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Cognitive Impact of a C4ISR Tactical Network

Abstract

This report details a naturalistic study that investigates the effect of communications and sensor technologies used by Soldiers in a tactical organization to gain intelligence against an adaptive enemy threat. Communication and sensor technologies were used to simulate current and future force capabilities for networked systems. Soldiers comprised an experiment force and simulated two platoons of an Intelligence, Surveillance, and Reconnaissance (ISR) force. Data collection included observational, quantitative, and qualitative methods designed to illuminate the contributions that networked information make to decision accuracy and timeliness. We document results to suggest that networked sensing and communication technologies enhance tactical decision making; yet these benefits come at the cost of basic instincts of Soldier survivability – to remain aware of the immediate environment. Field observations and self-report measures of frustration and workload demonstrate this effect. The metric of human trust in networks was useful to the overall analysis; we recommend specific ways in which this measure can be modified and improved. Our conclusions document that future networked battlefield operating systems must have redundant communication capabilities to protect against information warfare attack.

Introduction

The emphasis on investigating the cognitive impact of an integrated C4ISR suite of technologies was driven by the understanding that warfare will always be a human activity. Technology must support human decision making, but it will never replace it. The drive to develop sophisticated decision support systems and intuitive visual displays must include consideration for the ways in which Soldiers will utilize these systems on the battlefield. In network enabled operations, information is the essential ingredient driving the development requirements for the future network to provide the "quality of firsts".

According to United States Army White Paper, Concepts for the Objective Force (2001) the "quality of firsts" will provide US forces the ability to "See First, Understand First, Act First, and Finish Decisively" which will ensure success on the battlefield. The qualities of firsts are the expectations of the U.S. Army as it combines superior human elements of command with advanced control technology (Conner, 2005). This doctrine of network enabled Command and Control (C2) places the Warfighter at the center of a complex, dynamic, and uncertain web of information. This study measured the impact of networked human and sensor information on the cognitive performance of Soldiers at the tactical level. In this regard, this study provides a benchmark for future analysis of how valid the basic network centric warfare tenets may be for the Future Force at the Company and Platoon echelons.

In his analysis of the Operation Iraqi Freedom (OIF) 2003 Thunder Run (where lead elements of the 2nd Brigade, 3d Infantry Division attacked Baghdad from the southern outskirts, through the city and west to the airport), Conner (2005) noted that carrying the "robust intelligence capability [through a common operating picture] forward to the tactical level would prove almost completely lacking" (p.18). He characterized the existence of a 'digital divide' between operational and tactical commands, and suggested that the reasons for this divide were the great distances covered by tactical units and the vast amount of data attempting to be shared. Conner notes several examples in the early phase of OIF where "the promise of technology providing near perfect situational awareness had failed the tactical commander" (p. 20). Conner's analysis provides the context for the importance of the Cognitive Impact Study. Experience has demonstrated that providing the right information in the right format to the right Soldier at the right time is a problem that will require supporting technologies. However, as these engineering and networking solutions are in development, comparable research is needed in the cognitive domain to define tactical Warfighter network needs for information sharing, collaboration, and to define limits of perceptual processing. The Cognitive Impact Study was the first of its kind to examine the impact of an integrated network of manned and unmanned systems on the Warfighter operating at the center of a networked ISR system of systems.

To conduct this analysis, 39 Soldiers from the 1/29th Infantry Regiment, Fort Benning, Georgia were organized into two reconnaissance platoons and a Company Headquarters element. Each platoon was equipped with mounted and dismounted communications, battle command devices, and a number of dismounted Information, Surveillance and Reconnaissance (ISR) collection devices. Additionally, each platoon benefitted from higher echelon ISR tools to include Unmanned Ground Sensors (UGS) and several Unmanned and Manned Aerial Sensor (UAS) platforms. These Soldiers operated against a live but scripted Opposition Force (OPFOR).

The platoons were organizationally designed to replicate a legacy and a future force organization. The legacy platoon was named the Spin Out platoon (SO) and the Future Combat System (FCS) platoon was the notional future force platoon. Each platoon had similar communication technologies (both mounted and dismounted), but the FCS platoon benefitted from the integration of these technologies into their network, while the SO platoon's technologies were stand-alone applications. For an example of this difference, each platoon had use of a Small Unmanned Ground Vehicle (SUGV) that provided remote visual and imaging capabilities. In the FCS platoon, these images could be shared with the platoon network. In the SO platoon, the images were only available to the operator, who had to send voice messages to his platoon members if he needed to share information from the SUGV. This would be similar to having a camera phone without a data-share capability. These technologies are explained in below.

Communication Technologies

The assignment of communication devices to the platoons was designed to replicate a current force equipped with advanced communication support compared to a future force outfitted with a more integrated technology system. An obvious constraint in this effort was that existing and available technologies had to be used to surrogate these conditions.

The SO platoon used a dismounted battle command capability called Warrior Application (Warrior App). This technology runs on commercial laptop computers with a display screen that provides SA reports of the Blue Force, spot reports of OPFOR, text messaging, collaborative white boarding, and geo-referenced satellite imagery. Warrior App systems were used by the Platoon Leader, Platoon Sergeant, and Squad Leaders during all phases of the study. The Warrior App was integrated with the CERDEC-enhanced FBCB2[1] and allowed leaders to maintain SA while dismounted. The SO platoon also had use of the networked Javelin Container Launch Unit (JAV CLU). The JAV CLU allowed Soldiers to network with other communication devices to improve their SA through features that provided cooperative sensing and engagement capabilities. The JAV CLU also featured a Netted Close Combat Synchronization Tool (NCCST). This allowed Soldiers to receive and transmit imagery from other systems in their platoon, such as the identification of targets of interest, reduced time to prosecute target surveillance, and reduced time and increased accuracy for magnetic compass calibration via CLU to CLU collaborative calibration. One Soldier in the SO platoon operated the SUGV from a stand-alone control unit.

In the FCS platoon, two digital communication devices were provided to support dismounted C2; the Black Coral and the Digital Alert Display Device (DADD). The Platoon Leader and Platoon Sergeant were each assigned a Black Coral dismounted battle command device which allowed them to maintain

[1] The CERDEC has enhanced the fielded FBCB2 system to include features such as chat messaging, sensor imagery notifications and availability, and network status displays.

situation awareness away from their vehicles. Black Coral was integrated with Command Post of the Future (CPoF) server in the Tactical Operations Center (TOC). It allowed FCS platoon leaders to collaborate with CPoF operators at Battalion and Brigade echelons and to share information with their local teams. The DADD was provided to four Scouts. This is a thin flexible wearable display device worn on the forearm and was used for text messaging within the platoon and to the higher echelon. This capability is similar to the text messaging feature found on most cell phones. Soldiers were alerted to received-messages through a vibration feature. Soldiers could compose text messages or could use buttons to send messages from a pre-programmed library. Finally, two Soldiers in the FCS platoon were equipped with the Army Research Lab – Common Controller (ARL-CC). This system was used to control the SUGVs and provided a dismounted battle command display. This device also allowed Soldiers to receive still and video imagery from image based sensors.

Computer Network Operations (CNO) Intrusion Attacks

In addition to the physical challenges presented by the OPFOR, a team from ARL-Survivability Lethality Analysis Directorate (SLAD) conducted a series of network intrusion attacks targeting the leadership of each platoon to simulate network information warfare. The variety of attacks covered the full spectrum from monitoring the network traffic of the platoon, gaining unauthorized access to systems, to completely denying service for a given node (leader), which prevented that node from either sending or receiving information.

To conduct its monitoring and attacks, the CNO team monitored and perpetrated their network attacks from a vehicle in the FCS network. (The two platoons used different radio networks in the experiment.) [2] This allowed the CNO team to move with the FCS platoon and to "see" the entire network. Unfortunately, network latency (delay) in traffic passing between the SO to the FCS network was so high that many attacks targeting the SO platoon took too long to be effective in the dynamic live environment. Thus, the CNO attackers chose to focus primarily on the FCS platoon. For example, a single ping from the CNO team to the SO network sometimes took more than 15 seconds for a return response. Generally, responses less than 2 seconds and are needed to allow for successful network intrusion operations to occur. When delays of more than 2 seconds were experienced, the CNO team was forced to focus on fewer nodes; thus reducing the effectiveness of the attacks.

During the course of the trial runs it became apparent that the more difficult-to-detect network attack was the intermittent denial of service attack. The Soldiers were provided with some rudimentary tools for monitoring network connectivity. The network naturally experienced periods of limited connectivity due to terrain, distances between nodes, and mechanical failure. Thus, it was never clear to the Soldiers when the ARL-SLAD team was denying them service or if the network was really performing poorly. A more easily detected attack occurred when the ARL-SLAD team attempted to insert deceptive information into the network in the form of annotated images, bogus spot reports or misleading instructions. It is likely that these attacks were quickly identified by the Soldiers because of the small numbers of Soldiers targeted who had access to the C2 devices. Normally the suspicion of an attack was discussed via voice between the two "victims" and confirmed that there was indeed an intruder on the net. Once a tool was compromised the Soldiers stopped using it.

Cognitive Measures

This study captured observational, subjective, and objective data to measure Soldiers' use of technologies to obtain, share, and make sense of complex information about an adaptive enemy force. Measures of cognitive performance included workload, situational awareness (SA), and trust in the network. In addition to these measures, we captured direct feedback from the Soldiers as they described their

[2] The FCS Platoon used the Soldier Radio Waveform (SRW) and the SO Platoon used the Enhanced Position Locating Reporting System (EPLRS) radio network.

performance and use of the technologies after each mission. These comments were compiled every day into a database that was shared with analysts and technology developers to understand survey results or to refine features of technologies.

Workload

Workload is generally defined as the perception of imposed task demands on an operator (Hart, 1986, 1988; Hart & Wickens, 1990). Perceived workload is influenced by the difficulty, number of tasks, and complexity of demands in combination with the required level of performance (e.g. the mental and physical effort). These factors, in turn, drive the level of information processing required for a set of tasks (Hoon, Kim, Lee, & Hyun, 2006). Information processing is influenced by the environment and the set of technologies used in the completion of tasks. In the networked Future Force, Soldiers will receive information from devices that stimulate visual and auditory senses and require attention to display devices.

Subjective workload was measured using two instruments; the NASA Task Load Index (TLX) and the Mission Awareness Rating Scale (MARS). The NASA TLX captures six features of workload: mental and physical workload, temporal demand (time pressure felt), satisfaction with own performance, effort, and frustration felt (Hart & Staveland, 1988). These questions were measured on a 100 point scale. The MARS was used to measure the mental workload required to achieve SA (Matthews & Beal, 2002). These questions were scored on a four point scale (1 – very easy to 4 – very difficult). Participants completed each survey at the conclusion of each mission.

Situational Awareness

Situational Awareness was measured based on verbal and text reports provided by a platoon to the higher echelon commander. Generally, these reports followed the SALUTE format (Size, Activity, Location, Uniform, Time, and Equipment). In some cases, a SITREP (situational report) was provided to expound on an earlier SALUTE report or to report new enemy activity. These reports were scored for accuracy in two ways; the OPFOR leader provided a high, medium, or low score for each report after the mission and the reports were reviewed on the Google Earth Command and Control (C2) Operations (GEC2O) display with BLUEFOR and OPFOR position reports visible[3]. Additionally, subjective SA measures were used with four questions on the MARS instrument (Matthews & Beal, 2002). These questions captured subjective reports of perceived ability to identify, understand, and predict cues in the environment and to achieve mission goals. These were measured on a 1-4 scale (1 = very easy, 4 = very difficult).

Trust in Network

The Soldiers in both platoons were asked to report their impressions of how well the network performed at the end of each mission according to several factors. These included their ability to access services provided by the network, their ability to communicate over the network, the overall dependability of the network, and their trust of the network. These questions were scored on a 7-point scale (1 = low and 7 = high).

The Trust in Network investigation was exploratory and was intended to gain empirical evidence to document the process by which Soldiers conduct ISR operations with a tactical network. Our analysis was a useful first step and we discovered several findings that will guide future research.

[3] GEC2O was developed by Mechdyne, Future Skys and JB Management in close coordination with the US Army CERDEC C2 Directorate.

Decision Timeliness and Accuracy

Accuracy and timeliness of PIR completion was measured objectively using the GEC2O technology. Analysts reviewed missions from three days and were able to view BLUEFOR and OPFOR position reports on the high-resolution terrain imagery. The tactical message browser and mission timeline tool were open on the display such that messages and spot reports appeared on the screen when they were received. The messages that included time of report within the message format were used to measure latency between that time and the time the message was received by the network. In a complementary analysis, the NCO leading the OPFOR scored each SALUTE report on a high, medium, or low scale based on his knowledge of OPFOR ground truth. [4]

Results

The organization of the results section will proceed in the following manner. First, demographics of participants will be reported, followed by a brief description of technologies in use and then reports from Soldiers on the utility of these. Next, results from the decision accuracy and timeliness analysis will be presented. Finally, data from the supporting measures of workload, situational awareness, and trust in network will be provided.

Demographics

39 Soldiers participated in this experiment. The rank of participants was almost evenly divided between lower enlisted and NCO ranks. In the SO platoon, an equal percent (48%) were E4 and below or NCO (E5-E7) and one participant was an Officer. In the FCS platoon, 56% of participants were E4 or below, 39% were NCO, and one person was a Senior NCO. The platoons varied very little by years of experience in the Army. 67% of the SO platoon reported less than 5 years of Army experience and 33% reported 5-10 years of such experience. In the FCS platoon, 61% had less than 5 years of experience, 28% had 5-10 years, and .5% had 11-16 and over 16 years of experience. Soldiers were also asked to report their familiarity with computer games and unmanned systems. These questions were scored on a 3-point scale (1=not at all, 2=somewhat, 3=very familiar). In the SO platoon, 4% reported no familiarity at all with computer games, while 67% said they were 'somewhat familiar' and 29% said they were 'very familiar'. In the FCS platoon, 56% said they were 'somewhat familiar' and 44% said they were 'very familiar'. With respect to familiarity with unmanned systems, 52% of the SO platoon said they were 'not at all' familiar, 43% said they were 'somewhat familiar' and 1 soldier (5%) said he was 'very familiar' with unmanned systems. This contrasted to the FCS platoon where 28% reported they were 'not at all' familiar and 72% said they were 'somewhat familiar'. The most notable differences between the platoons were that the SO platoon was generally younger with less experience, they had fewer group members who reported being very familiar with computer games, and they had a larger number of respondents who reported being 'not at all' familiar with unmanned systems. The FCS platoon, by contrast, had a few members with more than 10 years of Army experience, had a higher percentage of members who were 'somewhat' or 'very' familiar with computer games, and a higher percentage of members who reported being 'somewhat' familiar with unmanned systems.

Soldier Feedback on Communication Technology

Analysis of the Soldier comments of all technologies in use illustrated the emergent nature of most of these systems; notably the high levels of reported frustration that will be discussed in the workload result section. However, it did appear clear that the dismounted technology provided to each platoon did not

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[4] This NCO is, coincidentally, an Intelligence Analyst and was very familiar with essential reporting elements of ISR reports. He provided needed subject matter expertise on determining whether a report was high, medium, or low in details that would support PIR completion.

perform equally well; in fact, the FCS platoon appeared to be at a disadvantage with the DADD. It is noted that each platoon did have radio communications within their organization, but each platoon was equal in that regard. Table 1 provides a sampling of both positive and negative comments from the FCS platoon on the DADD system and the SO platoon on the Warrior App system.

Technology	Observation
DADD (used by FCS platoon)	• System is hard to use once you dismount, glare on computer screen makes it hard to see, it is not with battlefield rhythm and may cause you to lose SA • Device booted up then crashed several times during operations. Could not send SITREPS. • Device needs to be faster and more responsive. Needs to be able to send images to individuals of choice. Needs to be able to tell who wrote the messages. It rarely worked to potential. It was hard to depend on. It is hard to type with the keys. Slow. Never knew who wrote messages I received. • 2 of 3 devices did not send or receive messages. The one that did seem to work sent out a spot report which was not displayed on FBCB2. • Device did not work at all. Could not send or receive. • Display unserviceable and non-functional. • I think I was able to send. Did not vibrate for sending messages. Did not receive any messages. Can't see screen at night with Night Vision Goggles. Never communicated DADD to DADD. Separate battery pack is (not good).
Warrior Application (used by SO Platoon)	• Good ability to see where everyone is at times. Good sending spot reports. • Device worked well today. Transferred to all but one of my leaders • Maps , messaging, spot reports good • Device only used for SA between squads. • Could not zoom enough to make a difference. • Devices worked very well. Free text worked some of the time. Certain people could receive but not transmit.– • Battery died 1340 hrs. Way too many soldier icons to determine SA • Radio communications good between Plt Leader and Bn Cdr • Dismounted and mounted communications good at Platoon level. No company communications. • New map loads work better, easier to distinguish positions • Warrior Apps worked great - was able to stay behind cover while recording target house.

Table 1: Soldier Comments of DADD and Warrior App

Decision Accuracy

Decision accuracy was measured with two complimentary methods; GEC2O screen shots and OPFOR NCO analysis. The GEC2O play-back mechanism was used to examine screen shots that allowed comparison of reported grid locations, enemy activity, number of enemy, and reports of high value targets to displayed icons. The GEC2O screen shots provided three types of icons that were of interest to this analysis. Two BLUEFOR circle icons are used to denote vehicles and dismounts and red circle icons denote OPFOR individuals. These icons, the message window, and the timeline feature are displayed in Figure 1. In addition to analysis of GEC2O screen shots, the FCS and SO platoon SALUTE reports were scored by the OPFOR NCO who had first-hand knowledge of OPFOR ground truth. These were scored on a scale of low, medium, or high soon after each mission. The discussion and screen shots that follow illustrate that the combination of human intelligence (HUMINT) and sensor images from ground and airborne assets allowed both platoons to have an accurate picture of OPFOR location, size, and activity.

Figure 1: Example of GEC2O Display

Figures 2 and 3 show examples of the level of detail provided by the systems. The UAV image captured by the ROVER 4 remote video terminal user shows three enemy vehicles and is annotated by the user to call attention to the vehicle locations.

Figure 2: Image sent by the ROVER 4 user to FBCB2

The second example of report accuracy is shown in Figure 3 below. The FCS platoon leader sent a message, after receiving HUMINT and sensor reports of OPFOR activity. The OPFOR reported grid location was entered into the GEC2O system and the yellow "push pin" icon shows the center of that reported grid location, which is within 20 meters of the actual OPFOR location.

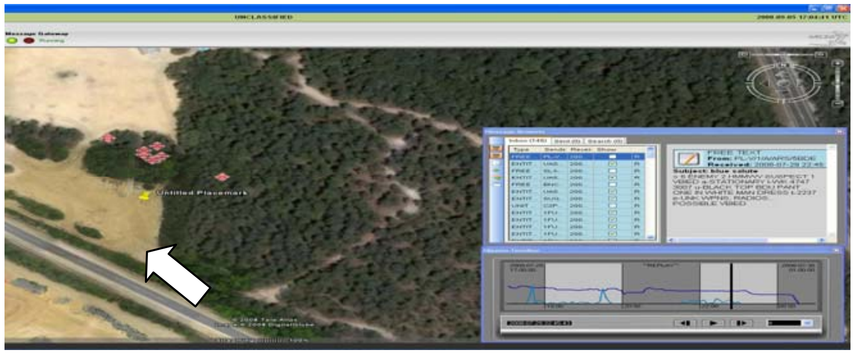

Figure 3: Grid location identified by yellow push pin and MGRS coordinates

However, the latency in message receipt had a serious impact on platoon survivability, as shown in the next image. In Figure 4, the SO Platoon sent a message to the FCS Platoon that the enemy force had escaped their location at Vietnam Village, approximately 2 miles to the south of the FCS platoon location. By the time this message was received, the OPFOR vehicles were in close proximity of the FCS platoon. This is noted by the two red icons in the midst of the BLUEFOR vehicle and dismount icons (see white arrow).

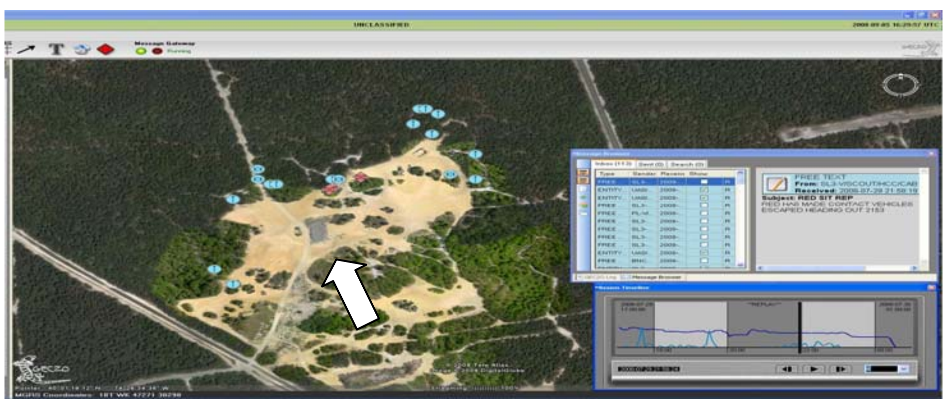

Figure 4: Report from SO Platoon alerts FCS Platoon

Decision Timeliness

The decision timeliness analysis focused on missions executed on July 24, 28, and 29. These missions were the most complete in terms of data collected. Day and night missions were conducted on each of these days. Message latency was recorded in minutes and seconds and converted to seconds for analysis. On average, the written reports that were submitted by both platoons had significant latency. The missions occurring in the day had slightly shorter latency, but this was not a significant difference as measured by a one way analysis of variance (ANOVA). Also, the difference in message latency between the three days was not significant. Table 2 below shows the statistics for these reports. On average, the latency for messages was 370.79 seconds, or 6 minutes and 11 seconds. This latency resulted from delays that occurred with the human operators and the network transport layer. Observations consistently documented that the time noted in the SALUTE report was, at a minimum, two minutes earlier than the time the message was sent. Each platoon used a radio or a dismounted communications device to report enemy activity to the Platoon Sergeant, located at the vehicle rally point. The Platoon Sergeant then fused this information and formatted the SALUTE report. Once the report was sent, it traveled through the network to the FBCB2 displays.

seconds			
day	time	Mean	Std. Deviation
July 24	day	323.0000	33.94113
	night	485.0000	.
	Total	377.0000	96.56086
July 28	day	265.0000	133.13402
	night	402.7500	78.85588
	Total	333.8750	125.23057
July 29	day	432.3333	94.95964
	night	389.2000	85.79452
	Total	405.3750	85.32783
Total	day	333.6667	122.80778
	night	404.2000	78.71157
	Total	370.7895	105.40376

Table 2: Message Latency

Workload

NASA TLX was used to identify platoon members' relative perceptions of workload across six workload components. As previously described, two platoons (SO and FCS), each equipped with their unique set of sensor and communications equipment, conducted tactical missions against a scripted OPFOR. Within the platoons, Soldiers experienced different task demands based on their position and use of a sensor technology. Every Soldier had access to a basic radio platform, weapon, and was expected to operate in accordance with the assigned mission. In addition, some Soldiers operated sensor technologies that required transportation, set up, use, and break-down. The leaders operated a communications device in addition to the radio, and also had to fulfill their leadership duties. The workload analysis focused on two questions; did the platoons differ with respect to workload domains and did Soldiers report a range of workload scores?

Repeated measures Multivariate Analysis of Variance (MANOVA) was used to analyze the workload survey data to answer the first question. This survey measured six factors of workload on a 100 point scale. These six factors are mental and physical workload, temporal demand, satisfaction with own performance, effort, and frustration. Each participant was assigned to either the SO or FCS platoon for the duration of the experiment. The subject pool for this analysis was 36 (19 in SO and 17 in FCS). The analysis included one within factor (day), two between factors (platoon [SO or FCS] and leader [yes or no], three two-way interactions (platoon*day, platoon*leader, and leader*day), and one three-way interaction of platoon*leader*day.

Of these main and interaction effects, only the main effect of platoon was significant (Wilk's λ F (6,27) = 3.71, p =.008). To determine which dimension of the workload construct contributed to this difference between platoons, the between-subjects effects were examined. Only one subscale dimension, 'satisfaction with own performance', was significant [F=17.54 (1,32) p<.005]. This was a significant difference because the SO platoon, on average, had a mean score on 'satisfaction with own performance' of 74.43 compared to a mean of 53.04 for the FCS platoon. The chart in Figure 5 shows that the SO platoon had higher average scores for leaders and non-leaders than the FCS platoon.

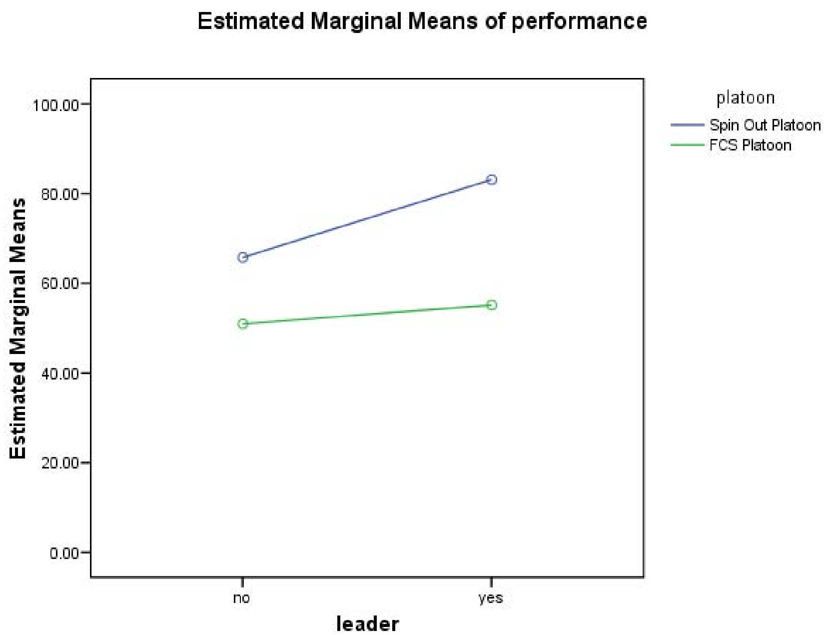

Figure 5: Average Self-Reported Performance

Though this analysis determined that the only source of difference between the platoons fell in the subjective perception of performance, both platoons had high scores on all components of the workload scale. The NASA TLX has no established "red line" above which workload scores are dangerously high (Hill, 2008). The TLX is most often used as a measure of relative workload, comparing one group to another given the same or similar environments.

Table 3 displays overall means for workload for each of the dimensions. These means show leader and non-leader mean scores. On average, these scores suggest the following general conclusions:

- Leaders had higher mental workload than non-leaders
- Non-leaders had higher physical workload than leaders
- Leaders had higher temporal (time pressure) workload than non-leaders
- Leaders had higher satisfaction with own performance than non-leaders
- Leaders had higher effort scores (mental and physical) than non-leaders
- Frustration scores were nearly identical for both groups (56.79 compared to 57.2)

Estimates

Measure	leader	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
mental	no	43.461	3.871	35.575	51.347
	yes	52.206	6.743	38.472	65.940
physical	no	46.902	3.864	39.032	54.773
	yes	43.819	6.730	30.110	57.527
temporal	no	47.636	3.838	39.819	55.453
	yes	52.419	6.684	38.804	66.033
performance	no	58.356	2.542	53.178	63.534
	yes	69.113	4.427	60.094	78.131
effort	no	56.686	3.421	49.719	63.654
	yes	58.931	5.957	46.796	71.066
frustration	no	56.789	4.203	48.227	65.351
	yes	57.200	7.321	42.288	72.112

Table 3: Average Workload

The measurement of workload was important in the Cognitive Impact Study due to the impact of multi-modal tasks on Soldier performance. An inverse relationship is expected to exist between workload and situational awareness; workload that is exceedingly high is expected to negatively impact the ability to develop and maintain SA. For this reason, we were interested in having a measure of workload that was directly related to SA.

The Mission Awareness Rating Scale (MARS) (Matthews & Beal, 2002) was used to provide a measure of Soldier perceptions of mental workload associated with the acquisition of SA. The questions are scored on a four point scale (1 – very easy to 4 – very difficult). As the MARS results are reviewed, the reader is cautioned that lower scores correspond to ease of understanding or lower mental workload. Repeated measures MANOVA was used to investigate if differences existed between the two platoons with respect to responses on the workload subscale (questions 5-8) of the MARS. These questions probe the level of mental workload required to identify, understand, predict, and achieve mission goals. No significant differences were found for either the main effect of platoon (Wilk's λ $F(4,18) = .99$, $p = .44$) or the main effect of day (Wilk's λ $F(8, 14) = .43$, $p = .88$) or the interaction effect of platoon * day (Wilk's λ $F(8, 14) = 1.8$, $p = .15$).

However, consistent with the finding presented earlier that the SO platoon generally reported higher satisfaction with their performance; the SO platoon, on average, reported having low mental workload than the FCS platoon. . An example of this is provided in Figure 6. Figure 6 shows that for three of four days, the SO platoon, on average, reported lower scores for question 4 "How difficult –in terms of mental effort—was it to decide on how to best achieve mission goals during this mission?" However, the FCS platoon had nearly identical mental effort scores for each day, and these scores were higher than any of the SO platoon scores. This suggests that the FCS platoon, on average, reported that they had to work harder in terms of mental effort to achieve mission goals. The days included in this analysis are July 24, 28, and 29.

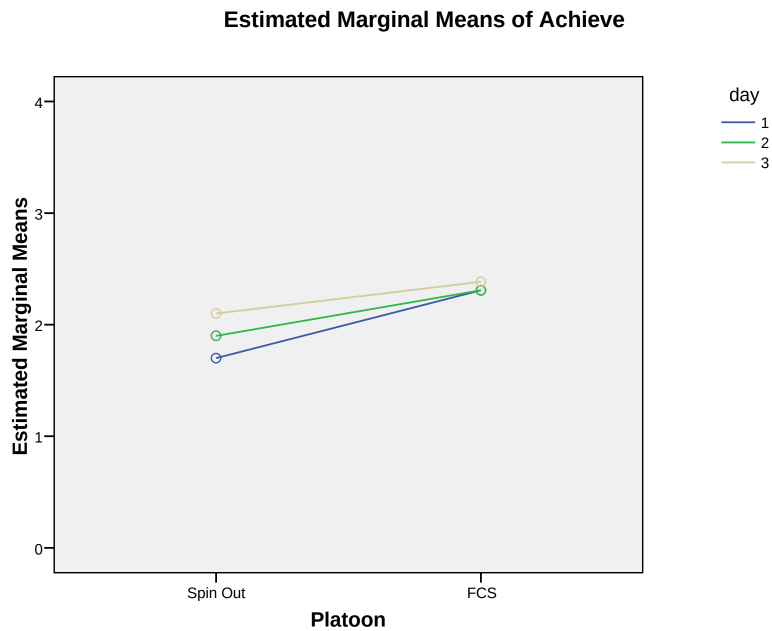

Figure 6: Reported Levels of Performance

The MARS data also was used to contrast subjective SA and mental workload between day and night conditions. Paired sample t-tests were used to examine the relationships between day and night conditions on subjective SA and mental workload scores for three days: July 24, 28, and 29. Missing and incomplete data prevented additional analysis for the remaining days of the experiment. The results for July 28 showed the only significant difference between day and night responses to subjective SA and mental workload (t (18) = 3.43 (two tailed), p=.003), SD-.5). On average, members of both platoons indicated that they were able to understand cues more easily in the night condition than in the day condition (M [day] = 2.22, SD = .81, [night] = 1.72, SD = .75).). This led analysts to further examine the data to determine what conditions made the night of the 28th easier. The GEC2O data provided clues to this question. The next two screen shots show the locations of the Blue and Red forces in the MOUT facility and the number of sensor reports received at this point in the mission. The first screen shot, displayed in Figure 7, shows a GEC2O image that had been annotated to show OPFOR dismounts. Figure 8 shows that the BLUEFOR had a forward presence in the MOUT environment to observe OPFOR activity. This combination of HUMINT and excellent quality of sensor images was most likely the explanation for the relatively low ease of understanding scores on the MARS during this mission.

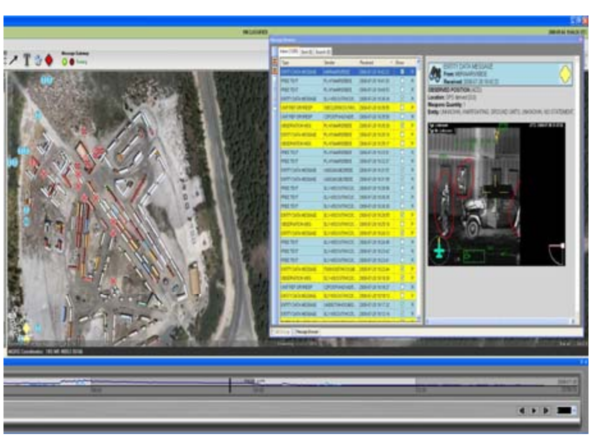

Figure 7: Screen shot of July 28 Mission

Figure 8: Screen shot of July 28 Mission

Situational Awareness

High levels of workload frequently result in lower situational awareness (SA) because of the inability to process and share information (Hoon et al., 2006) due inadequate or immature technologies, and poor human systems integration. The bar charts in Figures 9-10 display objective ratings of each platoon's ability to report on PIR during missions. The PIR reports were scored by the OPFOR NCO leader on a 1-3 scale (1 = low, 3 = high). Each group of shaded bars in each graph differentiates each day's reports (e.g. the first four bars in the FCS Platoon chart were recorded on the first day). Different numbers of reports were provided by the platoons for each day, depending upon the requirements of the mission and their ability to detect enemy activity.

Visual inspection of the graphs in Figures 9 and 10 shows that the FCS platoon had better overall performance in completing PIRs than the SO platoon; though this difference is small and not statistically significant. This is an interesting finding given the higher average perception of own performance on the part of the SO platoon.

The FCS platoon completed a total of 37 SALUTE reports over the course of all missions, compared to 35 reports from the SO platoon. If the medium and high scores are combined for each platoon, the FCS platoon had 92% of their reports in the medium-high range compared to 88.5% for SO platoon. This analysis confirms the GEC2O results; both platoons performed exceptionally well in accurately reporting PIR.

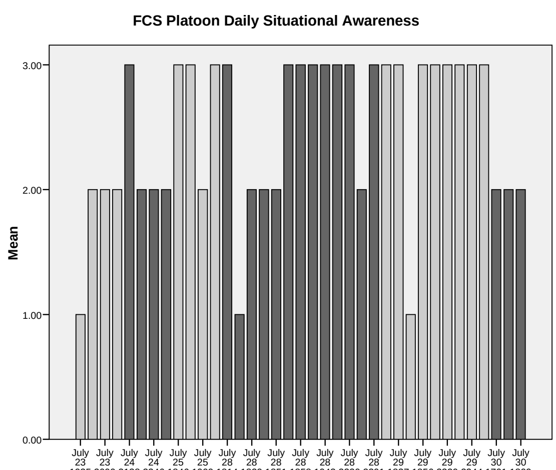

Figure 9: FCS Platoon Daily Situation Awareness

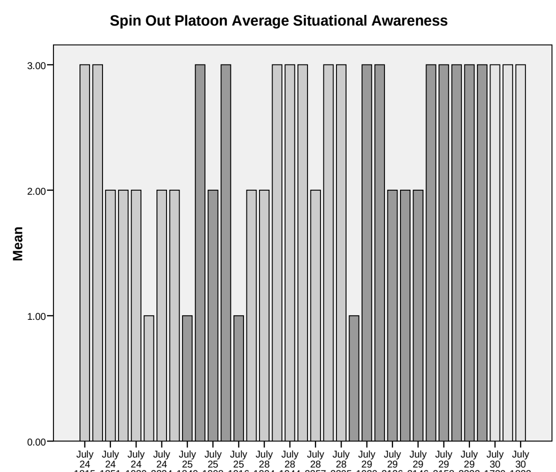

Figure 10: SO Platoon Average Situation Awareness

Trust in Network

The Soldiers in both platoons were asked to report their impressions of how well the network performed at the end of each mission according to several dimensions. These included their ability to access services provided by the network; communicate over the network; overall dependability of the network; and trust in the network. These questions were scored on a 7-point scale (1 = low and 7 = high). A repeated measures MANOVA was used to explore differences in network trust ratings between each platoon over four days of measures. A significant difference emerged in the between subject effects for each of the four categories: access, communicate, depend, and trust. The statistics for these are shown in the table below and indicate that the differences were more noticeable in the aspects of communicate (Wilk's λ $F(1,13) = 6.48$, $p = .024$), depend (Wilk's λ $F(1,13) = 9.67$, $p = .008$) and trust (Wilk's λ $F(1,13) = 7.59$, p

=.016). The factor of access was nearly significant at (Wilk's λ F (1,13) = 4.60, p =.051). The graphs in Figures 11-14 provide a visual representation of these data. The mean scores for trust in the network are presented in Table 4, and show, on average, higher scores for the SO platoon compared to the FCS platoon.

Tests of Between-Subjects Effects

Transformed Variable: Average

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	access	440.183	1	440.183	38.213	.000
	communicate	1072.913	1	1072.913	139.218	.000
	depend	397.964	1	397.964	77.951	.000
	trust	432.055	1	432.055	74.844	.000
platoon	access	52.983	1	52.983	4.600	.051
	communicate	49.912	1	49.912	6.476	.024
	depend	49.364	1	49.364	9.669	.008
	trust	43.788	1	43.788	7.585	.016
Error	access	149.750	13	11.519		
	communicate	100.188	13	7.707		
	depend	66.369	13	5.105		
	trust	75.045	13	5.773		

Table 4: Tests of Between-Subjects Effects

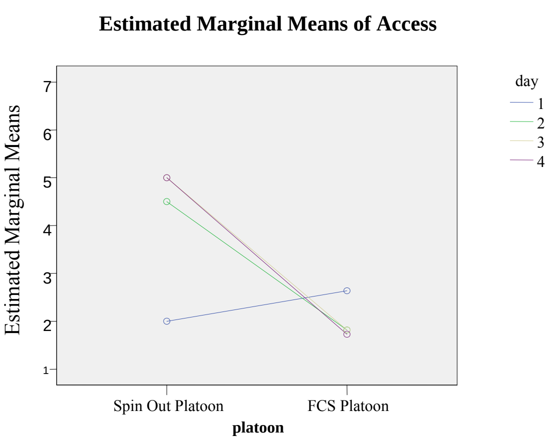

Figure 11: Average Network Access

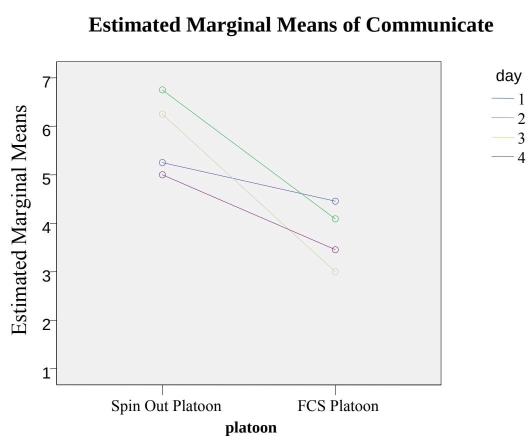

Figure 12: Average Ability to Communicate over the Network

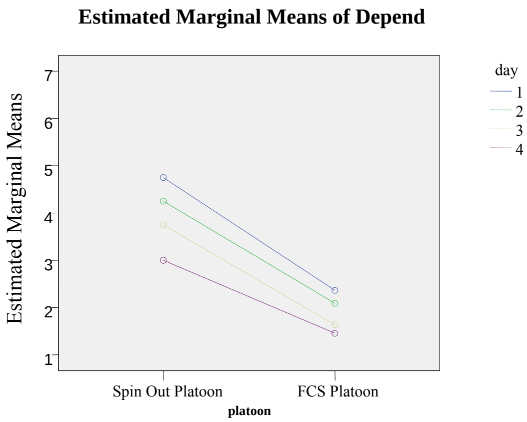

Figure 13: Average Network Dependability

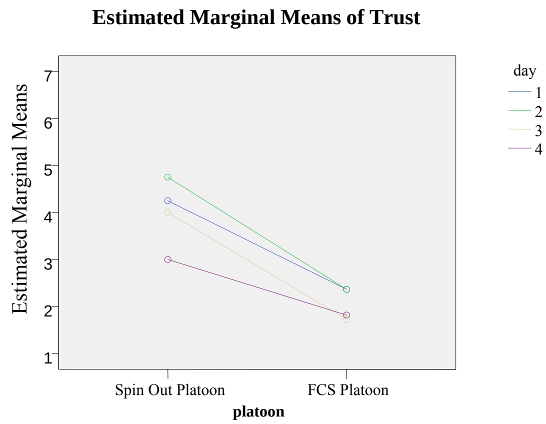

Figure 14: Average Trust in Network

Discussion

The Soldiers operating in this experiment were trained in both classroom and field settings. In the classroom, they were introduced to the technologies and learned about all relevant features they would be expected to use. This training was followed by static field training with technology developers where the Soldiers had the ability to interact with the systems with expert help nearby. The platoons then had several days of pilot testing where they became more familiar with their technologies in the context of mission formations they would be expected to execute in the experiment. This pilot testing allowed both Soldiers and engineers to identify and resolve deficiencies in either training or system performance. By the time the experiment began, 8 days of classroom, static, and mobile field trials had been performed. This experiment was somewhat unique in the amount of training that was made available to the Soldiers. Additionally, many of these Soldiers had participated in C4ISR OTM E07, and were generally familiar with operating integrated technology suites for ISR missions.

The Soldiers who participated in this experiment were all male with an average age of 24 and were almost evenly divided between lower enlisted (E1-E4) and NCOs (E5-E7). Ninety-six percent of the SO platoon and 100% of the FCS platoon reported that they were 'somewhat' or 'very' familiar with computer games. Researchers were interested in this statistic to determine if this familiarity would help the Soldiers in their use of unmanned systems during the experiment. Conversely, 95% of the SO platoon and 100% of the FCS platoon reported that they were 'not at all' or 'somewhat' familiar with unmanned systems. The one question that arises (but is not answered by any empirical or observational data) is whether or not the SO platoon may have adapted to challenges they experienced during the missions more positively than the FCS platoon due to their relative lack of Army experience. In other words, this platoon may have been less bound by doctrine or training and may have been more open to new ideas with respect to using unmanned systems and new communication devices. This subject should be precisely explored in future exercises.

The survey results suggest that the ability to communicate within and between echelons may play a central role in general performance indicators. The SO platoon reported that their communications device for intra-squad text communication worked well, compared to the FCS platoon's technology. Though SO platoon members did not out-perform the FCS platoon in objective measures of decision timeliness or accuracy, the SO platoon consistently, and to a significant difference, rated their performance higher than did the members of the FCS platoon. Members of the SO platoon also measured their trust in the network higher than the FCS platoon.

The exploratory Trust in Network analysis aided our understanding of how Soldiers conceptualize a tactical network and the various technologies that are supported by the network. The fact that the FCS platoon was targeted by information attacks to a greater extent than the SO platoon is a probable explanation for the lower trust scores from that platoon. Additionally, the poor performance of the dismounted communication device used by the FCS platoon could have contributed to the low trust scores. However, it is laudable that the FCS platoon overcame these hindrances to attain a high level of accuracy in their PIR. With this experience, we can recommend a full range of future research to understand the nature of the relationship between network performance, user trust in the network, and communication behaviors.

The fact that the Soldiers stopped using a communications technology when they believed they were under cyber attack is useful for developing future TTPs in networked operations. In this system of systems configuration, alternate communication devices existed. Thus, when a Soldier in the FCS platoon stopped using a technology because of a perceived system failure due to cyber attacks, they continued developing their SA picture of enemy activity by listening to radio communications. This prevented them from being completely isolated from their platoon during mission execution. Redundancy of communication methods is clearly an enabler of information dominance in a network that is open to attack and organic node loss. However, embedded data collectors noted that when Soldiers stopped using their technologies, the completeness and timeliness of their situation reports and processes for information dissemination within the platoon were slightly degraded. This was largely due to the time required to reboot a technology and to mentally reinsert themselves into the mission.

The communication behaviors required of the Soldiers in this experiment were demanding due to the multi-modal nature of the devices. Soldiers were asked to tactically position themselves using their technologies to gain SA of enemy activity. In some instances Soldiers were able to establish both visual contact with the enemy through their own eyes and through a remote video terminal or sensor. They communicated using a radio system within their platoon. They had dismounted devices that allowed them to enter text information or to observe icons and reports on a display. Some Soldiers were asked to operate the SUGV in a tele-operation mode. In addition to these tasks, they had to execute dismounted maneuvers through dense pine forests in extreme heat. In the case of the night missions, they were expected to do all of this with night vision goggles. In this context, the measurement of workload was of central concern.

In spite of the Soldiers' ability to use the technology suite to develop highly accurate reports, information sharing had an unacceptable latency rate of more than 6 minutes. This latency was caused by several factors. First, the Soldiers had to fuse data from several different sources (e.g. sensor or human) and several types (e.g. image, text, streaming video). Second, the Soldiers experienced periodic machine malfunctions, which impacted their ability to compose messages and transmit these over the network. If devices were working, visual data (image and video) had to be transformed into textual information. Alternately, if a dismounted communications device was not working, the Soldiers reported information to a Soldier operating an FBCB2 display in a vehicle. This Soldier collated information from several dismounted squads, and waited until he had enough information to send forward. Finally, the speed of message transfer was dependent on the network.

The environment, technologies, and mission requirements all contributed to the high levels of workload experienced by both platoons. The variety of technologies used in the experiment, with various levels of success, contributed to high levels of frustration. Given the nature of workload, high frustration levels would be expected to contribute to a lack of information processing resources needed for task completion. The Warrior Application used by the SO platoon, though not without problems, did function sufficiently well for the platoon leaders to share information throughout most of the missions. Conversely, the DADD, used by the FCS Platoon squad leaders and scouts, did not enable communication within the dismounted sections. This was identified as a possible explanation for the difference between the two platoons in their assessment of performance.

Frustration, a component of the subjective workload assessment, was consistently high throughout the experiment and appeared to have two sources; only one of which was anticipated. The frustration associated with malfunctioning technologies was expected and is a given condition in a world where technology solutions abound. The source of frustration that was unexpected was the unwillingness of leaders to allow technology users to modify tactics, techniques, and procedures (TTPs) in order to position their system to gain information collection advantages from a network perspective. Like the child who has to program the digital TV for his/her digital alien parents, the future Robotics NCOs may have to advise leaders of technology requirements in relation to the network.

The workload results also demonstrated the protective factor within squads and platoons that results from the ability to communicate and share information. And, while Soldiers advocate for small devices that do not significantly add to their already heavy dismounted load, the tablet personal computers in this example were more useful than the wrist-worn devices. In this case, the added physical workload may have been mediated by the improvement in performance and low mental effort scores.

Apart from the latency issue and relatively high workload, the ability to share sensor data between vehicle and dismounted positions greatly contributed to both platoon's ability to develop situational awareness. The mix of HUMINT text messages and spot reports, sensor images and spot reports, and the BLUEFOR position reports provided by these technologies contributed to high levels of situational awareness. We noted earlier the finding that both platoons found it was easier to identify cues during night missions than in the day. This is consistent with the "we own the night" philosophy of technology-aided visualization and with the difference between urban and forested terrain. This finding was also present in the urban terrain where landmarks were easier to differentiate compared to forested and sandy terrain.

Conclusion

This analysis illustrates the balance that must be achieved between the art of Command and the science of Control for the future of tactical networks. The results of this cognitive impact study show conclusively that the ability of Soldiers to Soldiers' use of technology to view enemy activity from air and ground perspectives and to communicate this information within and between units contributes greatly to their situational awareness. However, the process of extracting this information and transforming it to text messages that must be transmitted over a network cause unacceptable delays that must be addressed in future organizational and network configurations.

We believe workload to be a critical component in understanding the cognitive impact of an integrated C4ISR network. Subjective workload can provide insight into the nature of the tasks assigned to individuals and teams of Soldiers. It can also guide the development of adaptive automation to reduce Soldiers' workload. Understanding how various tasks contribute to high levels of workload can lead to the design of smart displays that reduce certain types of workload factors, such as time demands, mental fatigue, and frustration. Alternately, knowledge of Soldier strategies to reduce high levels of workload can lead to better human systems integration with various technologies to reduce workload burden. Finally, understanding subjective workload levels will determine the type and amount of technical support required by Soldiers.

Frustration with the use and performance of the provided technologies was a major feature of networked operations for the participants in this study. In a battlefield environment that is inherently complex and uncertain, additional sources of frustration are counterproductive. The presence of Robotics NCOs who are trained in the features of both the network and the supported technologies can be one solution to this problem.

It should not be surprising that a suite of technologies increased the frustration and workload levels of the soldiers who operated these systems. Given the known association between high levels of workload and decreased situational awareness, this is a major focus area for technology developers and human factors specialists. Clearly, these integrated systems must be refined significantly prior to actual fielding.

For all of the aforementioned detractors of the integrated technology suite, it did represent the major factor in decision accuracy, albeit as the cost of timeliness. Accuracy of decision making was made possible by mixed asset sensor data (provided by human intelligence, air and ground sensors, and unattended ground sensors), the FBCB2 displays that depicted BLUEFOR positions of dismounts and vehicles and recorded messages and spot reports, common operating display, and the communications within the platoons (via radio and technology devices). The Soldiers in both platoons used their respective technology assets to the best of their ability and were successful to the limits of the technology performance (note the mixed performance of the dismounted communication technologies used by each platoon). Further, the FCS platoon demonstrated adaptation and innovation with their response to information attacks.

In spite of the ability of the technology suite to provide data to Soldiers, the information shared by the platoons had an unacceptable latency rate of over 6 minutes. This latency was caused by several factors. First, the Soldiers had to fuse data from several different sources (e.g. sensor or human) and several types (e.g. image, text, streaming video). Second, the Soldiers experienced periodic machine malfunctions, which impacted their ability to transmit. If devices were working, these transmissions had to be entered into a communications device that required typing information into a display. If a dismounted communications device was not working, the Soldiers reported information to a Soldier operating an FBCB2 display in a vehicle. This Soldier collated information from several dismounted squads, and waited until he had enough information to send forward. Finally, the message had to transit the network.

The good news from the Cognitive Impact Study was the high rate of PIR accuracy achieved by both platoons using an integrated sensor suite with redundant capabilities. The bad news was that this accuracy came at the cost of unacceptable time delays. At the tactical level of warfighting, information is perishable and must be shared in seconds rather than minutes. While radio communications provided near-real time information sharing in this network, alternate means of sharing data are required for MANETs in order to moderate bandwidth requirements. The accuracy attained by the FCS and SO platoons was supported in large part by the sensor imagery and text communications. Future iterations of tactical networks must allow the transfer of information with significantly reduced latency.

This analysis clearly documents the cognitive impact of an integrated technology suite on a tactical force conducting ISR activities against a thinking and adaptive enemy force. Technology assets contribute the element of accuracy to Soldiers while costing them the needed advantage of timeliness. The technology suite demonstrated in this study provides an effective roadmap for the future force. Technology capabilities have demonstrated positive impacts on Soldier situational awareness and decision making. The challenge remaining is to enable transfer of information in milliseconds rather than minutes. The requirements of the tactical force for information sharing are unique and will not be met by a 'one size fits all' network. Future research and development must focus on defining specific information sharing and collaboration requirements that can be realized with MANET features.

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