useful to him. After about two days into the exercise, the Brigade Commander found the lead researchers and told them that he could see how access to this data would complement his personal observations of his staff. He requested to see the data throughout the exercise. With OCT permission, the researchers obliged. As with the OCTs, it was easy to train the Brigade Commander on how the COD operated. He found value in the tool visualizations and asked to see several views of the data. At the end of the training event he requested a full report from the researchers. In addition, during the exercise he requested that we show the data to his visiting leadership (a Brigadier General and Major General) who were also complimentary of the tool. All of those stakeholders indicated that the social network visualization provided a valuable view of his organization, particularly as they were able to look at it both within specific time periods and across time.

As an example, Figure 4 displays a graphic that the Brigade Commander found useful. The social network diagram depicts Brigade staff face-to-face interactions over the course of the first seven days of the exercise. Staff members with the most connections to others in the network are presented near the center of the network. Staff members with the fewest connections to others are presented on the outside of the network. Staff members that are not well connected to each other (i.e., with several degrees of separation between them) are on opposite ends of the network (e.g. in Figure 4 the signal chief and CSM are not well connected via face-to-face communications). Using this specific visualization, this Brigade Commander reported that he was able to assess (based on his estimate of what the gold standard should be) the extent to which his staff was synchronizing in the manner he preferred and gave related feedback to his unit. Using this data, the Brigade Commander was able to confirm his general assessment that the Brigade staff was well connected and resilient (meaning there were lots of interdependencies among the staff). Key coordinating staff, such as the Brigade Executive Officer (XO), Brigade Operations Officer (S3), Information Operations (IO), and Chief of Operations (CHOPS), were central to the network. Further, the CDR himself was well integrated with those key members but generally off to the side, allowing them to train on and execute their roles. The Brigade commander

noted that the Intelligence (Intel) staff members were on the outer edges of the network and maybe should have been better integrated into the staff.

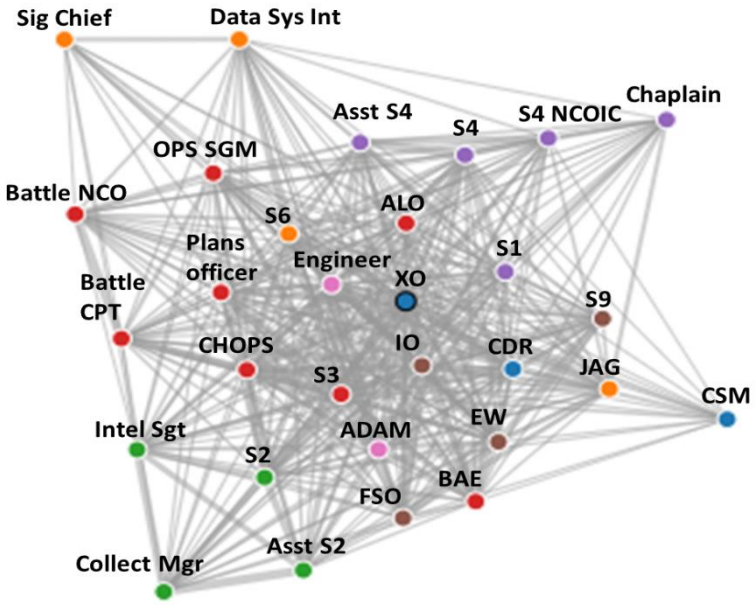

Figure 4: Brigade Warfighting Functions Network Diagram

Data Visualizations Provided Supporting Evidence for OCT Observation of Staff Synchronization

In general, OCT observations suggested that this unit was fairly strong in terms of staff synchronization and reported that the visualizations confirmed that assessment. Figure 5 shows the entire Brigade and Battalion staff network. From a researcher perspective, this represents a healthy and well-connected multi-organizational network. Such networks are characterized by high levels of cohesion within and among different units. For example, the Brigade staff in this figure have many ties to the battalion level within each of the battalions. By maintaining these open, extensive communication channels, units have regular opportunities to communicate and share important information. By contrast, a less healthy network would be less cohesive and have fewer ties among units and individuals. For example, if the two infantry battalions only had ties to the Brigade, and not to each other, then all coordination that needed to occur between these battalions would have to go through the Brigade. Not only does this slow down information transmission in the network, but it puts excess workload on members of the Brigade staff. In our observed communication network, OCTs noted that the two Infantry units were well connected. In addition, the Brigade Special Troops Battalion (BSTB) and Brigade Support Battalion (BSB) were integrated. Interaction patterns within the Field Artillery (FA) battalion were slightly different than other battalions, because the commander served as the Brigade Fires Support Officer (FSO), and was therefore interacting more with Brigade staff members. The Brigade Commander and OCTs agreed that the unit was high functioning throughout the training exercise. Overall, this network display was complementary to this subjective assessment.

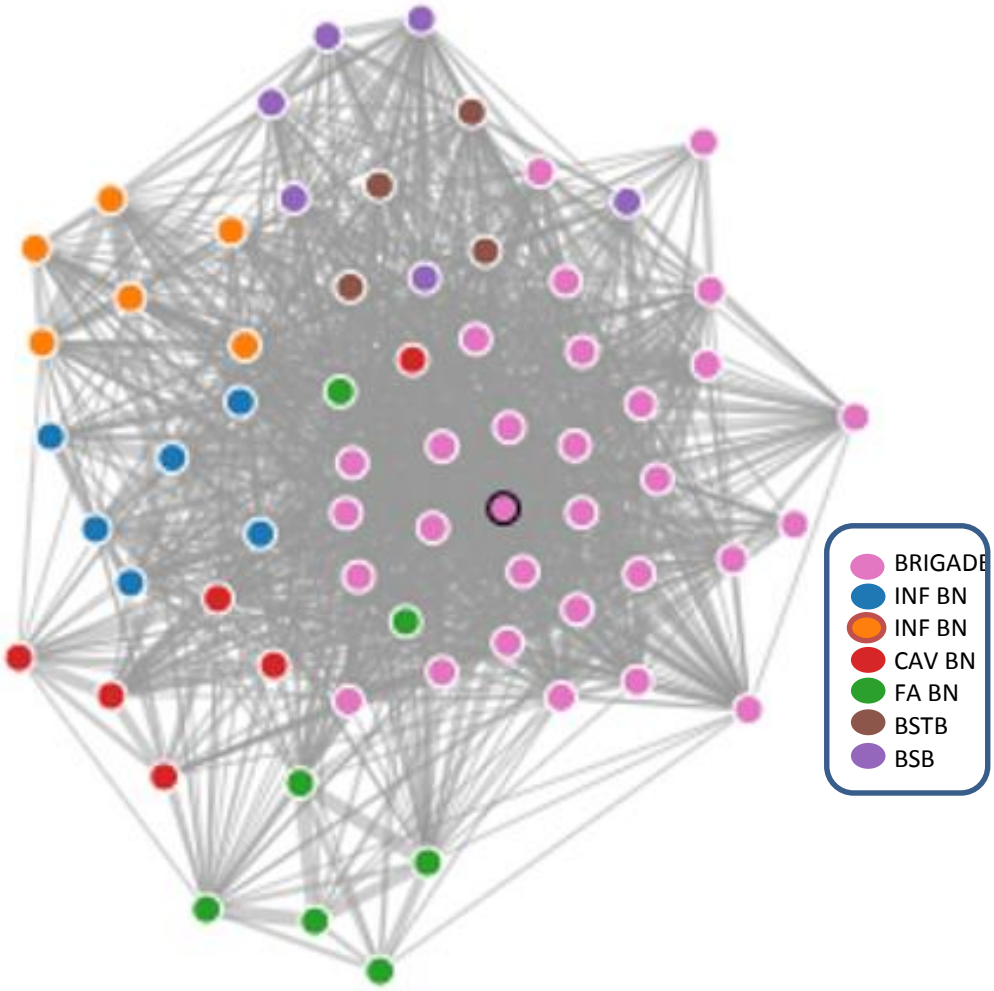

Figure 5: Entire face-to-face network captured via sociometric badges

As another example in which the data supported observations of the OCTs, Figure 6 visualizes the interactions between the brigade staff and supporting Battalions (BNs) as with the nodes representing groups. The figure indicates that the Brigade and battalions had reasonable face-to-face connections, with all battalions demonstrating strong connections with the Brigade. Most of these interactions were happening at key meetings, such as the Combined Arms Rehearsal, but there was also representation by LNOs and BN leadership within the Command Post. The star pattern also suggests a symmetrical pattern of face-to-face communications between battalions, highlighting the interconnectivity of each of the battalions throughout the exercise.

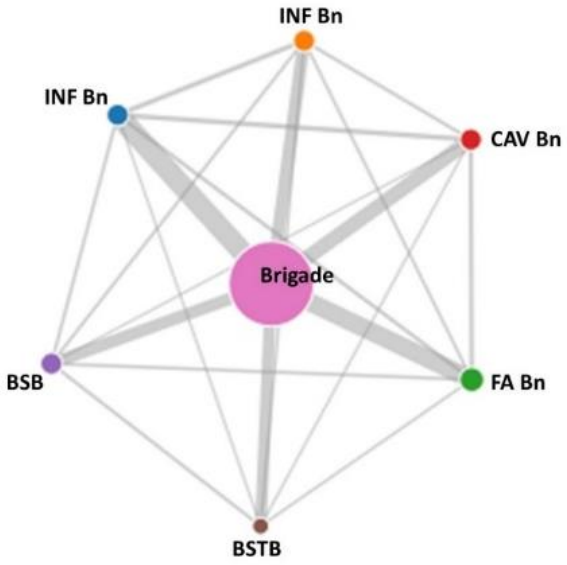

Figure 6: Brigade and Battalion Network

Data Visualizations Provide Hard Evidence for OCT Coaching

The most eye-opening observation with regard to utility was that OCTs found the data provided "hard evidence" in cases where the unit was not buying into their subjective observations. OCTs reported that a common issue for them is that their feedback is often seen as subjective, particularly as it relates to feedback on issues related to teamwork, staff synchronization, and the effect of personality issues on collaboration between critical roles. They found that the presentation of this data gave more weight to some of the feedback they were giving to units.

As an example, Figure 7 shows the Brigade Intel, Movement and Maneuver, and Command Team members' network during the main planning period (picture on the left) and the first few days of the simulated portion of the training (picture on the right). Wider lines between individuals indicate larger volumes of communication between them. As seen on the diagram on the left, during the front end of the exercise, the CHOPS, XO, and S3were central and communicating frequently. However, the OCTs observed there was some indication that these key positions were stepping into each other's roles. The OCTs coached these key members on the differences between their positions and saw positive progress. During the simulation phase (right diagram), the data show that although they continue interacting, they are interacting more with other nodes in the network, making an overall stronger network. Note that CHOPS is more tightly connected with the Battle Captain, Battle Non-Commisioned Officer (NCO), and Operations Sergeant Major, who becomes more centralized in the network to help run operations. The OCTs presented this data near the end of the exercise to provide evidence as to the impact their actions had on the rest of the staff.

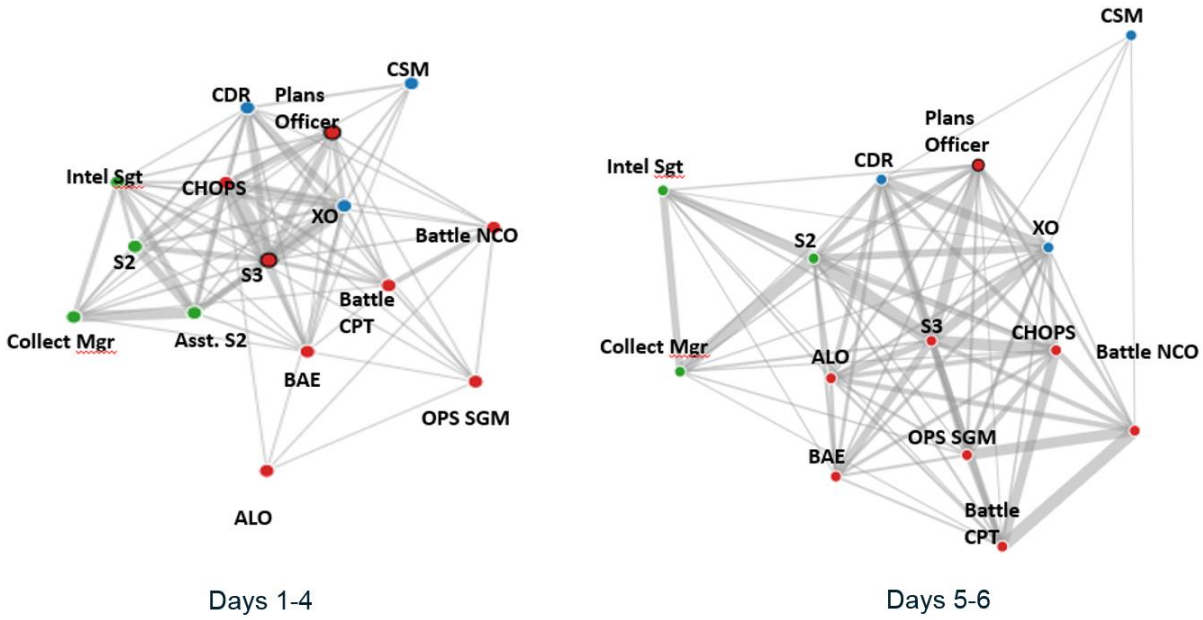

Figure 7: Intel, M2, and Command Team network before and after Start Ex

Figure 8 presents another example in which the JAG was having a difficult time understanding their role in the staff. For the first five days of the exercise, the OCT assigned to the JAG observed that they tended to stay near their assigned desk and did not attend coordination meetings or interact much with the rest of the staff. This activity was represented in the graph on the left of Figure 7. The OCT showed them this data to make the point that they needed to be more integrated and coached the JAG on their role and what he had to offer to the staff. On day six, the OCT felt like things clicked with the JAG and they were finally coordinating well with the rest of the unit. In fact, this was represented on the graphics to the right in which the JAG move into being more central with the other key staff members.

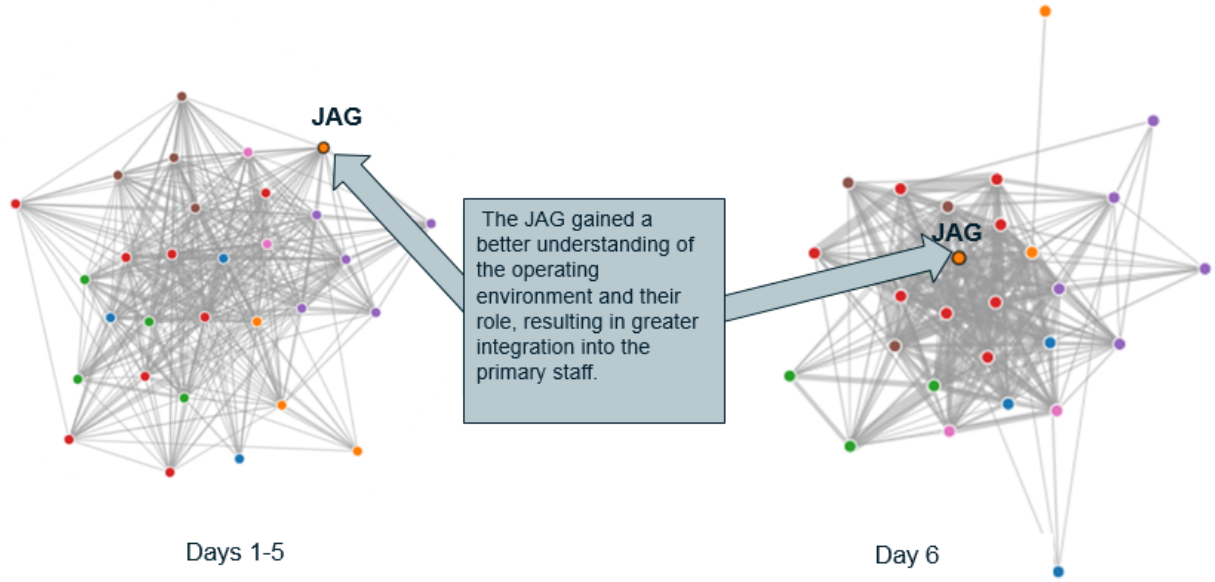

Figure 8: JAG Integration into the Staff

Summary and Future Research

The purpose of this research was to conduct an initial investigation on the use of communications driven social network visualization within the context of Army training, investigating the face-validity and utility of the data captured as well as the usability of the COD user interface. Overall, the reactions to the tool and social network visualizations were positive. The Brigade Commander was supportive and found the data gave him a critical view of his organization. OCT feedback indicated that the dashboard was intuitive and useful, and the information provided was consistent with OCT observations. OCTs also referenced the tool for specific time periods and interactions during the exercise. Additionally, network diagrams were used as "hard data" for individual coaching sessions and the final AAR.

Assessment is moving toward unobtrusive and real-time metrics. By leveraging multi-source, continuous streams of data, rather than obtrusive, static self-reports, we can start to uncover complex patterns of team behavior. This research provides some compelling evidence that the use of communications-based visualizations, such as social network diagrams, are useful in the assessment of Army staff organizations. The results from this work are expected to make important contributions to both research and operational communities. However, more controlled research is needed to better assess the impact of such visualizations on the effect of team learning and movement towards organizational interventions.

The COD interface was developed specifically for OCTs in support of providing better assessment and training for units. However, there are additional ways of leveraging and extending the technology. As an example, Soldiers have suggested that the COD would be useful command tool for leaders to better monitor and understand their organizations. Imagine if a commander could visualize how incoming Soldiers were settling into the organization or a new position. Or if leaders were able to evaluate their staff over time as they gained experience in operational settings. Research will continue to explore the use of the COD for leaders outside of the training domain. In addition, the underlying ACCRUE technology has a broader and flexible structure upon which to build additional visualizations and user interfaces for knowledge management, talent management, and other purposes. Continued research on these applications will be explored. Finally, continued research and development will also be conducted to incorporate quantitative measures related to human performance. Such data would facilitate the use of qualitative data presentations like the network diagrams.

ACKNOWLEDGEMENTS

This work was supported by DARPA, ARI, ARL, and OSD. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, by any of the government supporting organizations. The authors would like to expressly thank the OCTs for allowing the research team to develop requirements and test the tool within the context of their mission. We also thank the many units and Soldiers who allowed us to collect their communications data. We also appreciate the continued support of the Mission Command Center of Excellence, and the Mission Command Battle Lab in validating the use of this research for training purposes.

REFERENCES

Duchon, A., Orvis, K. L., DeCostanza, A. H., Rench, T., Wade, H., Sullivan, S., & Ziemkiewicz, C. (2014). *The command operations dashboard: A common operating pictures of the operators.* The 19th International Command and Control Research and Technology Symposium. Alexandria, Virginia.

Freeman, L. C. (2000). Visualizing social networks. *Journal of social structure*, *1*(1), 4.

Murphy, K.R., & Balzer, W.K. (1989). Rater errors and rating accuracy. *Journal of Applied Psychology, 74*(4), 629-624.

Olguín, D. O., Waber, B. N., Kim, T., Mohan, A., Ara, K., & Pentland, A. (2009). Sensible Organizations: Technology and Methodology for Automatically Measuring Organizational Behavior. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, *39*(1), 43–55. doi:10.1109/TSMCB.2008.2006638

Orvis, K. L., Duchon, A., & DeCostanza, A. H. (2013). *Developing systems-based performance measures: A rational approach.* A proceedings paper presented at the Interservice/Industry Training Simulation, and Education Conference, Orlando, FL.

Waber, B.N., Olguin, D.O., Kim, T., & Pentland, A. (2008). *Understanding Organizational Behavior with Wearable Sensing Technology*. Academy of Management Annual Meeting. Anaheim, CA. August, 2008.