13th ICCRTS

"C2 for Complex Endeavors"

Title: "C2 of Unmanned Systems in Distributed ISR Operations"

Topic 2: Networks and Networking
Topic 1: C2 Concepts, Theory, and Policy
Topic 9: Collaborative Technologies for Network-Centric Operations

Authors:
Elizabeth K. Bowman, Ph.D.
Jeffrey A. Thomas, M.S.
Army Research Laboratory – Human Research and Engineering Directorate

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **C2 of Unmanned Systems in Distributed ISR Operations**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Research Laboratory,Human Research and Engineering Directorate,Aberdeen Proving Ground,MD,21005**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
13th International Command and Control Research and Technology Symposia (ICCRTS 2008), 17-19 Jun 2008, Seattle, WA

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**35**	

C2 of Unmanned Systems in Distributed ISR Operations

Abstract

This paper describes a series of experiments to investigate issues of human-robot teaming and network centric operations. Experiment objectives were coordinated to address issues within and among the physical, communications, information, and human (cognitive/social) domain layers of the network. Objectives spanned the cognitive, social, and physical domains of the network. In the cognitive domain, researchers tested a predictive performance tool for robotic operators and measured operator situational awareness and workload during missions as these conditions related to reliance upon unmanned surveillance technologies. In the social domain, we documented the ad hoc development of social, task, and knowledge networks during missions. These human dimensions of the network were juxtaposed to the agile computing infrastructure operating over a Future Force surrogate network and an 802.11 network. Results show that many challenges exist across the layers of the network domain architecture. Primary among these is to develop a mobile ad hoc network (MANET) to support mobile and extended vehicle/dismount ranges in a variety of terrain conditions. In the cognitive/social domain, we need to understand what information Soldiers need from a network, when this information is of maximum use, and what form the information should take for maximum situational awareness and decision making.

Introduction

This report details the human factors analysis conducted in July 2007 at an experiment designed to investigate the impact of a suite of unmanned C4ISR technologies on platoon force effectiveness, as measured by individual understanding of networked information. The unmanned technologies included in the experiment architecture were the PackBot Small Unmanned Ground Vehicle (SUGV) and a Family of Unattended Ground Sensors (FUGS). The objective of the human factors assessment was to evaluate the contributions that unmanned technologies make to situational awareness when used in a relevant field environment and investigate the cognitive abilities that appear to be correlated with high performance on tasks associated with tele-operating a SUGV under non line of sight conditions. This contribution to understanding the human dimension of network centric operations is critical to establish communications capabilities to connect decision makers with essential elements of information.

Method

Situation Awareness and Workload Measures

In examining how unmanned systems impact platoon effectiveness with respect to Intelligence, Surveillance, and Reconnaissance (ISR) missions, ARL researchers and technology developers were specifically interested in understanding how a suite of unmanned technologies contribute to

Soldiers' ability to develop situational awareness (SA). Although SA is difficult to measure in a field setting because of the need to divert Soldiers' attention away from battlefield activities (Bowman & Kirin, 2006), a newly developed survey methodology utilizing standard Army ISR reporting techniques was implemented. This survey methodology uses the military standard SALUTE format with added questions to probe Soldiers' assessment and prediction of known battlespace activities. [1] These surveys (titled the SALUTE-AP; Bowman & Thomas, 2006) were given to each Soldier. Each survey was administered at approximately 20-minute intervals that coincided with natural or planned pauses in the scripted OPFOR activity. One analyst was assigned to the OPFOR and recorded ground truth as the mission progressed. This ground truth survey was used to score each individual Soldier SALUTE-AP at the conclusion of the mission. The survey was scored on a 3 point scale (1=low SA, 3=high SA), and provided an objective measure of Soldier SA.

SA of platoon leaders has been successfully measured in the field using the Mission Awareness Rating Scale (MARS) (Matthews & Beal, 2002). The MARS instrument includes two subscales that assess SA content and SA workload. Each subscale includes four questions that address the three levels of SA (identification, comprehension, and prediction). The fourth question is concerned with how well mission goals were identified. The four workload subscale questions are aimed at asking respondents to quantify the effort involved in making decisions and predictions regarding their mission as well as identifying and comprehending the information as presented to them. Matthews and Beal reported that the MARS was effective in differentiating between squad and platoon leaders' SA in a field training environment. The measure was also reported to be unobtrusive and easy to administer, requiring less than 5 minutes to complete (Matthews & Beal, p. 8). In this experiment, we did not administer the workload subscale and instead used the NASA Task Load Index to measure perceptions of workload. This measure requires participants to rate their workload according to six dimensions. These are mental and physical workload, time pressure felt, satisfaction with own performance, effort, and frustration felt. These questions are measured on a 10 point scale. The participants completed the MARS and the NASA TLX at the conclusion of each mission, or once per day.

Training

Soldiers received one week of hands-on training prior to the start of the test runs. This training included hands-on instruction on multiple unmanned technologies [two PackBot SUGVs, and six FUGS]. A refresher course was given on the Force XXI Battle Command Brigade and Below (FBCB2) version 4.4.2 battle command system. Each soldier received specialized training in operating the PackBot SUGVs.[2] Soldiers were given a demonstration about the PackBot's capabilities; its intended uses in the field; and the types of operator or control problems to anticipate as well as the appropriate techniques for problem solving. This training session also included details about the Operator Control Unit (OCU). After the one hour

[1] The SALUTE report is an acronym for the traditional categories of a tactical report: Size, Activity, Location, Uniform, Time, and Equipment. We added the categories of Assessment and Prediction. For each of those two latter categories, we asked Soldiers to express their level of confidence in their answers, measured on a 5 point scale (1 = low, 5 = high).

[2] Each Soldier was trained in the SUGV in order to participate in the cognitive test battery. Only two of these Soldiers used the SUGV in actual mission trials in support of the larger activity.

lecture style training sessions, each Soldier was instructed to drive the PackBot line of sight and non-line of sight inside. The one-on-one driving instruction included a series of performance tasks. The primary task was to drive the PackBot up and down a short flight of stairs, about one foot high. Soldiers became familiar with raising and rotating the head of the PackBot as well as the type of system feedback provided on the OCU.

Additionally, two Soldiers were trained in operating the FUGS. These Soldiers were selected by their platoon leader because they had experience with similar sensors. At the conclusion of the training, the technology developers verified that the Soldiers assigned to operate the technologies were sufficiently trained to safely operate the vehicles.

Also during this week, Soldiers were given four blocks of training on the Army Cognitive Readiness Assessment (ACRA) system. The objective in this phase of training was to allow each Soldier to become familiar with how to take four cognitive tests via a lap-top computer (O'Donnell, Moise, & Schmidt, (2004)). Each block of training lasted 15 minutes. Soldiers were given one (1) 30 minute break in the middle of training, resulting in a total training time of no more than 90 minutes. At the conclusion of the week, each technology expert verified that the Soldiers are sufficiently capable of operating the system with minimal support and the ARL scientist verified that the Soldiers understood how to complete each test in ACRA.

Scenarios

Missions were focused in the ISR domain. Five scenarios were developed to address the objectives described above; each relied upon the presence of an active but scripted Opposing Force (OPFOR). Three types of test ranges were employed, spanning the range of possible environments at the test facility. These are described in Table 1. Each mission was conducted in the same manner. Soldiers would load into vehicles at the assembly point and convoy to the designated test site for that day. They would unload unmanned systems and arrange vehicles as designated by the test director to maximize network connections. When the Soldiers were in position, the OPFOR was directed to enter the test range and conduct activities as directed by the test director. Surveys were administered during and after the mission as detailed below. The test director called an end to the mission when all activities were concluded.

Table 1 Test Locations

Test Range	Characteristics	Dates
Case 1, TAC 9D	Open rolling sandy areas with lightly forested sections.	18 and 25 July
Case 2, TAC 12A	Open sandy areas with heavily forested sections including 'Vietnam Village', a set of three huts in a forested area.	19 and 20 July
Case 3, MOUT	An urban site configured in a triangular shape.	24 July

Demographics

10 Soldiers from the New Jersey Army National Guard participated in this experiment. These Soldiers were members of one platoon and therefore knew each other well. Their average age was 29 (SD = 9.3). This was an Infantry company; all Soldiers were male. All but one Soldier reported a military occupational specialty (MOS) of 11B. More than half (N=6, 60%) of the Soldiers reported less than five years of military service. Three Soldiers reported between 5 and 15 years of military service and one reported 16 or more years of military service. Sixty percent of the Soldiers (N=6, 60%) were NCOs (E5 and E6). Four Soldiers were lower enlisted ranks, one E3 and three E4s. Four (40%) of the Soldiers reported having a high school diploma. Three had an undergraduate college degree, one had taken some graduate courses and two had a graduate degree. These Soldiers reported that they had little experience with unmanned systems and a communications network except for their participation in PM C4ISR OTM's 2006 activity, in which most of these Soldiers took part.

Army Cognitive Readiness Test Experiment

During the first week of the training phase of the experiment, a small excursion experiment was conducted to investigate if scores from a cognitive test battery could be correlated with performance operating a SUGV. Literature in human robotic interaction consistently show that individual cognitive attributes such as spatial orientation and visualization (Gugerty, 2004; Chen et al., 2006), time velocity estimation (Rastogi, 1996; Darken, Kempster, & Peterson, 2001, Fong, Thorpe, & Baur, 2003; Van Erp & Padmos, 2003), attentional control (Chen & Joyner, 2007), and the span of control of multiple systems (Barnes, Cosenzo, Mitchell, & Chen, 2005) are critical to safely and successfully operating unmanned technologies.

To determine if these cognitive attributes relate to objective performance data from operating unmanned technologies in an ISR mission, a small controlled field test was conducted. The field test used the Army Cognitive Readiness Assessment (ACRA) system and one PackBot SUGV with its associated Operator Control Unit (OCU). The ACRA system is an Army-specific, field-useable performance test battery generation system developed by NIT, Inc., under a Phase II Small Business Research Initiative (SBIR) grant. It consists of a suite of 12 cognitive tests that best represent 16 critical cognitive attributes of the warfighter. The battery of tests and their relationship to each of the 16 critical cognitive attributes were established by subject matter experts (SMEs) and input from cognitive scientists at the Army Research Laboratory (ARL) and NTI, Inc. Four of the twelve cognitive tests in ACRA were chosen for this study: (1) Motion Inference (time estimation); (2) NovaScan C (multitasking, spatial manipulation, working memory); (3) Rapid Decision Making (reaction time, selective attention); and (4) Tower of Hanoi (executive planning). These tests were selected using an optimization methodology (i.e. T-Matrix).[3] The T-Matrix optimization selects the tests most related to a set of cognitive demands associated with tele-operating robotic assets in an ISR mission.

[3] See O'Donnel, Moise, & Schmidt, 2004 for a detailed description about the T-Matrix optimization methodology.

This study was conducted on a small area where several high mobility and multipurpose wheeled vehicles (HMMWV) and other motor pool inventory were parked (hereafter referred to as the PackBot Track). Seven Soldiers drove a PackBot (Figure 1a) non-line of sight, around seven HMMWVs while searching for four targets. Soldiers drove the PackBot using an OCU, such as the one shown below in Figure 1b. Each Soldier was informed that their performance would be determined by how well they were able to complete the task and the number of targets identified. Overall performance was based on how fast they completed the course; the number of targets identified; and the number of errors committed (i.e. hitting a parked HMMWV or reckless driving).

Figure 1a and b: PackBot SUGV and Operator Control Unit (OCU)

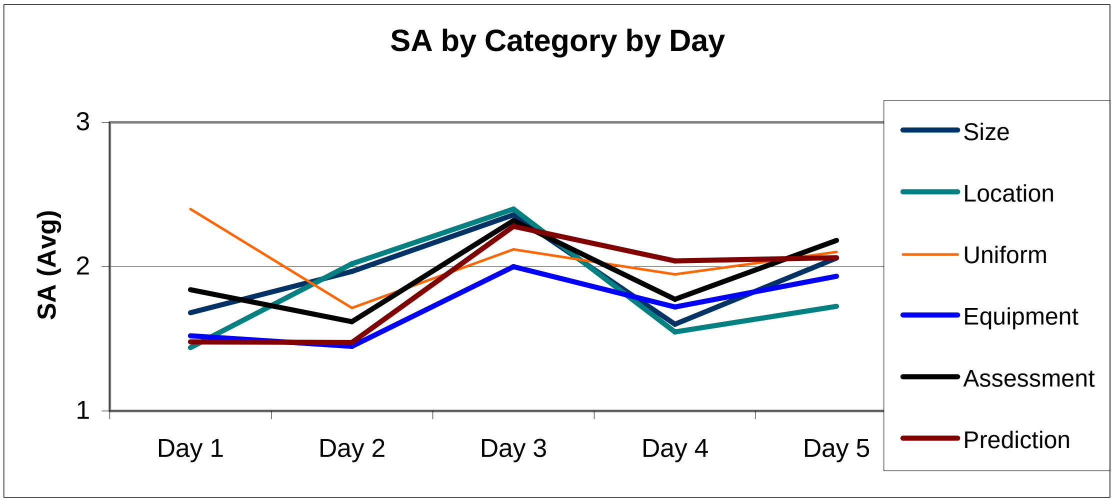
Once the Soldiers finished their training on ACRA and the PackBot, each were allowed a 15 minute practice session to drive the SUGV non-line of sight on the PackBot Track. This practice session gave each Soldier an opportunity to become familiar with the rules of the test and the course. Prior to the start of each test session, Soldiers completed the ACRA testing on a laptop. Upon completion of testing, the Soldier reported to the PackBot Track where he received oral instructions for completing the course. Soldiers were not allowed to reverse the course, and were timed using a stopwatch. As each Soldier completed the course, two ARL researchers followed behind the PackBot and recorded any errors. This testing routine was repeated twice (2 trials) over a two day period.

Results

Situational Awareness

The data from the SALUTE –AP were aggregated by category (i.e. size, location, uniform, equipment, assessment, and prediction) and are displayed in Figure 2. These scores show that SA within each category of the SALUTE-AP varied by day.

Figure 2 SA by Category by Day



These data were analyzed using a repeated measure multivariate analysis of variance (MANOVA) to determine if Soldiers differed in their ability to gain SA in each category identified on the SALTUE-AP by day. The results show a main effect for SA data with regard to three of the seven categories for reporting OPFOR activity; size, location, and prediction (see Table 2 below). The category of "time" was not included in the analysis as this variable was treated as a constant across each run to help control the overall variability of the SA data as it related to administering the survey. Problems in data collection regarding the "activity" question required that these data be excluded from the analysis. The three variables allow the comparison of Soldiers' understanding of the size of the enemy force, their location, and probable future activity as these varied by day of mission.

Table 2 Significant Results

SALUTE-AP Category	Assumption		Significance
Size	Sphericity Assumed	$F(4,16) = 3.529$	.030
Location	Sphericity Assumed	$F(4,16) = 3.067$	.047
Prediction	Sphericity Assumed	$F(4,16) = 3.695$	.026

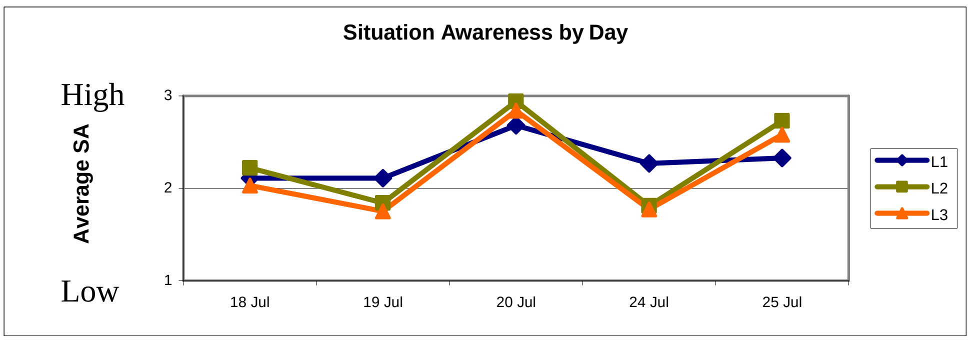
Pairwise comparisons were computed to determine which days were significantly different for each SALUTE-AP category. The results of this test are displayed in Table 3. This analysis shows that Soldiers' understanding of the size of the enemy force and their location was lower on Day 1. Soldiers' predictions of future activities of the OPFOR were more accurate on Day 1 and Day 2 of testing. This may be largely due to the differences in location on both of these days (e.g. open areas that made it easier to detect activity).

Table 3 Pairwise Comparisons

Pair	Mean Difference	Standard Error	Significance
Size			
Day 1 – Day 2	-.286	.079	.022
Day 1 – Day 3	-.680	.120	.005
Location			
Day 1- Day 2	-.580	.15	.018
Day 1 – Day 3	-.960	.172	.005
Prediction			
Day 1 – Day 3	-.800	.228	.025

The following results of the SALUTE-AP survey compares average levels of SA by day and by location. An average score was created for the platoon by combining individual scores for the level 1, 2, and 3 questions. These scores are displayed in Figure 4 and show that for each record run, SA scores, on average are fairly high.

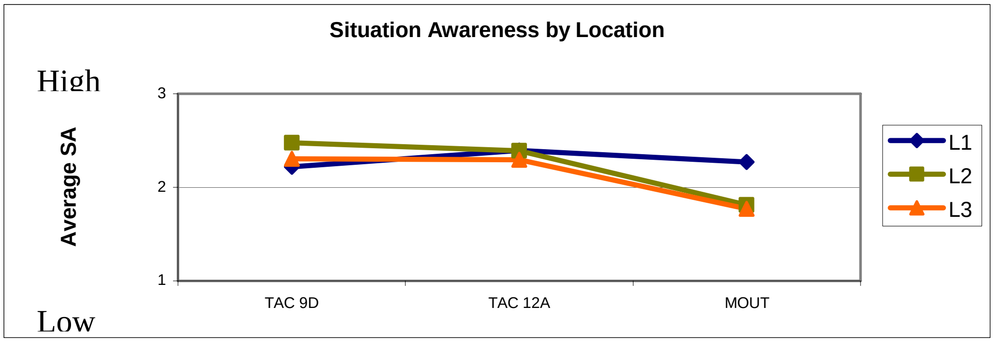
Figure 3 Average Situation Awareness by Day



Most scores fall within the 1.5 to 3.0 range. The scores ranged from low (1) to high (3). Many of the Soldiers demonstrated a high level of SA as measured by the questions of enemy activity. These high SA scores are due, in part, to the integrated battle command system that allowed Soldiers to push and pull information across the network. This enhanced FBCB2 system allowed the platoon leaders (PL and RNCO) to communicate and obtain sensor images from distributed SUGVs, a family of UGS, and the higher echelon UAS when it was available. The higher SA scores on 20 and 25 July are due in part to the availability of the UAS. The UAS imagery provided an overall picture of the area of operations, thus allowing Soldiers to make sense of aggregate information from ground sensors (FUGS and SUGV). The difference in SA scores by day is also due in part to the different locations where ISR missions were conducted. As previously stated, ISR missions were conducted in three separate locations. This allowed Soldiers and the multidisciplinary research team an opportunity to use the full capabilities of the range facilities at Ft. Dix, NJ and to study the behavior of each system in different conditions. The location of ISR missions differed by day due to range availability.

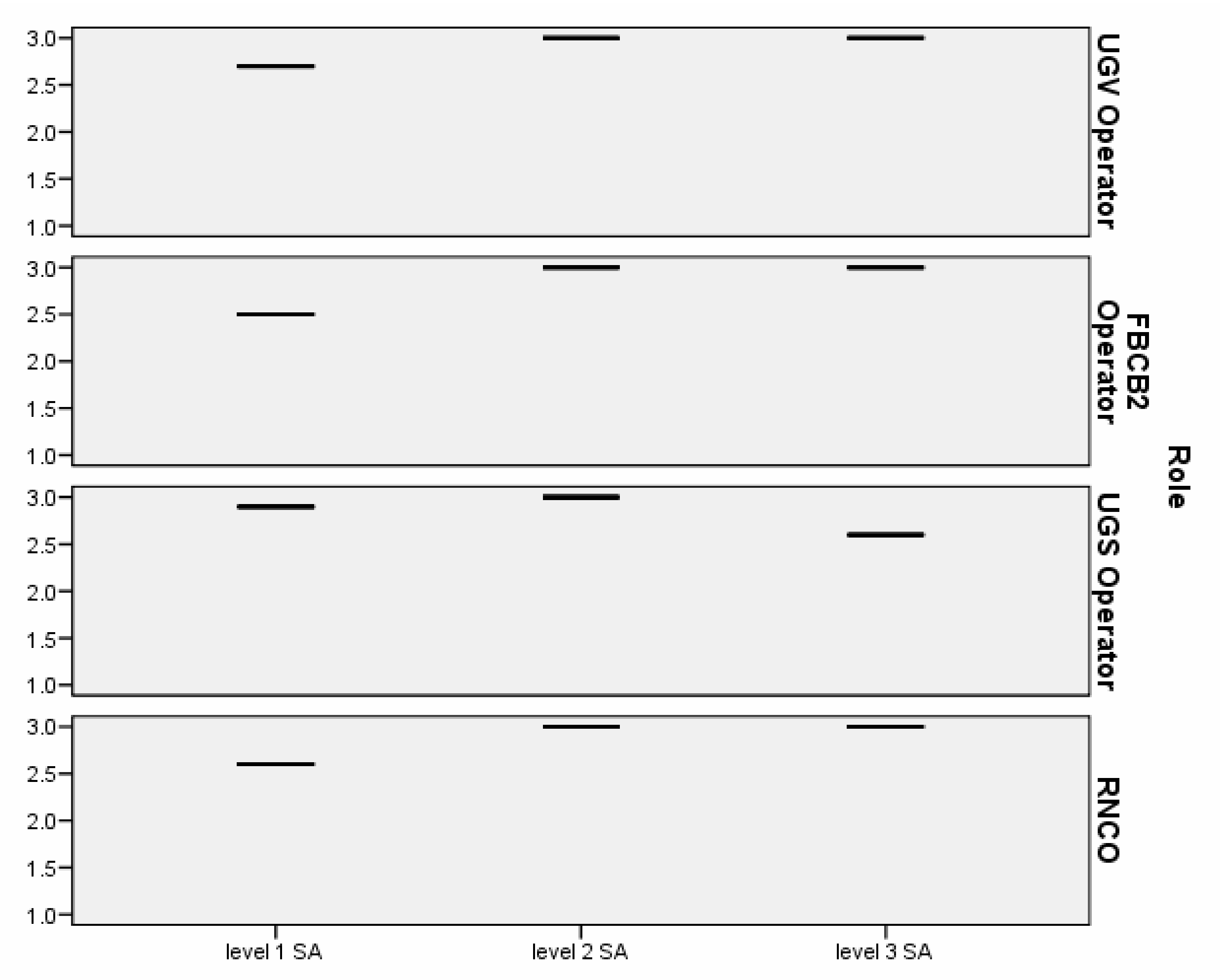
Figure 4 demonstrates how average SA scores differed by location. In the 9D and 12A sites, mean scores for levels 1, 2, and 3 were similar. In the MOUT site, scores for level 2 and 3 (assessment and prediction) were noticeably lower. Unlike the 9D and 12A sites, researchers could only access the MOUT site on one day due to limited availability. On the day that the mission was run in the MOUT site, many technical problems were encountered with the unmanned assets and the communications systems, resulting in much confusion among participants. However, level 1 scores were relatively high for this mission, as they were on the other days. As Figure 4 shows, most scores were above 2, suggesting better than average SA for levels 1, 2, and 3 for TAC 9D and 12A, and level 1 for the MOUT site. The higher scores for level 1 indicate that the unmanned assets allowed the Soldiers to accurately report the number, location, and equipment of the enemy force. The lack of the UAS in support of this mission, and the frequent problems with voice communication contributed to the inability to develop higher levels of understanding and projection. This is a key finding and suggests that unmanned images alone cannot substitute for human communications through a stable network.

Figure 4 Average Situation Awareness by Location



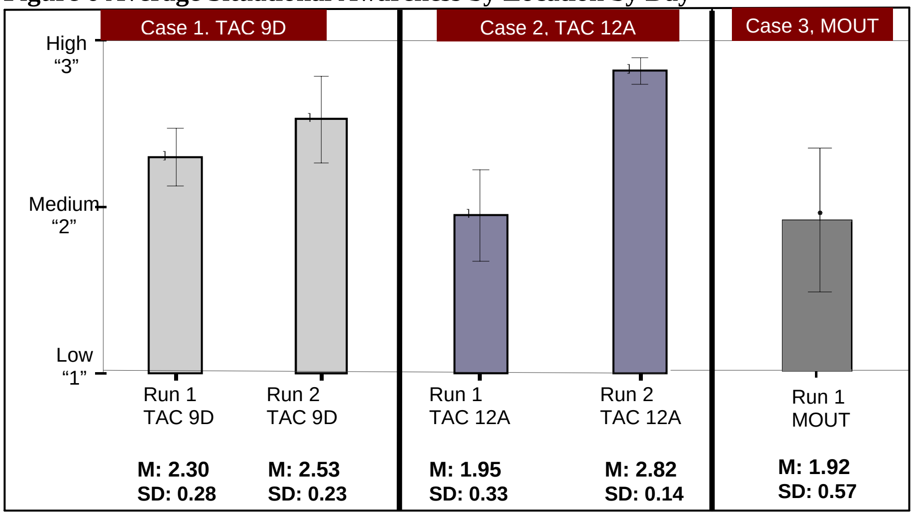
To demonstrate how SA scores varied by position, a representative sample of one day's SA scores is presented in Figure 5. These scores show how scores differed by position for level 1, 2, and 3 SA. The positions reported in the figures represent the operators of the unmanned systems and the Robotics NCO (RNCO). The operators of the unmanned systems had views of a portion of the battlespace, depending upon where their systems were deployed or emplaced. The FBCB2 operator and the Robotics NCO were both integrating information from the sensor systems on the command interface. Thus, they had a better overall perspective of the enemy actions, but this understanding required more time to process. The Robotics NCO also represented the highest enlisted ranking individual in this group; as such he was better able to place his understanding in perspective and anticipate possible enemy actions in the future. The scores represented in Figure 5 reflect one operator per position, thus the box plot figure is displayed as a line rather than a box reflecting many scores.

Figure 5 SA Levels 1 – 3 by Position, 20 July



Typically, the assessment (level 2) and prediction (level 3) of activities are more difficult than simply reporting known activity (level 1). Given that levels 2 and 3 require greater cognitive processes, we expect that these levels would be more difficult to achieve than level 1 (Endsley, 2000; Matthews & Beal, 2002). However, on 20 July observers noted an exceptionally well-connected network and a change in how the Platoon used their unmanned assets. During the after action review on the previous day, Soldiers reported that they experienced significant problems with maintaining connectivity to both SUGVs. When the SUGVs were working, they were collocated and not spread across the area of operations (AO). This arrangement was determined by the Robotics Non-Commissioned Officer (RNCO) and the Platoon Leader (PL) as not being the most optimal use of the SUGVs. Also on this day, the FBCB2 systems in various vehicles were not functional. These issues, taken together, handicapped the Platoon's ability to observe OPFOR activities within the AO. Thus in preparation for the second run of ISR missions in TAC 12A, the Soldiers re-positioned themselves and the SUGVs to maximize network connectivity. The PL and RBNCO separated the SUGVs so that each viewed a separate area within the AO. These changes resulted in a better use of the network to share information and resulted in a significant gain in SA (see Figure 6).

Figure 6 Average Situational Awareness by Location by Day

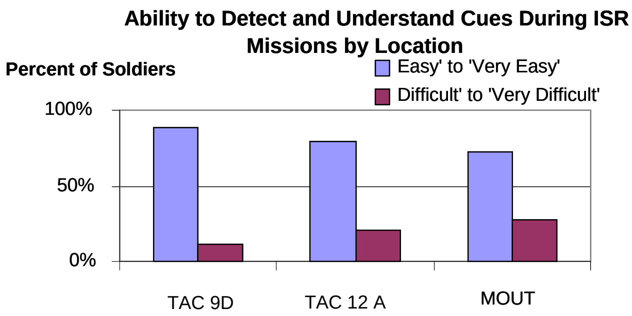


In Case 1 - TAC 9D, SA was not significantly different between runs. However, higher SA on the second run in TAC 9D should not be surprising considering Soldiers were drawing from an accumulation of lessons learned and experiences since the start of the exercise. Soldiers reported better SA on the second run in TAC 12A; $F(1,7) = 36.59$, $p = .001$. As previously stated, observations from the data collection team suggest that the increase in SA may be a result of Soldiers reporting less problems with achieving continued connectivity and that they used each system more efficiently and expertly to obtain information. Overall, SA is lower for the MOUT site when compared to ISR missions in TAC 12A and the TAC 9D. This effect may be best explained by the general complexity for conducting coordinated ISR missions in urban terrain. Abandoned buildings, cars and random debris provide obstacles that interfere with the maneuverability of these unmanned systems and also threaten continuous connectivity for information transfer. In conclusion, SA was moderate in most locations. Compared to 2006 data collection where a ceiling effect was suspected for SA analysis, these data appear to describe a more realistic pattern of SA. This was aided by researchers' attempts to complicate the scenarios by varying OPFOR activity and using various types of terrain features for ISR missions.

The MARS survey provided another key piece of information; subjective SA. The questions were measured on a 4 point scale (1=very easy, 4=very difficult) and were administered at the conclusion of the mission. The four questions ask Soldiers to rate the difficulty they experienced in identifying mission-critical cues, to understand activity, to predict what was going to occur, and how to best achieve goals in the mission. The data displayed in Figure 7 demonstrates that the majority of Soldiers (90% (N=10)) agreed that it was *easy* or *very easy* to identify mission critical cues using surrogate FCS unmanned systems in open terrain (DTA-5) compared to 80% in forested terrain (TAC 12A) and 73% in the MOUT Site. These high scores are likely due to the capabilities of the technologies and emergent TTPs for using each technology in the different field environments. Consistent with our expectations, the characteristics of the open area (TAC 9D) was much easier to detect and identify cues during

ISR mission because this area lacked trees or buildings which may have provided more obstructions to viewing OPFOR activity.

Figure 7 Average Subjective SA



When comparing objective and subjective SA, we see a positive trend. Soldiers perceived that they were able to achieve high levels of SA with very little effort, and their objective scores for SA are consistently high.

Workload

The NASA Task Load Index was used to measure perceptions of workload. This measure requires participants to rate their workload according to six dimensions. These are mental and physical workload, temporal demand (e.g. time pressure felt), satisfaction with own performance, effort, and frustration felt. These questions are measured on a 10 point scale. Participants completed this survey at the conclusion of each day.

Multiple Analysis of Variance (MANOVA) and ANOVAs were conducted for the workload data. These analyses investigated the differences in workload reported by the individual Soldiers.

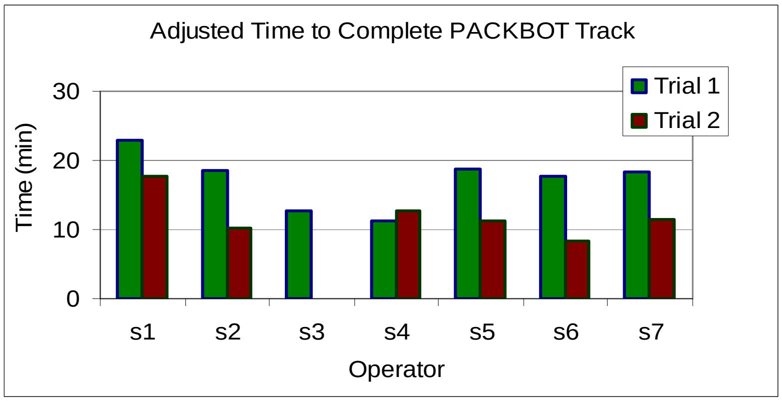
The MANOVA showed a main effect for Components of Workload, F (5, 30) = 20.47, $p < .00$ and a main effect of Day, F (4,24) = 4.69, $p < .00$. To determine which component of workload contributed to the main effects, pairwise comparisons were run. These data show that mental workload was the highest component (M = 63.57 (5.87)), followed by temporal demand (M = 63.93 (7.13)) and frustration (M = 65.71 (6.35)). Visual inspection of the descriptive statistics for mean reports of workload by day show that the highest average workload was reported on day two (M = 62.74 (5.05)). Comparisons of these data with average SA reported earlier in Figure 6 indicate that the higher workload ratings on day two may be a potential cause of the lower SA scores for that day.

Army Cognitive Test Battery

Soldiers maneuvered a PackBot SUGV through a carefully designed obstacle course where they were required to identify targets, maneuver through a course while executing several functions of the vehicle. This was a timed course with a data collector following the Soldier to record target detections, errors, or unfinished course elements.

Accuracy and efficiency scores for each Soldier are shown in Figure 11. Low performance scores indicate higher efficiency (less time to complete course, more targets identified, and little errors). Overall, Soldiers improved their performance between trials. This was expected as Soldiers committed fewer errors and identified more targets in the second trial.

Figure 8 Adjusted Completion Times on PackBot Track



Note. Adjusted time (AT) is computed as a function of the total time to complete course (TT), the number of targets identified (TI), the number of targets missed (TM), and the number of errors (E).
AT = [TT + (E x 30s) + (TM x 60s)] – (TI x 60s).

Non-parametric correlations were computed to assess the relationships between ACRA subtests and the PackBot Track performance measures. It was hypothesized that the ACRA tool would demonstrate significant relationships with the PackBot Track performance metrics relevant to common cognitive skill-sets for operating unmanned technologies. Scores on ACRA and the PackBot Track were averaged across trials. Due to the large number of ACRA metrics, only a small number were selected for analysis. Only the variables for which strong correlations exist are provided in Table 4.

Table 4 ACRA and PackBot Track Correlations

		Time to Complete Course (sec)	Targets Identified	Errors
Rapid Decision Making	Ave.RT			
	P		-.879	.87
	Sig		*.009*	*.011*
Time Estimation	Ave. Error			
	P	-.875		
	Sig	*.010*		
Spatial Orientation	Per. Cor			
	P	.735		
	Sig	*.060*		

Three of four ACRA subtests were strongly related to at least one performance measure from the PackBot Track. Rapid decision making demonstrated relation to the number of targets identified and the number of errors committed. Time estimation (as measured by the Motion Inference Test) also demonstrated a relationship to the PackBot Track metrics. The overall time taken to complete the PackBot Track is significantly correlated with an ability to infer motion and the perception of motion. Finally, spatial orientation (as measured by the Manikin Test) percent correct revealed relation to the overall time taken to complete the PackBot Track.

Results on the Tower of Hanoi subtest revealed little relationship to any of the PackBot Track performance measures. This could be an artifact of the performance test, which required little planning and problem solving (as measured by the Tower of Hanoi).

The above results demonstrate the overall validity and sensitivity of the ACRA to unmanned system operations. The results also highlight how specific cognitive metrics are related to objective performance. However, given the small sample size and the larger number of ACRA metrics, additional research must be conducted. It is strongly recommended that additional research include a variety of controlled user testing involving different operational tasks for tele-operating unmanned systems.

Conclusions

The C4ISR technologies used in this activity, when used independently, provide robust and important contributions to Intelligence, Surveillance & Reconnaissance (ISR) tasks within a platoon organization. When data from these technologies are combined in a suite of tools, it becomes a challenge to display the information in such a way that will not overwhelm the Soldiers' abilities to develop actionable knowledge. Effective networked operations require the synchronization of the physical and the cognitive/social levels of the architecture. In addition to evaluating a network's capability to transmit data within a time interval and among nodes, we must concentrate on delivering the minimal amount of data that has the highest impact on Soldier decision making. The methods used in this activity were useful in documenting the impact of the network on Soldier SA and identifying capability gaps.

The cognitive attributes of rapid decision making, time estimation, and spatial orientation were demonstrated to be significantly correlated with high performance on PackBot SUGV tasks of target detection, vehicle maneuverability, and course completion times. This finding, when combined with observations and reports of problems associated with Soldiers' use of the SUGV Operator Control Unit (OCU), can be used to drive enhancements to OCU features.

The use of the SALUTE-AP situational awareness survey demonstrated that this innovative measure was robust in a field test and useful for evaluating individual Soldier SA at three levels. Though mean levels of SA were high in all test environments, the MOUT site did introduce more uncertainty and less awareness of OPFOR activity. This is undoubtedly a natural conclusion and suggests that additional support is needed in the decision making process. Findings that the Robotics NCO had the highest levels of reported workload are consistent with the requirement for information fusion from the unmanned systems prior to sending reports to the higher headquarters.

The results from the ACRA tests demonstrate the overall validity and sensitivity of the test battery to unmanned system operations. The results also highlight how specific cognitive metrics are related to objective performance. However, given the small sample size and the larger number of ACRA metrics, additional research must be conducted. It is strongly recommended that additional research include a variety of controlled user testing involving different operational tasks for tele-operating unmanned systems.

This experiment demonstrates how the introduction of unmanned technologies can assist in the rapid development of situational awareness among a reconnaissance platoon. However, this experiment also demonstrated that these technologies are used at a cost to the human operators. These costs include physical workload, mental workload, and network connectivity. The unmanned systems require human intervention to emplace or operate the sensors and replace batteries or extract the vehicles from untenable situations (e.g. holes, ruts or obstructed sight). The operators and decision makers must expend cognitive effort to accurately geo-locate images detected by sensors; this is more difficult than most would expect. The annotation image provided by the ARL Packbot OCU was an excellent example of making this process much easier. Finally, the highest levels of SA were observed only when the voice communications were working with the unmanned sensor images. The sensor images alone were not sufficient to portray the enemy picture to the decision makers. Network performance that allows the transmission of voice or text communication in addition to sensor images is essential to rapid decision making.

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Command and Control of Unmanned Systems in Distributed ISR Operations

Dr. Elizabeth K. Bowman

Mr. Jeffrey A. Thomas

13th International Command and Control Research Technology Symposium

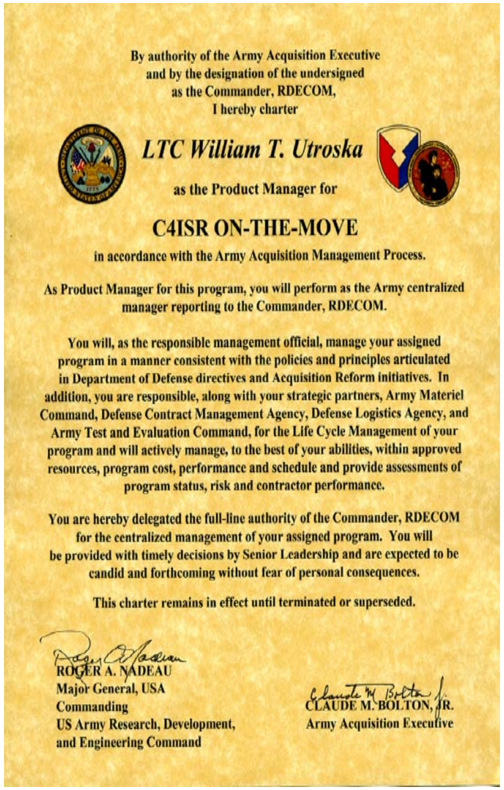
16-19 June 2008

Plan of Discussion

- Introduction to experiment setting
- The distributed communications network
- Unmanned sensor systems
- Experiment design
- Dependent measures
- Results
- Conclusions

C4ISR On The Move Campaign of Experimentation Charter: Provide a relevant environment/venue to assess emerging technologies in a C4ISR System-of-Systems (SoS) configuration to enable a Network Centric Environment IOT mitigate risk for FCS Concepts, Future Force technologies and accelerate technology insertion into the Current Force.

- Perform Systems of Systems (SoS) integration
  - Objective hardware and software
  - Surrogate & Simulated systems as necessary due to maturity, availability and scalability
- **Conduct Technical Live**, Virtual, and Constructive **technology demonstrations**
  - Component Systems Evaluations
  - Scripted end-to-end SoS Operational Threads
  - **Technology experiment/assessment in a relevant environment employing Soldiers**
- Develop test methodologies, assessment metrics, automated data collection and reduction, and analysis techniques



By authority of the Army Acquisition Executive
and by the designation of the undersigned
as the Commander, RDECOM,
I hereby charter

LTC William T. Utroska

as the Product Manager for

C4ISR ON-THE-MOVE

in accordance with the Army Acquisition Management Process.

As Product Manager for this program, you will perform as the Army centralized manager reporting to the Commander, RDECOM.

You will, as the responsible management official, manage your assigned program in a manner consistent with the policies and principles articulated in Department of Defense directives and Acquisition Reform initiatives. In addition, you are responsible, along with your strategic partners, Army Materiel Command, Defense Contract Management Agency, Defense Logistics Agency, and Army Test and Evaluation Command, for the Life Cycle Management of your program and will actively manage, to the best of your abilities, within approved resources, program cost, performance and schedule and provide assessments of program status, risk and contractor performance.

You are hereby delegated the full-line authority of the Commander, RDECOM for the centralized management of your assigned program. You will be provided with timely decisions by Senior Leadership and are expected to be candid and forthcoming without fear of personal consequences.

This charter remains in effect until terminated or superseded.

ROGER A. NADEAU
Major General, USA
Commanding
US Army Research, Development, and Engineering Command

CLAUDE M. BOLTON, JR.
Army Acquisition Executive

Ft. Dix Range

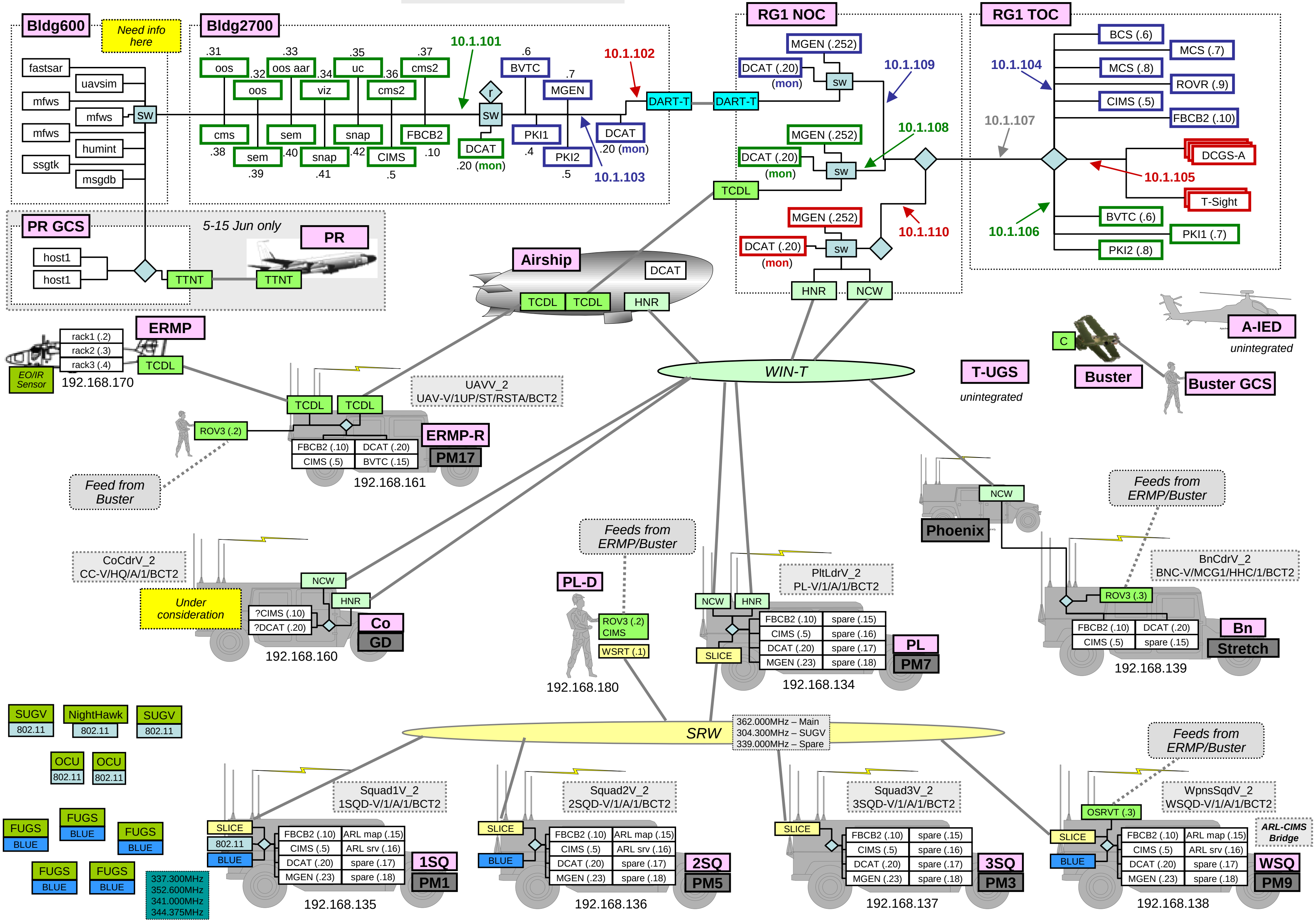
SENSORS

Fleet of instrumented vehicles

Daily Mission Runs

Test Range	Characteristics	Dates
Case 1, TAC 9D	Open rolling sandy areas with lightly forested sections.	18 and 25 July 2007
Case 2, TAC 12A	Open sandy areas with heavily forested sections including 'Vietnam Village', a set of three huts in a forested area.	19 and 20 July 2007
Case 3, MOUT	An urban site configured in a triangular shape.	24 July 2007

SV-1



Bldg600
Need info here
fastsar
uavsim
mfws
mfws
mfws
humint
ssgtk
msgdb
SW
Bldg2700
.31 oos
.32 oos
.33 oos aar
.34 viz
.35 uc
.36 cms2
.37 cms2
cms .38
sem .39
sem .40
snap .41
snap .42
CIMS .5
FBCB2 .10
10.1.101
r
SW
DCAT .20 (mon)
.6 BVTC
.7 MGEN
PKI1 .4
PKI2 .5
DCAT .20 (mon)
10.1.102
10.1.103
DART-T
DART-T
RG1 NOC
MGEN (.252)
DCAT (.20) (mon)
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10.1.108
MGEN (.252)
DCAT (.20) (mon)
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TCDL
MGEN (.252)
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RG1 TOC
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10.1.107
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MCS (.7)
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ROVR (.9)
CIMS (.5)
FBCB2 (.10)
DCGS-A
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T-Sight
10.1.106
BVTC (.6)
PKI1 (.7)
PKI2 (.8)
PR GCS
5-15 Jun only
PR
host1
host1
TTNT
TTNT
Airship
DCAT
TCDL
TCDL
HNR
ERMP
rack1 (.2)
rack2 (.3)
rack3 (.4)
TCDL
EO/IR Sensor
192.168.170
WIN-T
A-IED
unintegrated
C
T-UGS
unintegrated
Buster
Buster GCS
UAVV_2
UAV-V/1UP/ST/RSTA/BCT2
TCDL
TCDL
ROV3 (.2)
FBCB2 (.10)
DCAT (.20)
CIMS (.5)
BVTC (.15)
ERMP-R
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Feed from Buster
NCW
Phoenix
Feeds from ERMP/Buster
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BNC-V/MCG1/HHC/1/BCT2
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FBCB2 (.10)
DCAT (.20)
CIMS (.5)
spare (.15)
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Stretch
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CC-V/HQ/A/1/BCT2
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HNR
?CIMS (.10)
?DCAT (.20)
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Feeds from ERMP/Buster
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ROV3 (.2) CIMS
WSRT (.1)
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PL-V/1/A/1/BCT2
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HNR
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FBCB2 (.10)
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CIMS (.5)
spare (.16)
DCAT (.20)
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SUGV 802.11
NightHawk 802.11
SUGV 802.11
OCU 802.11
OCU 802.11
SRW
362.000MHz – Main
304.300MHz – SUGV
339.000MHz – Spare
Feeds from ERMP/Buster
FUGS BLUE
FUGS BLUE
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FUGS BLUE
FUGS BLUE
337.300MHz
352.600MHz
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Squad1V_2
1SQD-V/1/A/1/BCT2
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Participants

- **10 Soldiers from NJ ARNG**
- **Soldiers were organized into elements of a reconnaissance platoon**
- **Key leader positions included Platoon Leader, Platoon Sergeant, Robotics NCO, and two dismounted recon squads with sensors**
- **Sensors included:**
  - **Class 1 Unmanned Air System (UAS)**
  - **PackBot Unmanned Ground Vehicle (UGV)**
  - **Family of Unattended Ground Sensors (UGS)**

- **Soldiers operated ISR scenarios against an Opposing Force (OPFOR)**
- **Scenarios were designed to replicate current threats (IED emplacement, weapons storage, prisoner exchange, high value target meeting)**

Procedure

- Training
  - Equipment
  - FBCB2
- Scripted scenarios conducted over 5 days
- Dependent Measures
  - Situational Awareness
  - Workload: Mission Awareness Rating Scale (Matthews & Beal, 2002) and NASA TLX (Hart & Staveland, 1988)
- Cognitive Predictors of UGV Performance: Excursion Experiment to validate cognitive test battery

Data Collection Methods

Instrumentation, Field/Lab Data Collection, Interviews, Observation, Reduction, Analysis

SALUTE-AP

OPFOR Action (Ground Truth)	Size	Activity	Location	Uniform	Time	Assess-ment	Confidence 1-5 (low –high)	Prediction	Confidence 1-5 (low –high)
5 Civilians moving around, 4 OPFOR with weapons preparing to unload truck and build a structure	4 enemy 5 civ 2 unsure	Taking equip out of truck	48 WK 22345 58764	Black t-shirts, camo pants	1230	Enemy forces ready to build or deploy device	3	May be setting up an ambush firing point	3
2 standing guard / 2 erect radio antenna	2 red 2 civ	Building a structure	NC	NC	1300	Building a structure, possibly radio tower	4	Preparing to send messages	4
Take down antenna and depart	2 red 2 civ	Tearing down antenna, departing	NC	NC	1500	Activity is finished, group will RTB	5	Group may relocate, site may be used again	5

- *Based on SAGAT (Endsley, 2000)*
- *Utilizes standard Army reporting categories*
- *Causes minimal intrusion*
- *Easy to train*
- *Easy to administer and analyze*
- *Scored on low-medium-high scale*

ICCRTS Presentations:

Bowman & Kirin, 2006

Bowman & Thomas, 2007

SA: Mission Awareness Rating Scale

Answered on a 4 point scale from low to high:

1. Please rate your ability to ***identify*** *mission*-critical cues in this mission.
2. How well did you ***understand*** *what was going on during the mission?*
3. How well could you ***predict*** *what was about to occur next in the mission?*
4. How aware were you of ***how to best achieve*** *your goals during this mission?*

SOURCE:
Matthews, M. & Beal, S. (2002). Assessing situation awareness in field training exercises. Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.
McGuinness, B., & Ebbage, L. (2002). Assessing human factors in command and control: workload and situational awareness measures. Proceedings of the 2002 Command and Control Research and Technology Symposium, Monterey, CA.

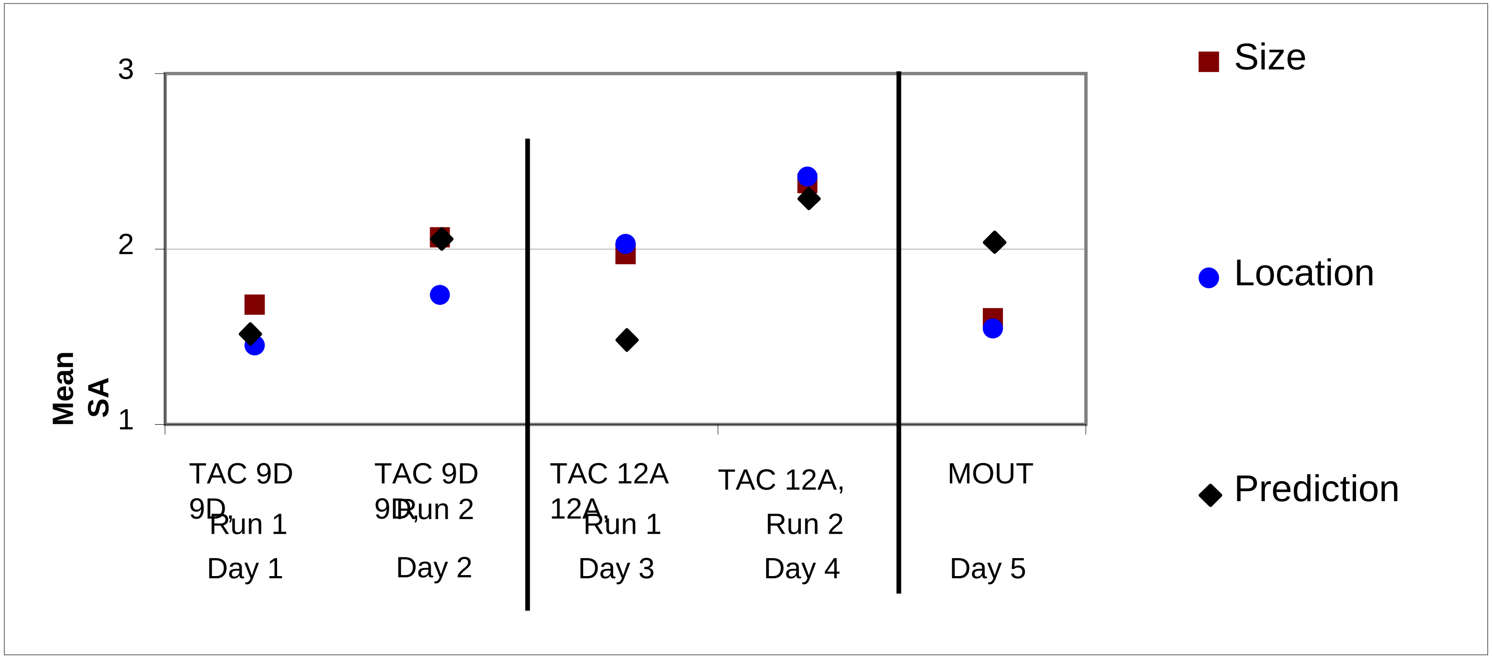
Workload: NASA TLX

1. *Based on six scales (mental demand, physical demand, temporal demand, performance, effort, and frustration level.*
2. *Ratings on 6 scales are weighted according to subject's evaluation of relative importance.*
3. *Ratings range from 1-100.*

SOURCE: Hart & Staveland, 1988

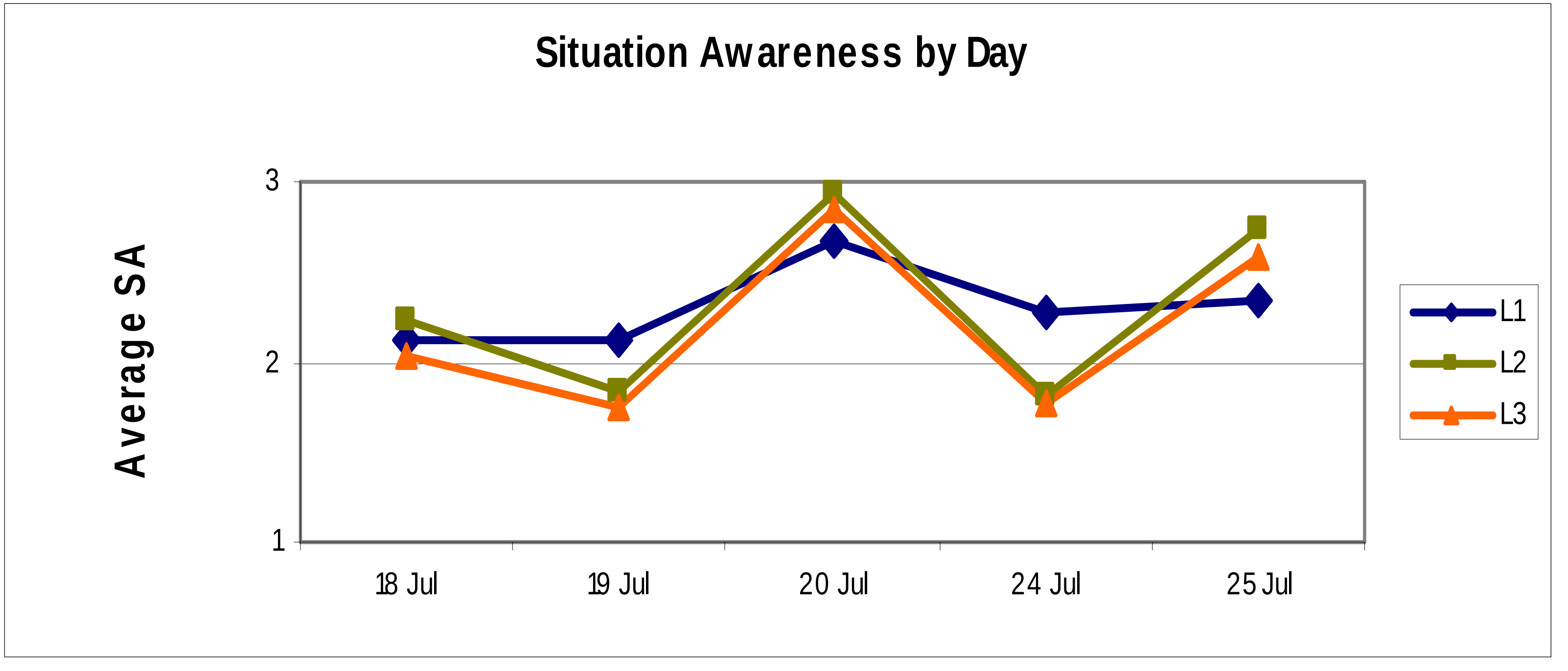
SA Results: Report type

- *On average, subjects differed in their ability to identify size, location, and possible future activities.*
- *Size, Location, and Prediction were statistically significant variables*



SA Results: Effect of Day

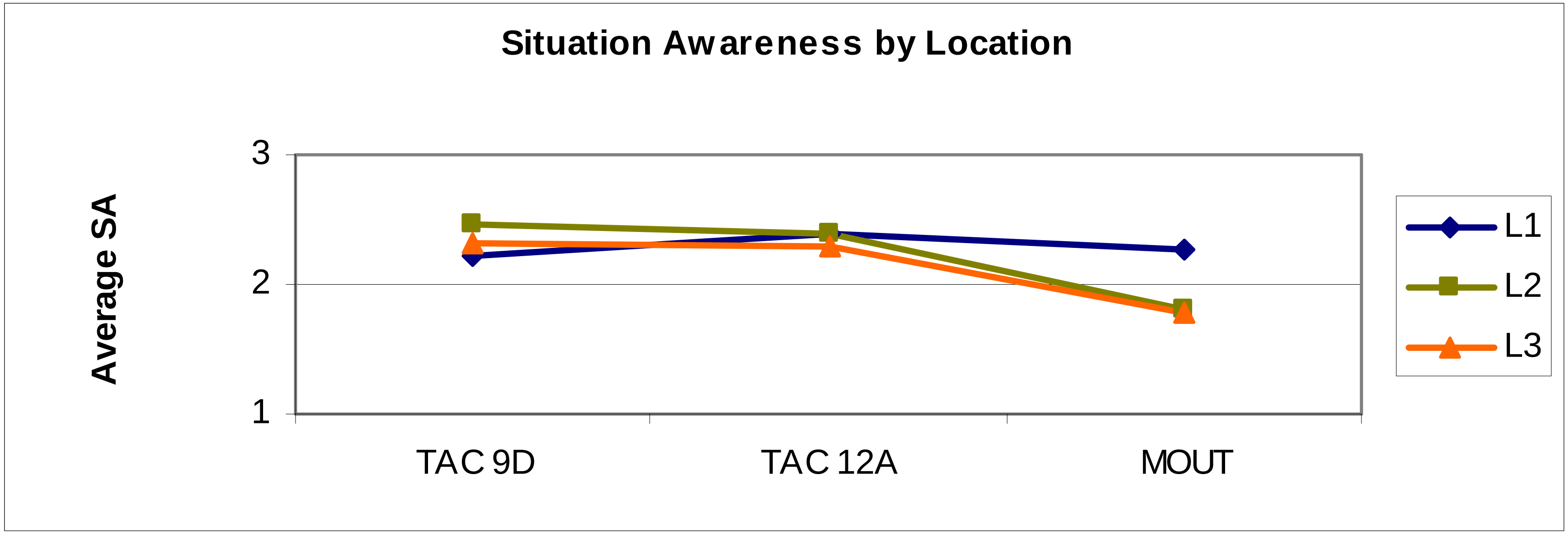
- *Level 1 and Level 2 and 3 SA variable*
- *20 and 25 July high scores influenced by availability of Class 1 UAS*



SA Results: Effect of Location

SA results for Level 1, 2, and 3 were consistent in open rolling terrain with slight vegetation.

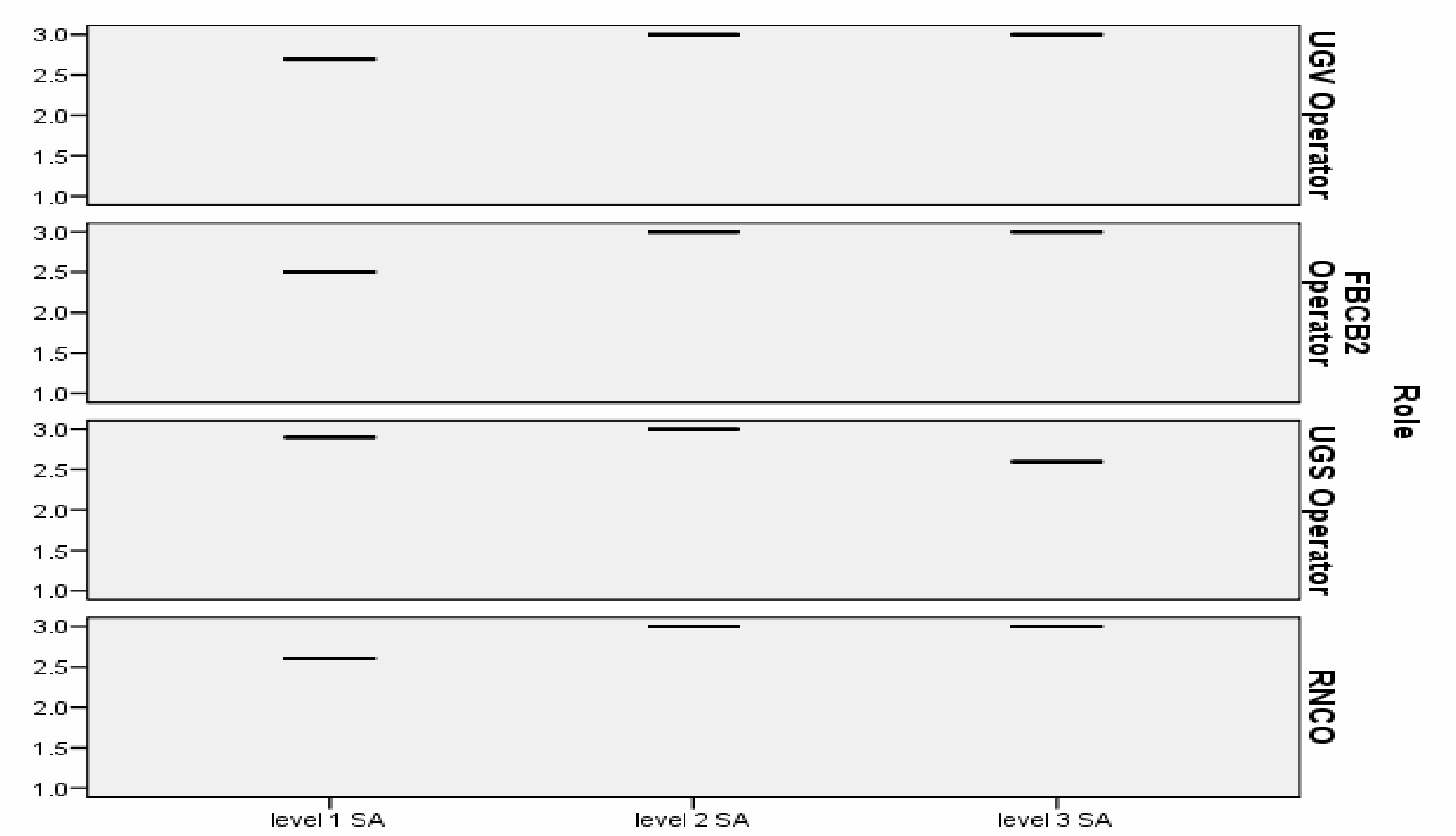
SA results for level 2 and 3 dropped noticeably in MOUT site where OPFOR activity was more complicated and more difficult to understand and predict.



SA Results: Effect of Role

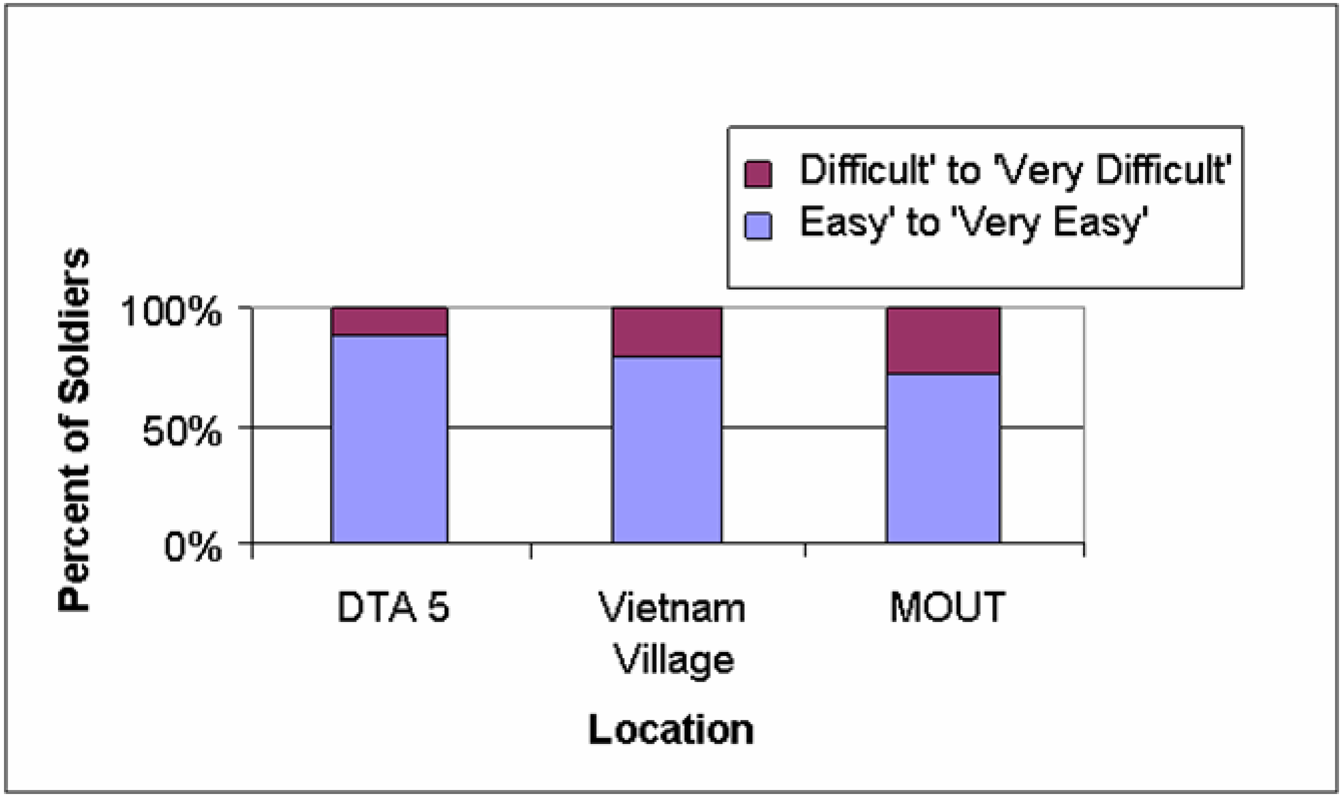
Slight differences in level 1, 2, and 3 for all operators; most noticeably UGS operator in level 3.

With respect to level 1, UGS and UGV operators had higher levels of SA due to robotics-eyes-on activity.



MARS SA Results

Consistent results to SALUTE-AP showing that SA was easier to achieve in open areas compared to MOUT site.

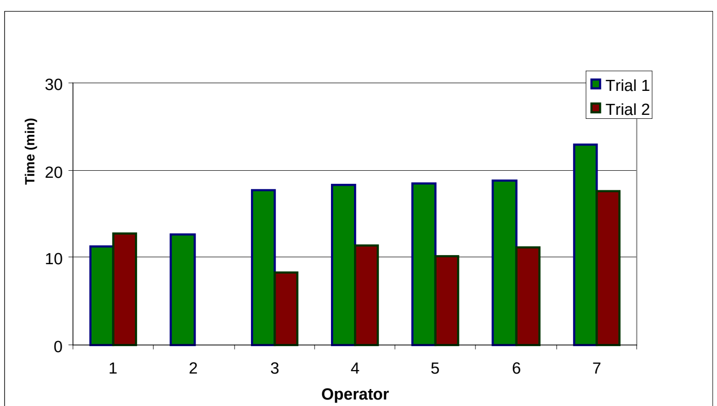


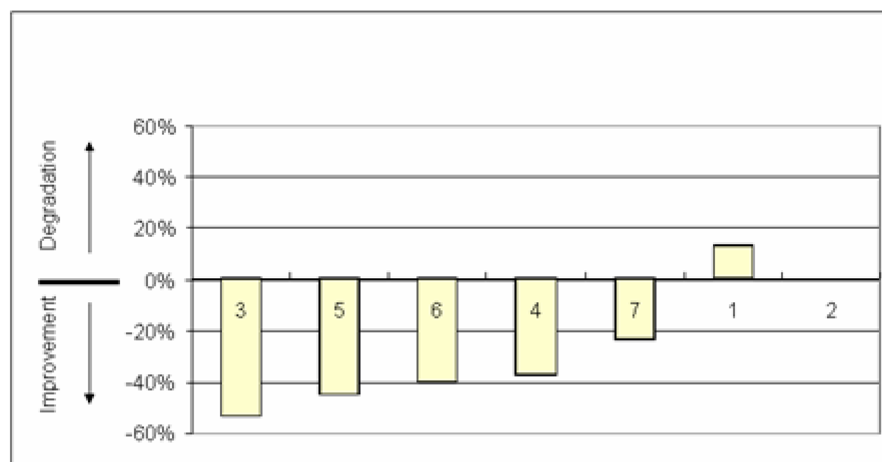
Workload

- *Mental Workload was the highest component of workload (M=63.57 (5.87), followed by temporal demand (M = 63.93 (7.13)) and frustration (M = 65.71 (6.35)).*
- *Highest average workload was reported on day two (M = 62.74 (5.05)).*
- *High workload on day two could be an explanation for lower SA scores on that day.*
- *Frustration was related to technology problems.*

Army Cognitive Readiness Assessment Test Battery

- **Designed to predict performance with the Packbot Unmanned Ground Vehicle (UGV) system with 9 Soldiers in two obstacle course settings.**
- **Rapid decision making, time estimation, and spatial orientation were found to be highly correlated to SUGV operation.**





Conclusions

- A suite of ISR technologies prove challenging to users
  - Display and information overload
  - Difficult to synchronize information from various sensors
- Cognitive attributes of rapid decision making, time estimation, and spatial orientation were demonstrated to be correlated with operating a UGV

Conclusions

- SALUTE-AP method robust to field conditions and a valid measure of SA levels
- Suite of sensors contributed to high level of SA in short time period, but at costs of physical and mental workload
- The ability to predict performance in operating these systems can optimize training time and reduce expensive operational accidents from unskilled operators.