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Collaborative Awareness: Experiments with Tools for Battle Command

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ABSTRACT

In this paper, we report on the findings of recent experiments conducted by the Multicell and Dismounted Command and Control (M&D C2) program jointly conducted by Defense Advanced Research Projects Agency (DARPA) and the US Army to investigate operational implications of using a new approach to battle command and control (C2). The approach is predicated on synthesized and analyzed information presented to the commander and staff organized into a small command cell. We present an experimental design, and data collection and analysis methodology that allows for exploration of the cognitive processes of the commanders and staff. The experimental methodology helped the program team to determine and analyze the factors that influenced the decision making and collaboration processes of the commanders and staffs in the tasks of battle command.

Introduction

As the United States (US) Army develops its future force [1], and in the process begins to rely heavily on superior information and speed to augment its armor and firepower, battle command tools and techniques must change as well in order to provide the commanders and staff with superior information, processed and analyzed in a manner that allows for improved situational awareness (SA) and decision making.

In the fall of 2000, DARPA and the US Army began the Future Combat Systems Command and Control (FCS C2) program [2] to develop execution-based battle command prototype software with integrated battlefield functional areas (BFAs) and a reduced staff to address the need for future battle command tools. In addition to the prototype software, the FCS C2 program developed an extensive laboratory for experimental analysis of the software and battle command techniques for the future force. Between October 2000 and May 2003, this program executed five experiments in which military officers executed simulation-based wargames against a free-play opposing force. As a result, the prototype future force battle command software was developed through collaboration between warfighters and technologists working to design solutions for future battle command.

While FCS C2 was seen as a successful program, it addressed only part of the required solution by providing a new command and control capability for the so-called Unit Cell, a notional combined-arms experimental force designed specifically for the purposes of these DARPA/Army program experiments. In order to provide a full battle command solution for the network-centric environment envisioned for the US Army future force, a multi-cell (multiple force elements) and multi-echelon environment allowing for control and collaboration between peer units and across echelons would be needed.

In October 2003, DARPA and the Army again teamed up on the M&D C2 program [3]. The purpose of this program was to leverage the command and control capability built within the FCS C2 program and to expand it for multiple echelons, from the individual dismounted Soldier to the brigade level and above. Additionally, the experimental testbed would be expanded to allow for experimentation with multiple peer units and across multiple echelons. With this expanded approach came the requirement for extensions in experimental design and analysis methodologies. The M&D C2 team set out to design a controlled experiment and an analysis framework that would allow for exploration into the commanders' and staffs' cognitive processes to determine what software tools, information, and collaboration activities impacted their key decisions and influenced the outcome of the battle. Since May 2003, the M&D C2 program has completed two experiments with the third and final experiment to be completed in January/February 2006. In these experiments, it has been shown that the M&D C2 battle command system capability to continuously and autonomously fuse data providing the commander and staff with a shared situational portrait enables SA and facilitates situational understanding required for effective command.

The remainder of this paper discusses the components of the M&D C2 battle command system prototype, the motivation for and objectives of the experiments, the experimental design and methodology, the data collection and analysis methodologies, and a selection of the key findings from recent experiments.

Battle Command Support Environment

The Battle Command Support Environment (BCSE) is the main software product of the M&D C2 program and constitutes a battle command decision support system that integrates the BFAs. It provides the commander and his/her staff with a toolset for collaborative planning and execution of the battle across multiple echelons. The BCSE consists of the Commander Support Environment (CSE), the Soldier Support Environment (SSE), the Platform Support Environment (PSE) and the Collective Intelligence Module (CIM). Each of these components and the capability it provides in the multi-echelon C2 environment is described below.

Commander Support Environment

The CSE is a digital command and control system that provides the commander and his/her staff with an interface for pre-mission collaborative planning and command and control during mission execution. The CSE's graphical user interface (GUI) conveys the current battlefield situation to the commander and staff fusing the large flow of input data and presenting information in a relevant Common Operating Picture (COP) based on commander's intent. The CSE integrates multiple BFAs by providing the ability to task and retask battlefield assets, monitor execution, and facilitate maneuver, reconnaissance, and effects management through a single GUI.

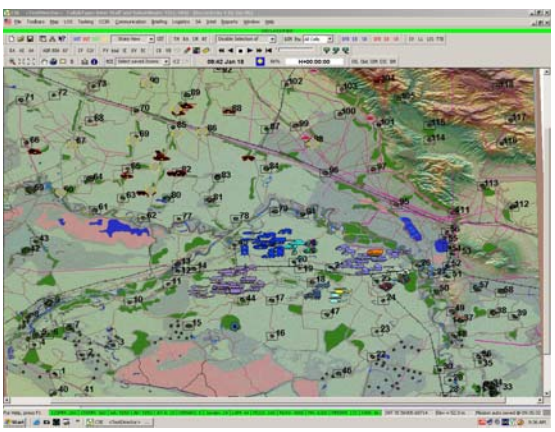


Figure 1. An example configuration of the Commander Support Environment (CSE).

Figure 1 shows an example configuration of the CSE GUI. The CSE allows the user to configure the GUI such that processed information is provided and displayed based on their preference and intent. The user has the capability to specify display and location of toolbars and windows as they desire. The CSE provides multiple map view options including 2-dimensional (2-D) and 3-dimensional (3-D) displays. The user can specify parameters governing display of map size, icons, gridlines, contours, features, etc. Additionally, the user can set alerts that trigger pop-up windows when specified events occur (e.g., engaged by enemy, friendly entity dead, target detection, etc.). The CSE provides flexibility to accommodate the preferences of different commanders and staff performing various functions.

During the planning phase, the CSE is used by the commanders and staff at multiple echelons to develop plans simultaneously and collaboratively. The CSE provides tools that allow for collaborative briefings to take place across vertical and horizontal echelons. The briefing tools allow all users participating to interact in the briefing by using pointers and drawing tools and/or by placing icons and graphic control measures (GCMs). Additionally, the users have the capability during planning to develop reconnaissance and surveillance (R&S) plans and pre-program assets to search specific areas and fly specific routes. The CSE contains tools that assist the planner in coordinating and synchronizing an R&S plan and determining optimal flight areas for maximum coverage. Additionally, the CSE allows for ground or air assets to be dedicated to battle damage assessment (BDA) when targets are engaged. The CSE also provides tools for planning effects. Prior to mission execution, the CSE allows for the configuration of an attack guidance matrix (AGM) specifying what types of weapons should be used against targets of varying priorities. Additionally, the CSE allows for pre-planned fires against suspected target locations. The CSE provides planning tools for ground maneuver as well. Tools can be used to analyze terrain and determine the fastest or most concealed route for ground vehicles. The best route can then be assigned to a specific platform or a group formation to execute when the mission begins. The planning tools provided by the CSE help to achieve a more consistent and complete SA among commanders and staff, and between echelons.

During the mission execution phase, the CSE presents the current battlefield situation to the user via the GUI. The user has the capability to monitor the progress of the mission and make changes to the platform tasks on the fly as necessary. The CSE contains a synchronization matrix that assists the commander and his/her staff in determining whether all platforms involved in the mission are synchronized and on schedule to complete tasks as configured during the planning phase. The intelligence manager can monitor execution of the R&S plan and re-task platforms to perform BDA or reconnaissance of specific targets or areas as the situational picture changes. As suspected targets are detected during the battle, the CSE fuses target information and provides a detection catalog and an human target recognition (HTR) interface to the user for reviewing target images and data and specifying the target's (e.g., vehicle's) type and affiliation. If configured to do so, the AGM will then automatically fire at confirmed enemy targets using the preferred weapons as specified during planning. If not configured for automatic fire, the AGM can recommend a weapon for the user to select against each target. The CSE also contains a threat manager that determines the highest threats to the unit and allows the user to view location and images of the threat targets and engage those that pose the highest threat. Individual friendly ground vehicles and formations can be modified and re-tasked throughout the battle in response to the dynamic operational picture. The mission execution tools provided by the CSE allow the commanders and staff to monitor the battle in real time and to act on the processed information through modification of tasks and identification and engagement of targets.

Soldier Support Environment

The SSE is a scalable version of the CSE which provides SA, planning, and control to a dismounted infantryman via a simulated helmet-mounted display. Soldiers can transmit information, in the form of reports, imagery, or fire requests to any other C2 node. The SSE has a tailorable interface that allows for 2-D and 3-D visualization, mission-specific plans and graphics, text messaging and voice communications among SSEs, terrain analysis tools, and alerts.

Platform Support Environment

The PSE is a middleware decision support system that translates high level CSE tasks into platform level sub-tasks. This middleware compensates for limitations in existing battle simulation systems by translating Unit Cell commands into lower-level commands understood by the various simulation systems. The PSE then "listens" to data coming from the programmed, simulated entity and reprograms that entity to accomplish Unit Cell commands and satisfy requests from other entities. The commander tasks these robotic platforms through interfaces on the CSE.

Collective Intelligence Module

The CIM, aware of the commander's intent and the current tactical situation, defines a unit's automatic and recommended behaviors through the use of a knowledge based system. The results of the knowledge base activity trigger automated recommendations or actions, dependent upon commander's configuration of settings, in the form of survivability, reconnaissance, recommended or automatic fires, and BDA. Additionally, the CIM provides the CSE with alerts and cues of critical operational events based on the Commander's Critical Information Requirements (CCIR). The commander configures these rules through interfaces on the CSE.

Experiment Design

Motivation and Objective of the Experiments

The motivation and objective of the program's experiments were to explore the ability of the BCSE to support the information load and cognitive demands of future network-centric forces and utilize this system to determine the key capabilities, decisions and collaboration activities across multiple echelons that influence the battle. Figure 2 depicts the purpose of each experiment.

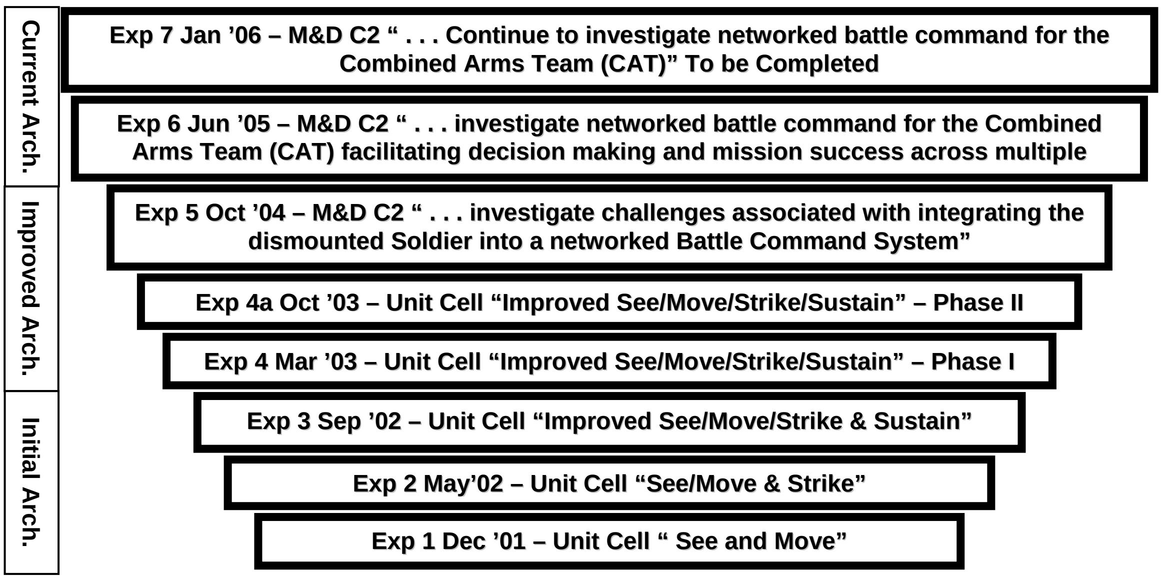


Figure 2. As the program progressed, focus of the experiments changed from investigation of single echelon battle command capabilities to multiple echelon capabilities.

Experiment Methodology

The experimental process and methodology was developed with the above motivation and objectives in mind. The experimental architecture evolved as the functionality of the BCSE increased and additional echelons were added to the experiments. Initially, the Department of Defense Architecture Framework (DoDAF) was utilized in an FCS C2 Study to determine the functions that were required in the battle command and experiment architecture. The architecture was built such that data collection and analysis could be conducted at every node and the results of the analysis could be used to feed the spiral development process. After each experiment the architecture was refined and improved.

The experiments were conducted in a simulation-supported, real-time, combined constructive and virtual environment located within the M&D C2 laboratory operated by the Program Executive Office for Simulation, Training, and Instrumentation (PEO-STRI) in Orlando, Florida. The base simulation used to model blue, red and neutral forces was a modified version of OneSAF Testbed (OTB). Attached to OTB was the Sensor Effects Model (SEM) which provided high-fidelity physics-based modeling of various sensor types. Also attached to OTB were a Mine Server, SNAP Server (Image Generation), Synthetic Virtual System (SVS), Driver Simulation, Gunner Simulation, and BCSEs. Data collection loggers were attached to each of these models across the simulation architecture to capture the relevant data flowing through the system for post-run analysis.

Recent experiments consisted of two pilot test runs and eight record runs. One record run was conducted each day for eight days, each run representing a single simulated battle (wargame). A run was executed in the free-play mode, i.e., each side was allowed and was capable of executing those actions is considered most advantageous to itself, as the situation unfolds. The area of operations (AOR), the force composition and the performance parameters of the combat systems involved remained the same between runs.

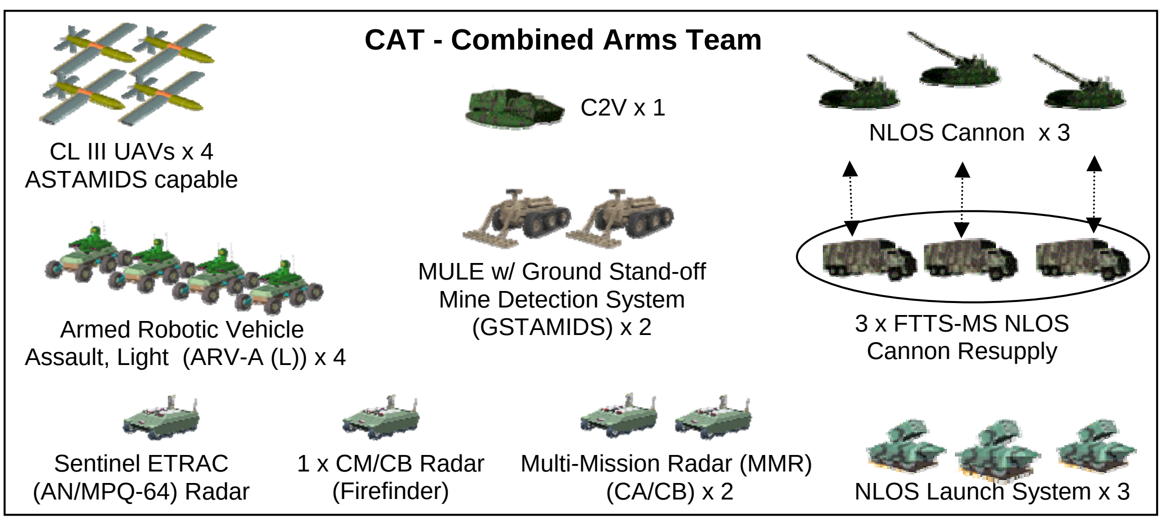
Control of blue entities was performed by a blue cell with approximately 20 human wargamers of varying levels of experience utilizing the BCSE and OTB. The blue wargamers were active duty or retired Army Soldiers with a variety of backgrounds and military experiences. Blue team members participated in a two-week in-class training course that was focused on teaching the participants how to use the BCSE. Control of red entities was performed by a red cell of approximately seven experienced human wargamers utilizing a specially developed red battle command system and OTB. The red wargamers were retired military officers from the U.S. Army, U.S. Air Force and U.S. Marine Corps with extensive operational and command experience. The red force was a part of the Training and Doctrine Command (TRADOC) Deputy Chief of Staff for Intelligence (DCSINT) World Class Opposing Force (OPFOR) Team. OPFOR participants also received two-weeks training prior to the experiment.

The experiments were conducted according to a set battle rhythm: specific steps were executed on schedule prior to and following each record run. Each experiment spanned two weeks.

Experiment Scenario

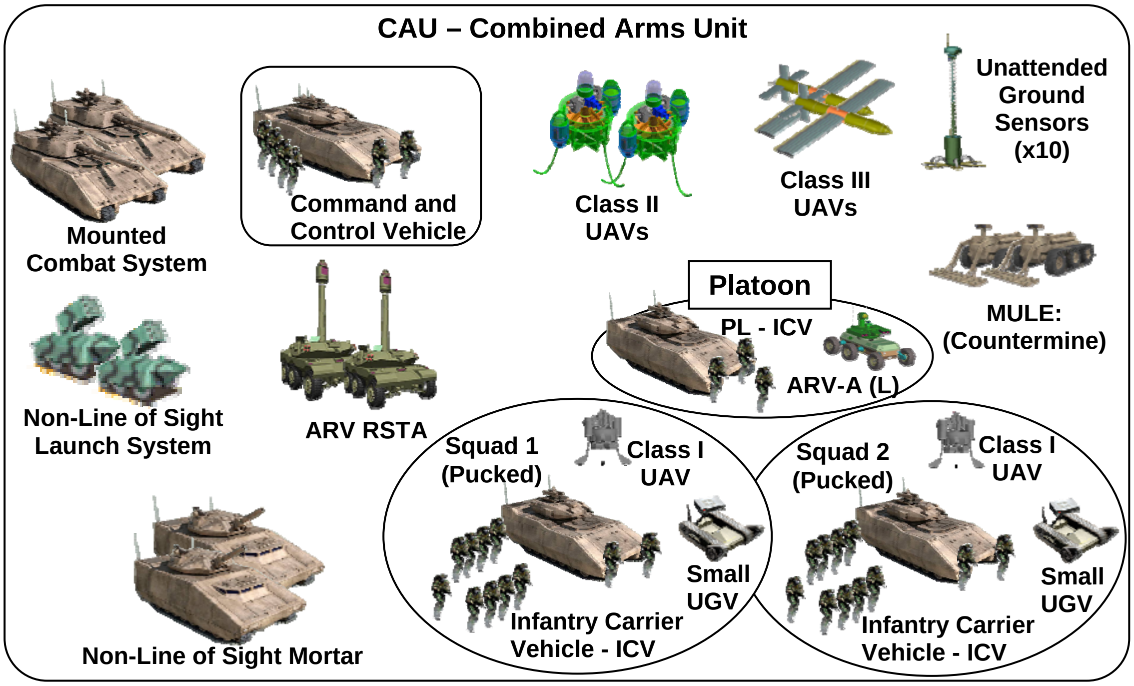
The most recent experimental scenarios were derived from a TRADOC-approved Caspian Sea scenario. The scenario was set in a river depression. The terrain was approximately 50 kilometers by 100 kilometers and was generally flat consisting of sandy soil, hard packed soil, swamps, wooded areas, and town areas with buildings. All operations were conducted during the day with clear weather conditions.

The experiments modeled two notional units of force called Combined Arms Units (CAUs) that reported to a single Combined Arms Team (CAT). Each CAU consisted of a platoon that controlled two squads. The CAT reported to a single Higher Headquarters (HHQ) commander notionally in charge of a Brigade Combat Team (BCT) as part of a Future Force Division. Figures 3 and 4 show the organizations of CAT and CAU. The CAT and CAU were developed as purely notional organizations for the experimental purposes and were not related to any specific plans for Future Force organizations.



MULE = Multifunction Utility/Logistics Equipment
CM/CB = Countermortar/Counterbattery Radar
ETRAC = Enhanced Target Range and Classification Radar
CL III UAVs ASTAMIDS capable = Class III Unmanned Aerial Vehicle with Airborne Standoff Mine Detection System
FTTS-MS = Future Tactical Truck System – Maneuver Sustainment
C2V = Command and Control Vehicle
NLOS = Non-Line of Sight

Figure 3. CAT organizational structure showing type and quantity of manned and unmanned assets.



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MULE = Multifunction Utility/Logistics Equipment
UAV = Unmanned Aerial Vehicle
ARV-A(L) = Armed Robotic Vehicle – Assault, Light
ARV RSTA = Armed Robotic Vehicle – Reconnaissance, Surveillance and Target Acquisition
ICV = Infantry Carrier Vehicle
UGV = Unmanned Ground Vehicle
PL = Platoon

Figure 4. CAU organizational structure showing type and quantity of manned and unmanned assets.

The red force was composed of four motorized rifle battalions, one self-propelled artillery battalion and a surface to air missile battery. It also included a mix of special purpose teams and insurgents. Figure 5 depicts the red force structure. These forces began each record run at 50% of full strength. In addition, a number of civilian and armed neutral entities were inserted in this scenario and the blue force was required to identify targets as enemies (as opposed to non-combatants or neutral) prior to engaging.

In the experiment scenario, blue was attempting to restore order and stability to a hypothetical country's government, which had suffered a failed coup attempt earlier in the year. Dissident forces held significant territory through a coalition of mutinous military and regional insurgents. They defended several command and support nodes throughout the region. The missions to be conducted by the CAU during the course of experimentation involved the clearing and securing of multiple objectives. Each run began with the blue force executing operations from a tactical assembly area north of the river and the red force defending south of the river. The operations were made more complex by of Rules of Engagement (ROE) that protected civilians in the vicinity of key objectives, and involved no-fire zones and protected targets (e.g. places of worship). In addition, new Fragmentary Orders (FRAGOs) were issued during the execution phase to force decision making on the move and dynamic re-planning. The specific blue and red objectives and battlespace conditions were modified between runs to vary the interactions and maintain an element of surprise.

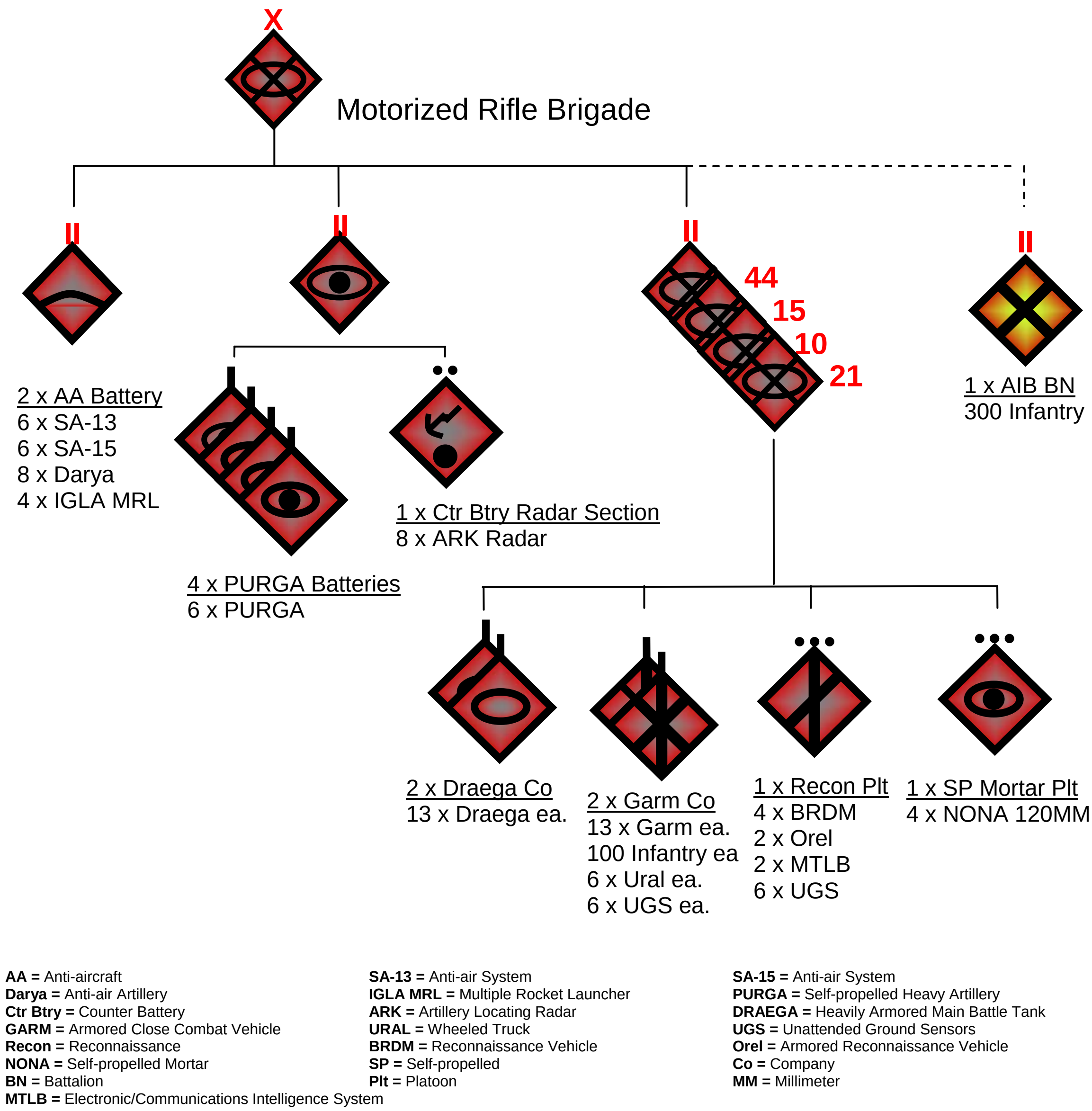


Figure 5. Red force organizational structure for a motorized rifle brigade at full strength.

Experiment Data Collection

The methods for data collection during the experiments provided the analysis team with both quantitative and qualitative data for review. Quantitative data were collected via automated loggers connected to each simulation model. The loggers collected entity state and activity information as well as commander and staff interactions within the BCSE. This data provided the analysis team with the information needed to determine what was actually occurring in the battle, what information was being provided to the commander and staff via the display and what tasks they were performing in the BCSE in reaction to the information provided to them.

The Qualitative data were collected via participant surveys, debriefs, and After Action Review (AAR) discussions. Wargamers (the Soldiers who played the roles of commanders and staff) were provided surveys and conducted debriefs following each record run so the analysis team could ascertain their individual thoughts and opinions. AARs were conducted after every record run and were effective means for discussion regarding the use of the BCSE as well as the tactics, techniques and procedures (TTPs) executed during the battle. Digital video and audio recordings of each Soldier were collected throughout the experiment and were useful when analyzed in conjunction with other data collected. Finally, a team of observers was monitoring each wargamer's audio transmissions, actions, and BCSE screen activities in real time during the runs. The observers were recording events of interest that highlighted the capability of the wargamer to interpret the information provided, to collaborate with other commanders or staff regarding that information, and to make decisions based on their SA. By evaluating this data, the analysis team can begin to understand the SA level of each Soldier and how they perceive and react to the information provided on the display and through collaborations with others.

Analysis Methodology

The objective in developing the analysis methodology was to examine the capability of the BCSE to support battle command requirements of multiple echelons in the future force. Additionally, the analysis team sought to evaluate the capacity of the BCSE to enable collaboration among multiple commanders and their staff leading to a consistent level of SA across echelons. Furthermore, the team wished to determine how the BCSE and the collaborations contributed to the commander's and staff's SA and enabled the commander and staff to make decisions that influenced the outcome of the battle.

Endsley's model of SA [4] was adopted as the basis for the analysis. The model describes the sources of SA and the losses associated with transfer of this information through the system.

In order to make intelligent and informed decisions, the commander must be armed with SA. Sources of SA for the commander are direct observation, the BCSE interface, and other commanders and team members. Ground truth, i.e., the actual state of the battle-relevant entities as simulated within OTB, is transferred partially to the BCSE system. It is important to note that sensors play a key role in what data is transferred from ground truth to the BCSE. The number of and deployment strategy of sensors ultimately determines the information that is captured and transferred to the BCSE. The information retained by the BCSE system is called system knowledge or SA_t. That information is then provided to the commander via the BCSE interface. The commander configures the interface as desired and focuses his/her attention on a specific area of the interest at a given point in time. The information displayed on the tailored interface is called the interface knowledge. The commander's perception of the information presented to him via the interface, through direct observations and through collaborations with staff and other commanders is called the commander's cognitive SA or SA_c. This represents the level of SA that the commander actually possesses. The analysis team sought to evaluate the capability of the BCSE to effectively provide information via the interface and facilitate collaboration resulting in increased SA_c among the commanders and staffs across the echelons.

In order to understand the information and tools that enabled the commanders to make decisions, the analysis team had to assess the level of SA provided to, and possessed by, the commanders and staff at given points in time. To this end, the team developed a process termed Commander's Read. During each read, the commander provided an assessment of the red situation, a blue combat effectiveness assessment, and an assessment of ongoing actions in relation to the tactical plan. The Commander's Read was performed periodically throughout the experiment and could be requested as necessary at points of special interest for the analysis team. The format for the Commander's Read is shown in Figure 6.

Armed with the information provided through the Commander's Read, the analysis team would now need to understand what BCSE information and tools, direct observations, and collaborations were factors in the development of the commander's SA_c. The analysis team developed a method for evaluating each of these influences.

- **Red Assessment:**
  - What is the enemy's disposition and activities?
  - What is the enemy's intent?
  - What is your confidence level for this assessment (High, Medium, Low)?
  - What is your basis for this assessment (intelligence update, specific Red entities acquired and displayed on the CSE, intuition, components of Red that have not been acquired)?

- **Blue Combat Effectiveness Assessment:**
  - What is your combat effectiveness assessment (Red, Amber, Green)?
  - What is your basis for this assessment (loss of key systems, sensor effectiveness, Red countermeasures, geospatial considerations, ability to C2 assets)?

- **Assessment of Action in Relation to the Tactical Plan:**
  - What is the status of plan execution?
  - What is your basis for this assessment and the impact of the assessed state on the plan (critical events, phases of operation, timing, maneuver)?
  - What risks do you face?

Combat Effectiveness Assessment Scale:

- **Green:** Mission failure is unlikely; force is capable of accomplishing mission. No reconstitution required for follow-on missions.
- **Amber:** Potential for mission failure exists; force is capable of accomplishing mission. Follow-on missions may require reconstitution.
- **Red:** Mission failure is likely; force is not capable of accomplishing the mission. Follow-on missions require significant reconstitution.

Confidence Level Assessment Scale:

- **High:** Surprise is not likely (very confident that the enemy disposition, activities, and intent are known).
- **Medium:** Surprise is possible (somewhat confident that the enemy disposition, activities, and intent are known).
- **Low:** Surprise is likely (not confident that the enemy disposition, activities, and intent are known).

Figure 6. The Commander's Read was developed as a means for the analysis team to determine the level of SA_c that the commanders possessed at given points in time.

To understand the elements of BCSE-provided information and tools that contributed to the commander's SA_c, the analysis team used direct observation during the experiment execution. With observers monitoring each of the commander interfaces as well as a video feed showing the actions of the commanders, the analysis team was able to determine what information was presented to the commanders via the interface at any point in time. The team could see how the commanders had their screens tailored and what areas of the terrain they were focused on. When key decisions were made and events occurred, the team could record what the interface was showing. Given the Commander's Read, the team could assess the difference between the information that was provided through the interface and what the commander actually perceived from that information. This provided the analysis team with the data needed to evaluate the capability of the BCSE to effectively provide information to the commander in a concise manner allowing for maximum understanding. Furthermore, through the participant surveys, debriefs and after action reviews, the analysis team was able to gather the inputs and opinions of the commanders and staff on what tools and information enabled their decision making. The analysis of this data guided improvements of the BCSE tools and of the training associated with its use.

The evaluation of collaboration was another focus of the analysis team as this was the other primary contributor to the commander's SA_c. The intent was to capture data related to each collaborative event that took place between commanders and staff members or other commanders. This data would be evaluated to determine how it contributed to or degraded the SA_c of the commander. This data was captured through video and audio recordings. In particular, the team captured data pertaining to: who initiated the collaboration, who participated, the general purpose, the outcome, and the primary tool used to collaborate. The data was recorded in an observer collection tool, and events were time stamped so the team could review the audio and video for further analysis as needed. The analysis of this data allowed the team to classify the effectiveness of collaborations. Additionally, the Collaboration Evaluation Framework (CEF) [5], provided a mechanism for the team to evaluate the use and effectiveness of technology in facilitating collaboration. This framework was used to capture and organize data related to how the characteristics of a collaborative task process are related to the collaborative behaviors and task transmissions of the participants. The analysis of this data can help to determine how technology can assist in collaboration, and guide the improvement of BCSE tools intended to facilitate collaboration.

Having all the data collected, the analysis team needed a means for visualizing this data and understanding the role of each piece of information at the time of a key event during the battle experiment. The team developed four charts for visualizing possible connection between data: a chart that showed the timing of and participants in collaborative events; a chart showing the Commander's level of SA_c based on Commander reads; a chart showing the BCSE level of SA_t; and a chart showing the battle tempo as a function of the number of CSE taskings at a given point in time. This approach allowed the analysis team to gain an understanding of how these different pieces of data may have contributed to a change in the commanders SA_c, possibly resulting in a key decision. If the commander missed a decision that could have positively impacted the battle, was it because the information was not available or because he did not perceive it correctly? The stacked chart in Figure 7 helped the team to answer some of these questions. It shows an example of three key events pertaining to one of the CAUs and its area of interest. The chart enabled process tracing and allowed the analysis to connect the key pieces of data.

The overall methodology discussed in this section facilitates analysis of the commander's level of SA_c and the major contributors to that SA_c. Given this approach, the analysis team was able to develop insights regarding how the BCSE tools and collaborations contributed to the commander's SA_c and enabled the commander to make key decisions that influenced the outcome of the battle.

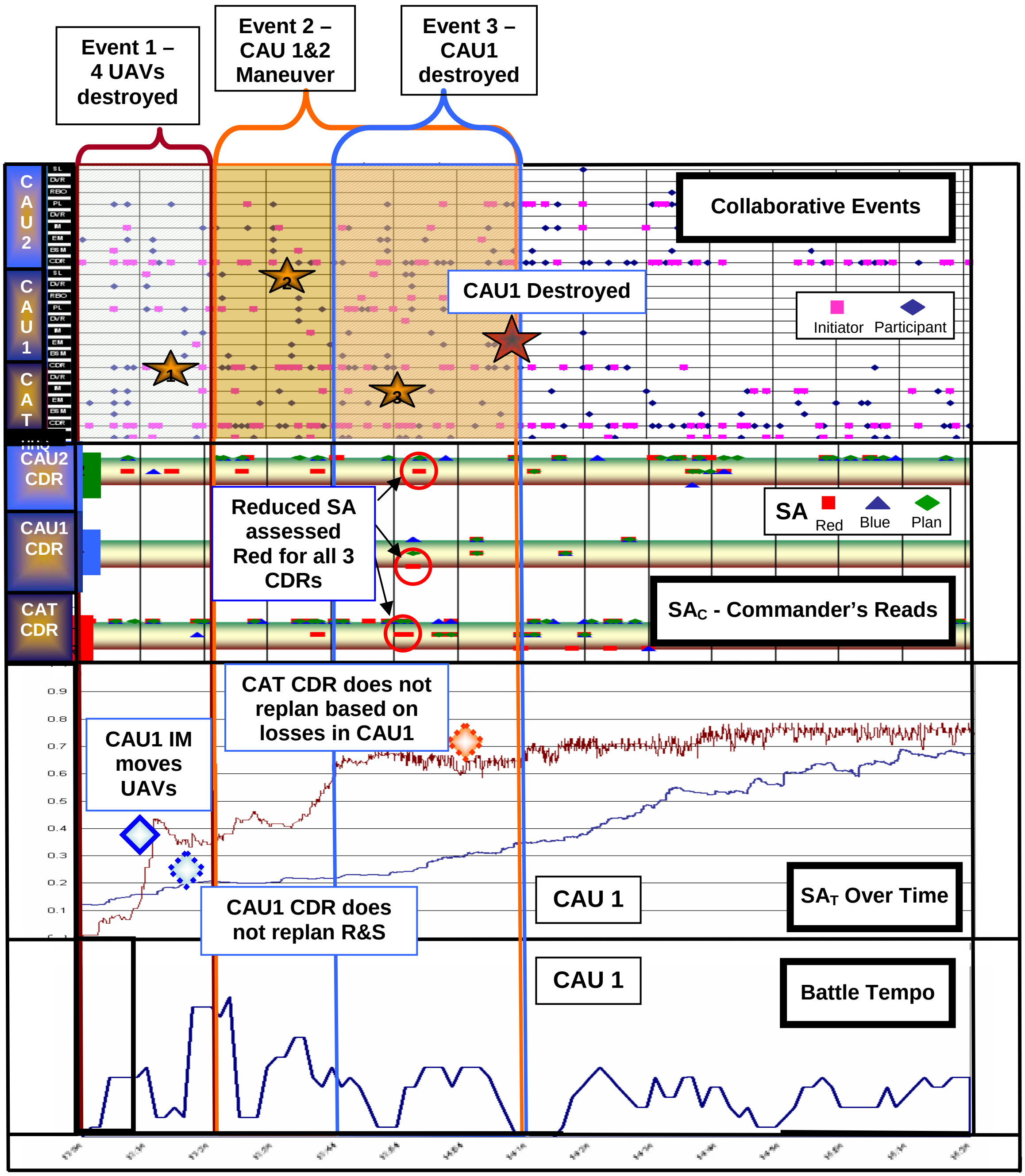


Figure 7. Example stacked chart for CAU 1 showing (top to bottom) collaboration events, commander's SA$_c$ level, system SA$_t$ level, and Battle Tempo.

Experimental Findings and Hypotheses

Experimental results highlighted some of the significant factors and phenomena in battle command. An understanding of these factors leads to improvements to the BCSE system and training. Additionally, the results provide information and insights that help develop tactics, techniques and procedures (TTPs) for commanding future forces. The following provides an illustrative sample of experimental findings.

Situational Awareness and Decision Making

The analysis of experimental results showed that the difference in system knowledge or the level of SA_t contained within the respective blue and red battle command systems is a key predictor of battle outcome. SA_t represents the level of information pertaining to knowledge of the opposing force platforms and combatants. In runs where the blue force gains an early lead in SA_t and is able to maintain a sizable lead throughout the run, they achieve the advantage at the end of the battle. Figure 8 shows the blue and red SA_t levels over several runs in experiment 4 and states the force that achieved the advantage in that run.

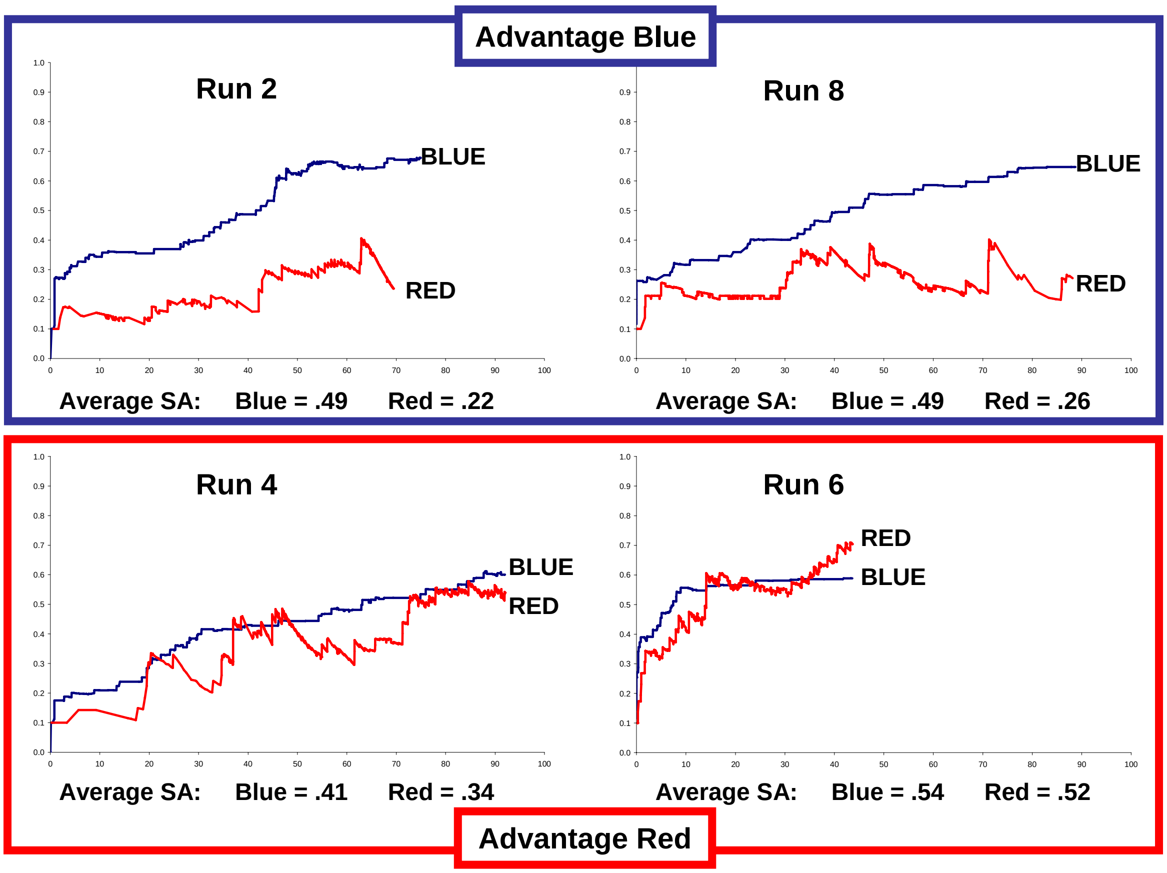


Figure 8. Blue and red SA_t levels throughout the designated runs in experiment 4 and the force that achieved the advantage in each run.

While this result may seem intuitive, the consistency with which the differences in SA_t levels predict battle outcome is quite remarkable. A lighter and more agile blue force wins to a large extent via its information dominance as opposed to armor or firepower dominance. The quality, quantity and speed of the information acquisition represented by the magnitude and slope of the blue SA_t curves as compared to the red SA_t

curves are the key deciding factors. The capability of the battle command tools to facilitate the information acquisition process and assist the commanders and staff in increasing their SA_c levels is critical.

One important factor determining the SA_t level is the early counter-reconnaissance fight. Figure 9 shows that when one of the CAUs is able to gain an information advantage early in the battle through its own reconnaissance and through countering the opposing force's reconnaissance effort, they usually achieve and maintain the advantage throughout the battle.

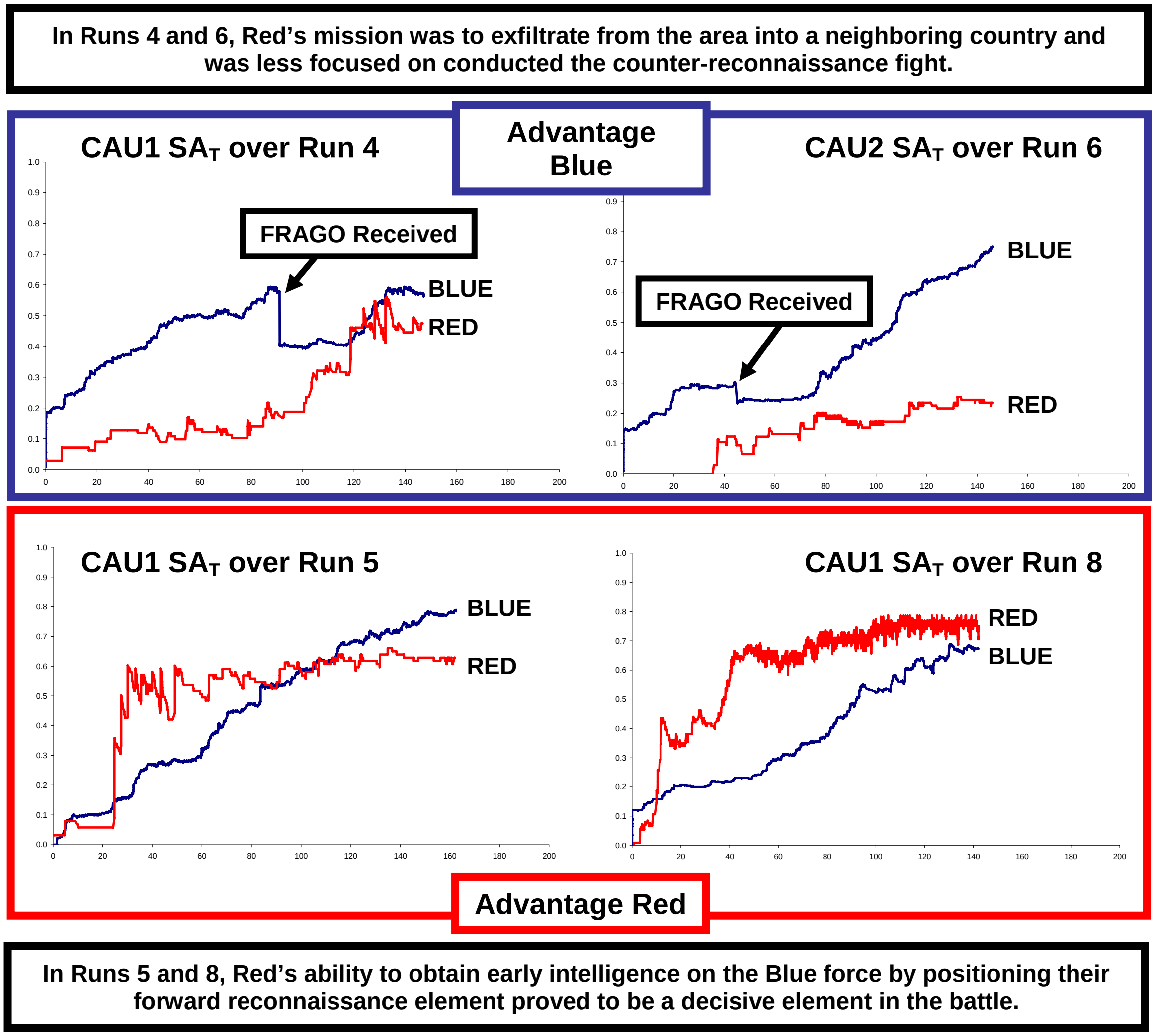


Figure 9. Blue CAU SA_t level versus red SA_t level throughout the designated runs in experiment 6 and the force that achieved the advantage in each run. These examples highlight the importance of early counter-reconnaissance.

Sensing the value of information early in the battle, and the need to maintain a high level of information pertaining to the opposing force in order to achieve an advantage in the battle, the commander focused a large portion of his attention on acquiring information. The observations and data showed that nearly fifty percent of all commander decisions were made to acquire information and develop the intelligence picture. Even though each command cell included the intelligence manager who was to control sensor assets and perform tasks related to acquiring and identifying targets, the commanders tended to focus much of their attention on these tasks and delegated most other tasks to the staff. Figure 10 shows the number of decisions the commander made pertaining to acquiring information.

	Automatable	Adjustment	Complex	Total
Move	3	37	4	44
See	32	49	0	81
Strike	8	35	5	48
Total	43	121	9	173

- All articulated choices were recorded as decision.
- 173 decisions were observed over 8 runs.
- Of 32 Automatable-See decisions:
  - 13 involve sensor allocation and positioning.
  - 5 involve changes to sensor mode (MTI/SAR).
  - 11 involve cross-cueing different sensors.
  - 3 involve micro UAV use to enhance BDA.

Decision Focus and Content

- **Move** – the movement of organic assets (25%)
- **See** – the development of the intel picture (47%)
- **Strike** – the application of effects (28%)

Decision Types

- **Automatable** – all variables known or can be calculated, something a computer can do (25%)
- **Adjustment** – mostly known variables within the plan context, required human judgment (70%)
- **Complex** – requires definition of options, criteria and decision process (5%)

MTI = Moving Target Indicator **SAR =** Synthetic Aperture Radar
UAV = Unmanned Aerial Vehicle **BDA =** Battle Damage Assessment

Figure 10. Focus of commander decisions favored sensor and information acquisition.

The same figure also shows that a large portion of the decisions made by the commander were automatable, meaning all variables were known or could be calculated, and the decision could be made by the computer system saving the commander valuable time. It should be noted that not all of the automatable decisions were actually automated: the BCSE does not currently contain tools for making all such decisions. Among such potentially automatable decisions, manual management of sensor assets was found to be a particularly time-consuming and difficult task. Often, gaps in sensor coverage resulting from inadequate deployment of sensors led to low levels of SA_t.

Such gaps in sensor coverage also lead to loss of information standoff. We use the term information standoff to refer to the need of the blue forces to avoid coming into the fire range of the unknown red forces. It is essential that blue acquire and engage red targets outside the range at which the red assets can acquire and engage blue platforms. Figure 11 shows the percent of each type of red platform engaged by blue when a blue platform was already within the red's engagement range. There is strong evidence that as this percentage increases, the ability of blue to achieve an advantage in the battle decreases significantly. Ultimately, this percentage directly relates to the level of blue SA_t and the ability of blue to maintain its SA_t advantage throughout the battle. If blue is able to properly deploy sensors in an effective and timely manner, the blue level of SA_t is high and the percentage of red targets acquired after blue is already within the red engagement range is low. One can understand why the commander finds it so important to focus a large portion of his attention on managing his sensor assets. However, since many of the decisions and tasks pertaining to sensor deployment and information acquisition are automatable, tools could be developed to assist the commander and staff in these difficult tasks and decisions providing for less human error and allowing them more time to concentrate on other tasks of importance.

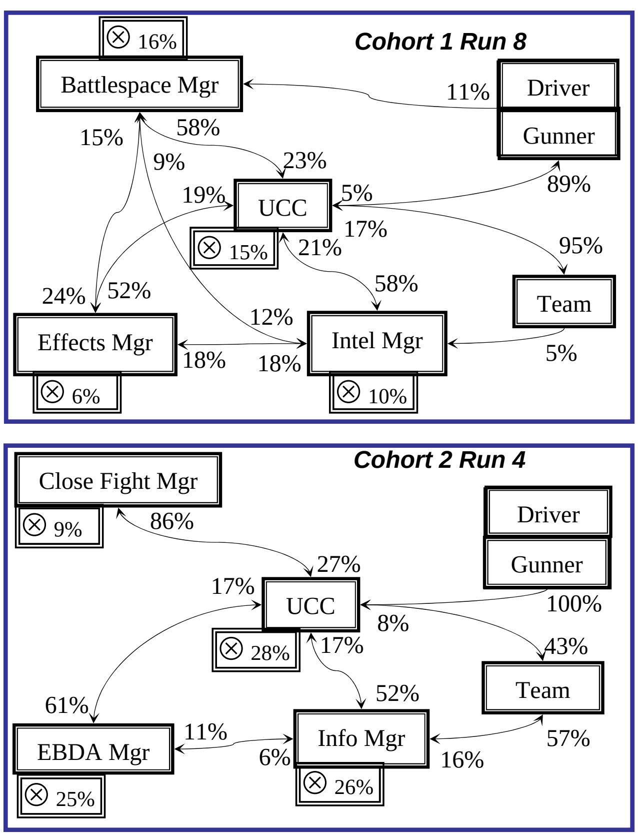
		% of Red Platforms First Engaged with Blue ground element within lethal radius of Red				
Type of Red Platform	Max Lethal Range(m)	Run 4	Run 5	Run 6	Run 7	Run 8
NONA	8,850	17%	50%	29%	75%	60%
DRAEGA	8,000	18%	39%	7%	29%	82%
GARM	8,000	7%	22%	14%	100%	29%
OREL	8,000	0%	100%	25%	0%	50%
All Included Systems		11%	36%	15%	61%	58%
Assessed Overall Advantage		Blue	Draw	Blue	Red	Red
% of Red Platforms Detected		55%	56%	52%	28%	59%

NONA = Self-propelled Mortar **DRAEGA = Heavily Armored Main Battle Tank**
GARM = Armored Close Combat Vehicle **OREL = Armored Reconnaissance Vehicle**

Figure 11. Blue's ability to detect and engage red assets outside the engagement range of red has a significant impact on the outcome of the battle.

BCSE Contributions

Information conveyed via the BCSE interface is one of the major contributors to the commander's SA_c. Results from the experiments and participants' inputs and feedback have fed the spiral development of the BCSE system over the last five years. The BCSE is an integrated and networked battle command prototype that enables experimentation with future battle command of network-centric forces. Through the use of this prototype, the commanders have learned how to command and control the assets that are likely to be found in the future force. During each experiment, the analysis team focused on determining how BCSE tools contribute to the SA_c of the commander and how these tools and the training can be improved to facilitate increased SA_c for the commanders. For example, experiments have shown that improved collaboration tools would provide for a more consistent SA picture within a single echelon and across echelons. Based on these findings, improvements were made to enhance the collaboration processes through the development of a briefing tool.



EBDA = Effects/Battle Damage Assessment **UCC =** Unit Cell Commander
Mgr = Manager

Figure 12. Communication patterns for two different cohorts or sets of operators.

The manner in which commanders and staff communicate and perform their functions differs greatly by role, experience level and personnel characteristics. Figure 12 shows the different communication patterns between two separate sets of wargamers performing the same missions. The arrows show the main directional flow of communications. The percentage values and their locations reflect the level of communication and to whom the communication was directed from that node.

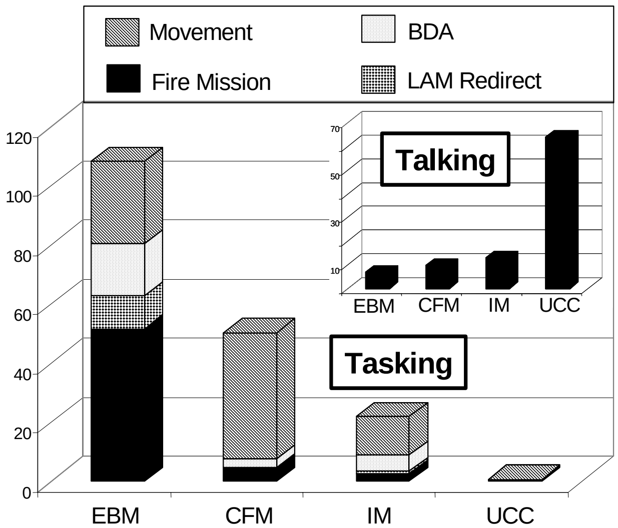


Figure 13. Commanders and staff perform their duties differently dependent on personality and role.

Figure 13 illustrates how wargamers performing different functions utilize tools in different ways and perform their functions in a different manner. The figure suggests that the Unit Cell Commander (UCC) spends the majority of time performing functions through talking while the Effects and BDA Manager (EBM) spends the majority of time performing functions by using the BCSE and tasking platforms.

To support such a broad variety of potential users, functions and styles, BCSE must be flexible. Experiments showed the BCSE allowed the staff to be multi-functional and share the available information and functions. The flexibility of the GUI and the capability to tailor this interface allowed the staff to self-organize their respective roles, functions and communication patterns (e.g., see Figure 12) as the variety of mission and personnel characteristics required. The flexibility and tailorability of the interface ultimately contributed to an increased level of SA_c for the commander and staff and helped them make efficient and effective decisions.

Another key finding of the experiments pertained to BDA. Command staff found that BDA has emerged as a critical and demanding task. The amount of time required to perform BDA and the complexity of the task causes the command staff member performing that task to lose awareness regarding the rest of the battle. Additionally, if the battle damage is not correctly assessed, the SA level of the entire blue force can be degraded.

Results suggest that automated tools are needed to assist the commanders and staff in performing BDA. Based on this analysis, additional BDA tools were developed, including a BDA guidance matrix, and the training pertaining to BDA was improved. Later experiments have shown that these tools and training have resulted in less time spent performing BDA, or tasking platforms to perform BDA, and more accurate BDA assessments. Additional automated tools that assist in performing BDA are still needed.

The difficulty associated with managing assets to perform BDA is a part of a larger sensor management problem discussed in the section above. Deployment and management of sensors in order to acquire information (i.e., detect targets, perform BDA, etc.) is a difficult task and is one that the commander often focuses a great deal of attention on. Undoubtedly, without the BCSE's support, this sensor management problem would be even worse because the current functionality in the BCSE provides valuable tools that significantly improve workload and allow sharing of these sensor management responsibilities across the staff. Nonetheless, an automated tool within the BCSE that assists the commander and staff in properly deploying sensor assets and managing those assets throughout the battle would contribute significantly to increasing SA_t. The system requires the capability to recommend sensor deployment such that sensors are optimally layered and areas of interest are covered with the types of sensors required to detect targets in the associated terrain. Additionally, tools are needed to show the level of sensor coverage applied to an area and the age of the information provided about that area. These types of tools would provide the commander with an understanding of whether an area had been adequately covered and how recently the area was covered, prior to maneuvering his forces.

Clearly, the contribution of BCSE tools to SA_c is critical. However, it must be recognized that commanders and staff members do not necessarily absorb all the information that is readily available in the BCSE interface. In many instances, the BCSE interface offered a wargamer a high level of SA_t but the wargamer did not correctly understand or interpret the information presented in the interface. This problem is manifested in limited correlation between the SA_c and the SA_t. Experiments showed that the commander assessment of available information was typically correct only 60% of the time (e.g., Figure 14). Without the support provided by the BCSE, it is believed this gap would be much greater (further testing is required to confirm this hypothesis). The BCSE capability to analyze and synthesize the data and present the data to the commander or staff through a tailorable interface greatly improves the amount of relevant information that each operator is able to absorb. There are multiple factors that lead to the 40% gap between the available information and the absorbed information. We discuss some of them later.

Time	UCC's Statement	Read Element	Assessment
12.55	"I'm not seeing much change in the situation at this time. Still believe the enemy was trying to show some force in the north sector and the choke point to deter my movement there. Still seeing minimal in the southern corridor and the central corridor looks pretty clear except for those two forward elements that we engaged. I believe the enemy is still defending deep."	a. not much change b. show force in the north to deter Blue movement c. minimal force in the southern corridor d. enemy defending deep	**Correct** **Correct** **Incorrect** **Incorrect**
23:09	"I'm still think the enemy is deep."	a. no change	**Incorrect**
24:57	"I'm thinking he is buying it [deception] because he's moving forward in that southern sector. He may be buying it and he may not be.	a. Red moving forward	**Incorrect – movement is neutral LAVs, not Red**
41:48	"The read hasn't changed much…" Team Cdr: "Do you still believe he is defending deep?" UCC: "Affirmative."	a. no change	**Incorrect**
57:30	"I think he's probably figured out that we're moving by now."	a. Red knows Blue is moving in the central corridor.	**Correct**

Figure 14. This sample of a directed commander read shows that the commander's understanding and interpretation of available information is often incorrect resulting in gaps between SA_T and SA_C.

Collaboration Contributions

Collaboration with staff members and other commanders is one of the major contributors to the commander's SA_c. The analysis team assessed the contribution of the collaboration events in order to determine which collaborations resulted in an improvement or degradation to the commander's situation awareness.

In many cases during experiments the commanders and their staff demonstrated high levels of task and asset sharing between and across echelons. In these cases, the collaborations had a strong positive effect on SA_c. The sharing of tasks and assets took advantage of less busy wargamers to assist those wargamers that were bogged down with their tasks. The mutual coordination and collaboration resulted in a more efficient and effective use of resources leading to a greater ability to acquire information and increase SA_c. For example, the CAU2 Effects Manager developed a technique for utilizing other unit's loiter attack missiles (LAMs - a type of loitering munitions envisioned in the experiment) when CAU2's munitions were running low. By using tools within the BCSE, the CAU2 Effects Manager (EM) would monitor the fuel status of

LAMs within CAU2's area of interest. When a LAM was running low on fuel, the EM would send a request to the owner to use the LAM on a specified target within her AOR. In this example, the CAU 2 EM initiated an effective collaboration via the implicit sharing of information within the BCSE and then finalized the collaborative event via a radio communication to relay the intent to use the munitions and to request approval. A number of similarly efficient forms of collaborations were observed that ultimately had a positive effect on the commander's SA_c and the outcome of the battle.

However, collaboration can also be detrimental. Recall the typical 40% gap between the available information and the absorbed information. One of the culprits was collaboration. In many cases, collaborations served to distract or confuse the commanders and staff and ultimately resulted in degradation to situation awareness. Let us consider one example.

At H+32 (i.e., 32 minutes into the run), Panther 6, the CAT commander, and Tiger 6, the CAU 1 commander, collaborate on an understanding of the red plan. The discussion is effective in that they are able to perceive, with a significant degree of accuracy, the plan that the red force is implementing. At H+38, Cheetah 6, the CAU 2 commander, states that the enemy is positioned further north than originally expected and he suspects the red intent is to defend heavy forward. This perception turns out to be incorrect. Yet, the CAT commander and CAU 1 commander, who earlier had an accurate understanding of red's plan, have now been biased strongly by the incorrect estimate of the CAU 2 commander. This example shows that collaboration that conveys incorrect information can have a detrimental effect on SA_c. At H+44, a subordinate directs the attention of the commander to the location of targets in a town that is nowhere near the objective of the commander. The commander should be focusing on targets around the objective but is induced to take the time to determine whether the information being reported to him is relevant or not. This is an example of collaboration misdirecting the attention of the commander and resulting in a detrimental effect on SA_c. Such counterproductive collaborations result in a reduction in the commander's SA_c. The commander loses his understanding of the red plan and reports an incorrect assessment only 20 minutes after he had correctly assessed the red plan.

Though counterproductive collaborations were observed as highlighted in this example, without the support of the BCSE and the capability to share assets and a common picture of the battlespace, these detrimental collaborations would occur far more frequently. It is important to recognize the significant contributions, both positive and negative, that collaboration can provide to a commander's SA_c. Through an understanding of this, the positive types of collaboration can be reinforced in training and enhanced through the development of tools to facilitate these types of collaboration. The counterproductive forms of collaboration can be discouraged and minimized.

Conclusions

The joint DARPA/Army M&D C2 program developed a battle command system prototype that enables experimentation with the Army future force command concepts offering insights into the key battle command factors that will influence the outcome of battles in the future network-centric environment. The findings of the experiments conducted during M&D C2 program have resulted in improvements to battle command software tools and training procedures, and have provided important conclusions related to the multi-unit, multi-echelon decision making and collaboration activities that contribute to the commander's SA_c and ultimately influence the outcome of the battle. The results are of a mainly qualitative nature due to the limited number of runs that can be conducted during experiments and the large number of variables that change between experiments. While it would be possible to control more variables throughout the experiments, this would result in a less realistic and dynamic environment. The analysis team thus far has concentrated on gathering observations and forming hypotheses in order to identify areas of more quantitative focus for future work.

The program has developed an experimental design, data collection and analysis methodology that explores the cognitive processes of the commanders and staff, particularly to determine the levels of their SA_c and the factors that influence the SA_c. Additionally, the analysis offers insights into the mechanisms by which SA_c helps the commander make decisions. The results have highlighted, for example, the importance of information superiority early in the battle, and the significance of maintaining that advantage through continued information acquisition and counter-reconnaissance.

The analysis has assisted in identifying technology within the BCSE that contributes to the improvement of the commander's SA_c. It highlights the need for additional tools to facilitate automation of time intensive tasks in order to free up time to perform other tasks that cannot be automated. The analysis also shows both positive and negative contributions of collaboration to the commander's level of SA_c.

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