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Battle Command Teams' Workload, Situational Understanding, and Shared Mental Models at Unit of Employment, Unit of Action, and Combined Arms Battalion Levels

by Bruce S. Sterling and Cheryl A. Burns

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14. ABSTRACT

This experiment assessed mental model congruence, workload, and situational understanding (SU) for command teams at three levels during an experiment that examined battle command of future forces at the Unit of Action Maneuver Battle Lab at Fort Knox, Kentucky. Compared to more subjective measures of workload and SU, objective measures of mental model congruence were low and did not improve as the experiment evolved. This suggests discrepancies between objective and subjective measures of performance. In addition, the command level with the least amount of experience achieved the highest and most consistent levels of congruence. Because of the nature of the experiment, we are unable to clearly determine whether the inability to develop and improve shared mental models of the situation can be attributed to doctrine or to shared understanding of doctrine, training, organization, or battle command tools. Smaller scaled, structured experiments using a well-trained, intact team would enable better measures of workload, SU, and mental model congruence. This in turn would help us to determine if organization and technology improved workload, SU, and mental models.

15. SUBJECT TERMS

Future Combat System; shared mental models; situational awareness; situational understanding

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Contents

List of Figures

List of Tables

1. Introduction

The purpose of this research was to determine if networked battle command provides command teams with a shared understanding (or shared mental model) of the situation to enable collaborative planning and execution. In order for the U.S. Army future force to succeed, that force will have to "see first, understand first, and act first" (Department of the Army, 2003). Compared to the current force, the future force systems will need to be much lighter and smaller to increase their ability to deploy. Thus, in order to ensure Soldier survivability, the future force must use sensors, including unmanned aerial vehicles and unmanned ground vehicles to see the enemy at a distance (see first). The future force must then use networked battle command and a common interface to provide the common operational picture (COP) to all platforms (understand first). Finally, the future force must use their agility and precision, long range fires in order to engage the enemy at a time and place of the unit's choosing (act first).

The future combat system (FCS) operational and organizational (O&O) plan emphasizes collaborative planning and execution, particularly among commanders, in order to see first, understand first, and act first (U.S. Army Training and Doctrine Command, 2002). This collaborative planning and execution is enabled by a shared mental model. That is, Soldiers must have a common understanding about those areas for which the plan requires information so that assets which enable the force to see first can be properly deployed. The unit as a whole must have a common understanding about the current situation and the potential problems in each other's areas of responsibility, so that the unit understands first. This common understanding enables the unit to act first, not as uncoordinated individuals or sub-units, but as a coherent whole.

Research by Stout, Cannon-Bowers, Salas, and Milanovich (1999) using a flight simulation task, showed that teams with more similar shared mental models did better planning, "pushed" more information (i.e., provided information without it having to be requested), and made fewer errors. Mathieu, Goodwin, Heffner, Salas, and Cannon-Bowers (2000) showed that team mental model congruence was positively related to team processes and team performance in a flight simulation task. Marks, Zaccaro, and Mathieu (2000), in a simulated armor platoon task, found that team mental model similarity was positively related to team processes and in novel situations, to team performance as well.

It is logical that command teams with better shared mental models would have better situational understanding (SU) and be more effective. It is likely that those who better understand how each team member sees the situation will be able to focus their efforts on attaining more relevant information and thus increase their understanding. Along with increasing their SU, it is likely that they could also increase their effectiveness by developing more relevant plans or taking more relevant actions.

The purpose of this research was to examine commander teams' mental models, perceived workload, SU, and effectiveness at unit of employment (UE), unit of action (UA), and combined arms battalion (CAB) levels. If the new, network-centric tools and organization of the future force are to succeed, they will have to facilitate the development of shared mental models for command teams at various levels by providing common information, which aids in developing SU and reduces workload. SU for this experiment is defined as comprehension of the friendly and enemy situation and projecting what actions need to be taken as a result of the situation.

2. Method

2.1 Experimental Overview

This experiment was performed at the Unit of Action Maneuver Battle Lab (UAMBL), at Fort Knox, Kentucky, from June 1 through 26, 2004. The experiment simulated battle command in a UA and used future organization, doctrine, and a surrogate of the future battle command interface (maneuver command and control or MC2). The simulation consisted of 13 days of individual, cell (e.g., first UA mobile command group 1; a brigade-like tactical operations center-vehicle containing six key personnel), and unit training and pilot tests, and six days of experimental runs.

The experimental unit organization consisted of one UE (division-sized element), with a partial staff, and several subordinate UAs (brigade-sized elements consisting of three maneuver UAs, a strike or aviation UA, and a fires UA). Only one UA had a substantial staff, with all staff organizations represented, and six subordinate battalion-level organizations; three CABs, a non-line of sight (NLOS) battalion, a forward support battalion, and an aviation battalion. Most of these battalions were represented by a small staff (two CABs had only a commander), but one subordinate CAB had a substantial staff and six subordinate company-level organizations (two mounted combat system companies, two infantry companies, a reconnaissance, surveillance and target acquisition [RSTA] company, and an NLOS mortar battery). Two companies had subordinate platoons. One of these two companies had subordinate platoon leaders and platoon sergeants only. The remaining company had subordinate platoon leaders, platoon sergeants, and three squad leaders in each platoon. The rest of the companies were represented by a company commander only. This design is referred to as a "slice" design, where at least one level of the organization is fully shown from lowest to highest—in this case, platoon through UE (see figure 1).

The rest of the UAs were played constructively, represented at most by a small staff consisting of a few "live" participants, with research assistants assigned to control subordinate battalions (the two maneuver UAs were played by only a UA commander).

Figure 1. Organization slice design.
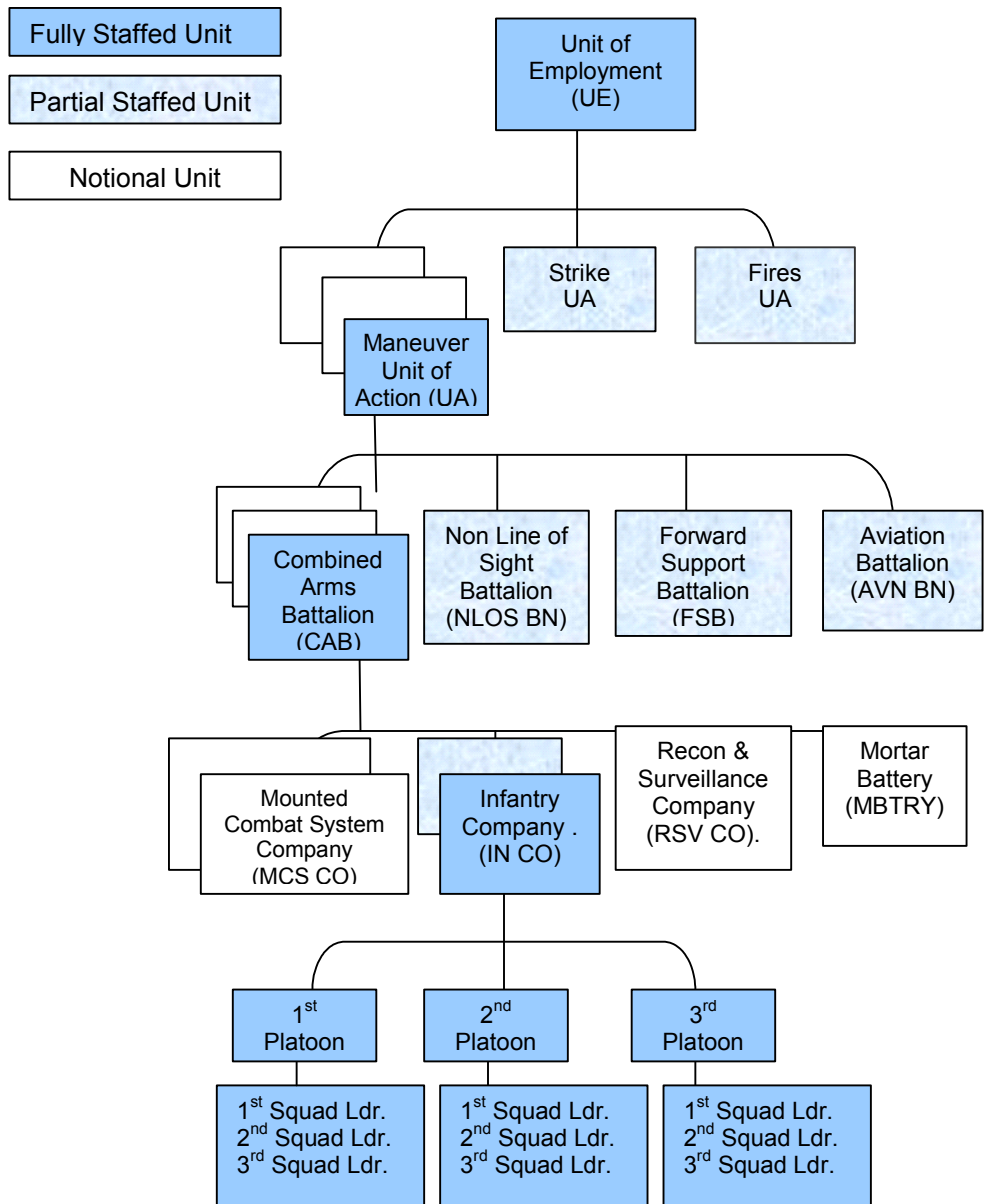
2.2   Participants

Participants were organized into command teams in the following manner:

UE command team - UE commander; first, second, and third UA commanders, fires UA commander, aviation UA commander.

UA-level commanders - first UA commander; first, second, and third CAB commanders, NLOS battalion commander, forward support battalion commander, aviation squadron commander.

CAB-level commanders - second CAB commander; A, B, C, D, company commanders, RSTA company commander, mortar battery commander.

2.3   Scenario[1]

2.3.1 Mission and Array

The mission of "blue" ground forces was to attack in zone to defeat enemy forces in a middle eastern country to facilitate the reinstatement of the legitimate government. Blue forces consisted of a joint task force with a combined forces land component command, in which the Army component consists of a UEy, with a Stryker division (SDIV) and a UEx. The UEx was composed of three maneuver UAs. The UA force design depicted in this analysis is based on the increment 1 resource-constrained threshold (2012) design depicted in the 30 June 2003 change 2 to the U.S. Army Training and Doctrine Command (TRADOC) Pamphlet 525-3-90 (2002). The UEx and UEy designs were developed after discussions and coordination with the combined arms center and TRADOC.

2.3.2 Intent and Concept of Operations

The intent of blue operations was for the three maneuver UAs to execute a river crossing and conduct a forward passage of lines to use UAs in turn to destroy threat defense belts. This penetration would enable the passage of the SDIV to eliminate threat forces and regain control of the capital city, enabling the coalition to restore the legitimate government. The concept of operations called for UA1 to destroy the first belt of threat forces to facilitate the forward advance of the other UAs. UA2 would engage and destroy second belt threat forces to the front and left flank to facilitate the forward passage of UA3 and to establish the UEx line of communication. UA3 would then exploit the penetration and attack remaining threat forces west of the capital city, the enemy center of gravity. The intent is to develop the situation out of contact, conduct stand-off engagements to set the conditions for close assault, and rapidly transition to ensuing operations.

Table 1 shows the experimental schedule. The pilot test was an attack in open terrain to isolate the city. Trial 1 was also an attack in open terrain, with the network functioning at 100% (non-degraded, i.e., no interference with digital or voice communications over the network). Trial 2 was a repeat of the attack in open terrain but with the network functioning at around 75%. The experimental runs in the second week (21 to 25 June) represent a mixture of full and reduced network functionalities, so they cannot be characterized as trial 1 or 2.

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[1]Taken from U.S. Army TRADOC Analysis Center report (June 2004) Future Combat Systems analysis of key performance parameter 2, Networked Battle Command.

Table 1. Missions by days (June 04)

Monday	Tuesday	Wednesday	Thursday	Friday
14 Pilot Test 1 Attack in open terrain to isolate city 100% of network function	15 Pilot Test 2 Attack in open terrain to isolate city 100% of network function	16 Pilot Test 3 Tactics, techniques, procedures development 100% of network function	17 Trial 1 Attack in open terrain to isolate city 100% network function	18 Trial 2 Attack in open terrain 75% network function
21 Day 1 Set Conditions Mixed Network Functioning	22 Day 2 Maneuver Mixed Network Functioning	23 Day 3 Seize key terrain Mixed Network Functioning	24 Day 4 Isolate Center of Gravity Mixed Network Functioning	25 Day 5 Attack Center of Gravity Mixed Network Functioning

2.4   Experimental Limitations

Workload, SU, and shared mental models assessment was constrained because of the following limitations of the experiment:

a. The experiment was not strictly controlled (free play versus scripted scenario), so that objective measures of SU and shared mental model could not be collected.

b. Because of the free play allowed in the scenario, there was no pre-determined "ground truth" at specific times to assess SU and shared mental models against.

c. Command teams were not well trained and were *ad hoc* in nature. Training for the experiment was limited. The command teams consisted of participants assigned to certain positions for the duration of the experiment with no previous experience working together. This limitation presents a major problem in the interpretation of the results, since it is difficult to determine whether shortcomings in the shared mental model should be attributed to lack of training or to other factors.

2.5   Data Collection and Analysis

Surveys for data collection were administered before the lunch break and (or) at the end of the day. They were administered on the same computer that participants used to perform their tasks during the trial. Surveys were given at these times to collect data while they were still fresh in the participant's experience but did not interfere with the experiment.

Workload consisted of measures shown in table 2. These workload measures were assessed on a seven-point scale from low (1) to high (7) and divided by seven so that they are on the same 0 to 1 scale as the shared mental model data. Thus, an average score of 5 (of 7) on a scale (e.g.,

frustration) would result in a figure of 71% frustration. This is the percentage reported on the y-axis in the figures in this report. This scale normalization allowed easy comparison of workload and mental model congruence. An overall measure of workload was also computed by the addition of the four measures of workload for each participant. We then divided by four and again divided by seven, so that the measure of workload is on a 0 to 1 scale comparable to the shared mental model data.

Table 2. Workload measures

Workload Measure	Definition
Frustration	Degree to which participants were prevented from achieving their goals
Mental Demand	How hard participants perceived they had to think
Temporal Demand	How much time pressure participants perceived
Effectiveness	How proficient participants perceived they were at performing their tasks
Overall Workload	Averaged sum of above four workload scales

Perceived SU was measured on a seven-point scale, from low (1) to high (7). We also divided the score by seven so that it is on a 0 to 1 scale similar to the shared mental model data. We used perceived SU versus a more objective measure, since the free play nature of the experiment made it difficult to assess "ground truth."

Shared mental model assessment was derived from commander and team mental model congruence. Commander and team congruence were computed based on answers to two questions in a daily survey. These questions were

What is the most significant threat to current operational success?

What is the second most significant threat to current operational success?

We used a technique developed by Lieutenant Colonel John Graham[2] to measure mental model congruence. Participants were asked to indicate the most significant and second most significant threat to current operations, choosing from a list of 22 possible threats. These threats consisted of eight battlefield functional areas each for friendly and enemy forces, plus six environmental factors. The 22 threats are shown in tables 3 and 4. The degree to which any two participants agreed on these ratings was assessed on a 0-to-1 scale, with 0 representing no congruence and 1 representing complete congruence.

Commander congruence was calculated as an average of the subordinate commanders' congruence with the superior commander's mental model (e.g., average congruence of the first, second, and third UA commanders, fires UA commander, and aviation UA commander with the UE commander's mental model). Team congruence was calculated as the average congruence among the subordinate commander team members. It does not include the superior commander so that it is completely independent from the commander mental model.

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[2]currently assigned to the Human-Computer Interaction Institute, Carnegie Mellon University

Table 3. Current threats for battlefield
functional area

Battlefield Functional Areas*
Command and control
Sustainment
Information
Communication
Maneuver
Fire Support
Air Defense
Aviation

*both friendly and enemy

Table 4. Current threats for
environment

Sensors
Terrestrial weather
Space weather
Terrain
Time
Civilian population

Both commander and team congruence were reported on a 0-to-1 scale, where 0 represents no congruence between mental models and 1 represents complete mental model congruence.

Data analyses consisted of descriptive statistics only. The method used to compute means for workload, SU, and mental model congruence by the three groups of commanders were described above. Because of the small number of participants, no inferential statistics were used.

3. Results

3.1 Situational Understanding and Workload

For UE- and UA-level commanders, SU and effectiveness workload ratings are relatively high (in the 70% range) and generally show a slight increase over time, suggesting increased perceived proficiency (see figure 2). Other workload measures (frustration, mental, and temporal demand) start in the 50% to 60% range and generally decline to the 40% to 50% range over time, also suggesting increased proficiency resulting in reduced perceived workload. This may suggest a learning curve over the course of the experiment. These data suggest that the battle command tools were effective in providing a moderate workload and good SU for the UE command team.

Similarly, figure 3 for UA and battalion-level commanders shows that SU and effectiveness were relatively high (in the 70% range), with a slight increase toward the end of the exercise, while

other measures of workload were lower (overall workload in the 60% to 50% range) and showed a slight decline over time. Again, improvement over the course of the experiment suggested that a learning curve is one possible interpretation. Although no formal surveys were administered, the subject matter expert (SME) observing the UE command cell suggested reasons for the relatively low workload ratings. One reason may have been an internal comparison with the workload induced by this 8- to 10-hour-a-day experiment to the workload at the National Training Center (NTC) or the Battle Command Training Program exercises running 18+ hours a day. In addition, the factors of vehicle motion, noise, heat, and the more hectic pace at the NTC may have made the workload of this experiment pale in comparison. Generally, these data suggest that the battle command tools, including the MC2 interface, provided a moderate workload and contribute to good SU. This conclusion is entirely based on subjective data. The more objective techniques such as Endsley's (2000) situational awareness global assessment technique (SAGAT) could not be used because of the free play nature of the experiment.
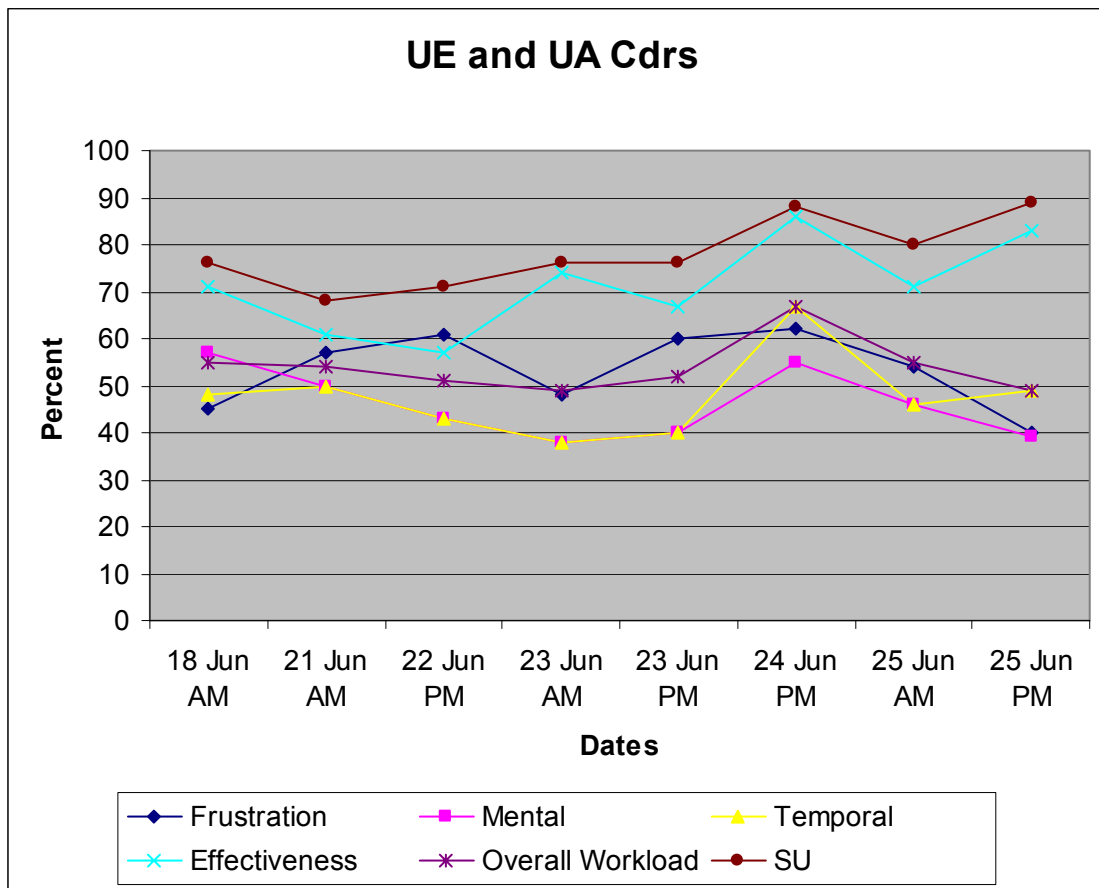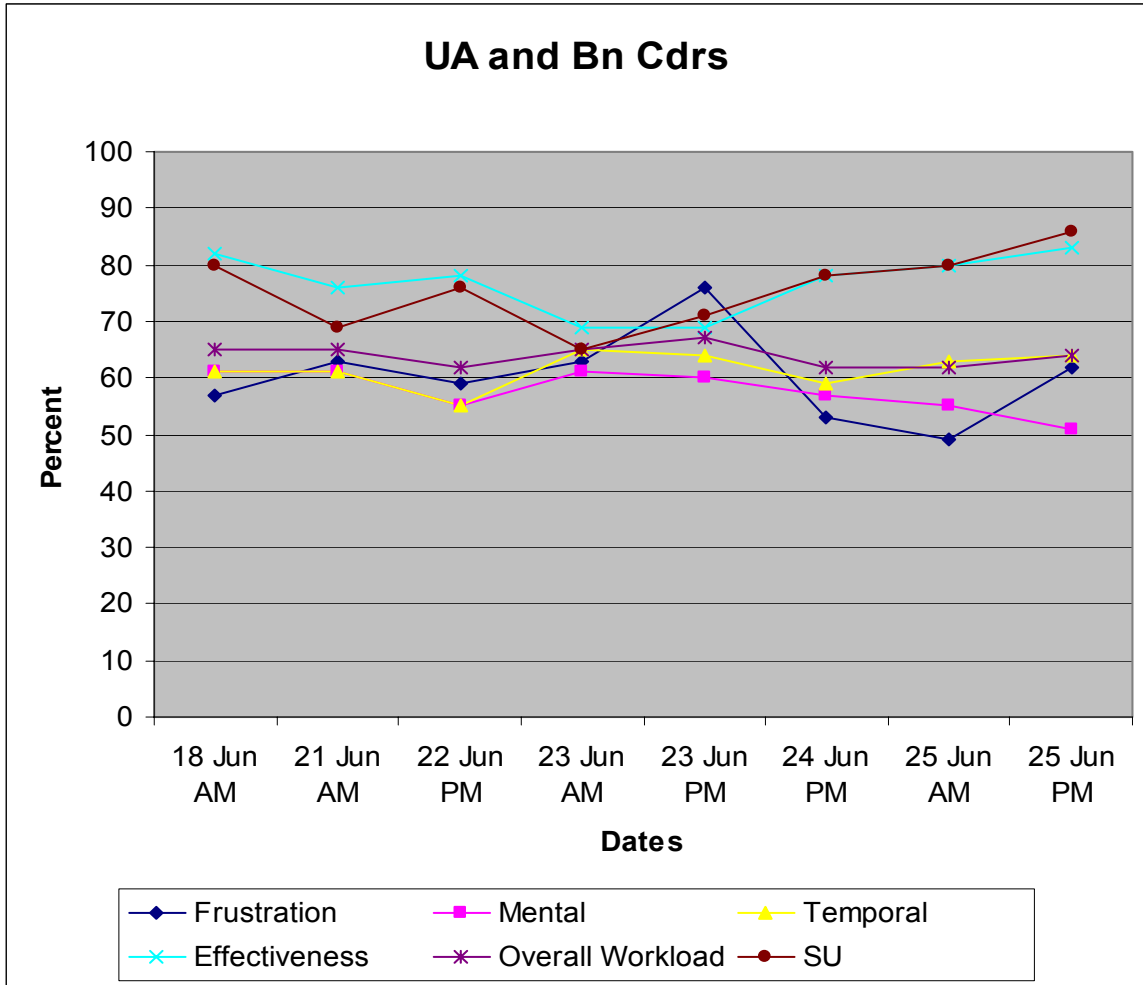

Figure 2. Workload and SU for UE command team.

8

Figure 3. Workload and SU for UA command team.

For battalion- and company-level commanders (figure 4), SU was quite high (around 90%) and relatively steady over time. Effectiveness declined from initially high levels (in the 80% range) to 70% about mid-exercise, and then increased toward the end of the exercise. One possible reason for the dip in effectiveness may be model-induced problems in fuel and ammunition shortages. This caused the commanders to spend considerable time on re-supply issues. The effectiveness improvement shown later may have been attributable to white cell (the cell that serves as higher headquarters and also directs the experiment) "work-arounds" in re-supply to compensate for perceived model inaccuracies in usage rates. Another possible reason for this dip in perceived effectiveness could be the slow rate of revising the COP during this period. The perceived SU also dipped slightly during this period, supporting this latter interpretation. Other workload measures were relatively steady over the exercise (overall workload around 60%). Thus for the command team involved in the lowest levels of the city fight (24 to 25 June), workload did not decline toward the end of the exercise. Even so, these data taken as a whole suggest that the battle command tools enabled command teams to maintain moderate workload (50% to 60% range) and good SU (80% to 90% range).
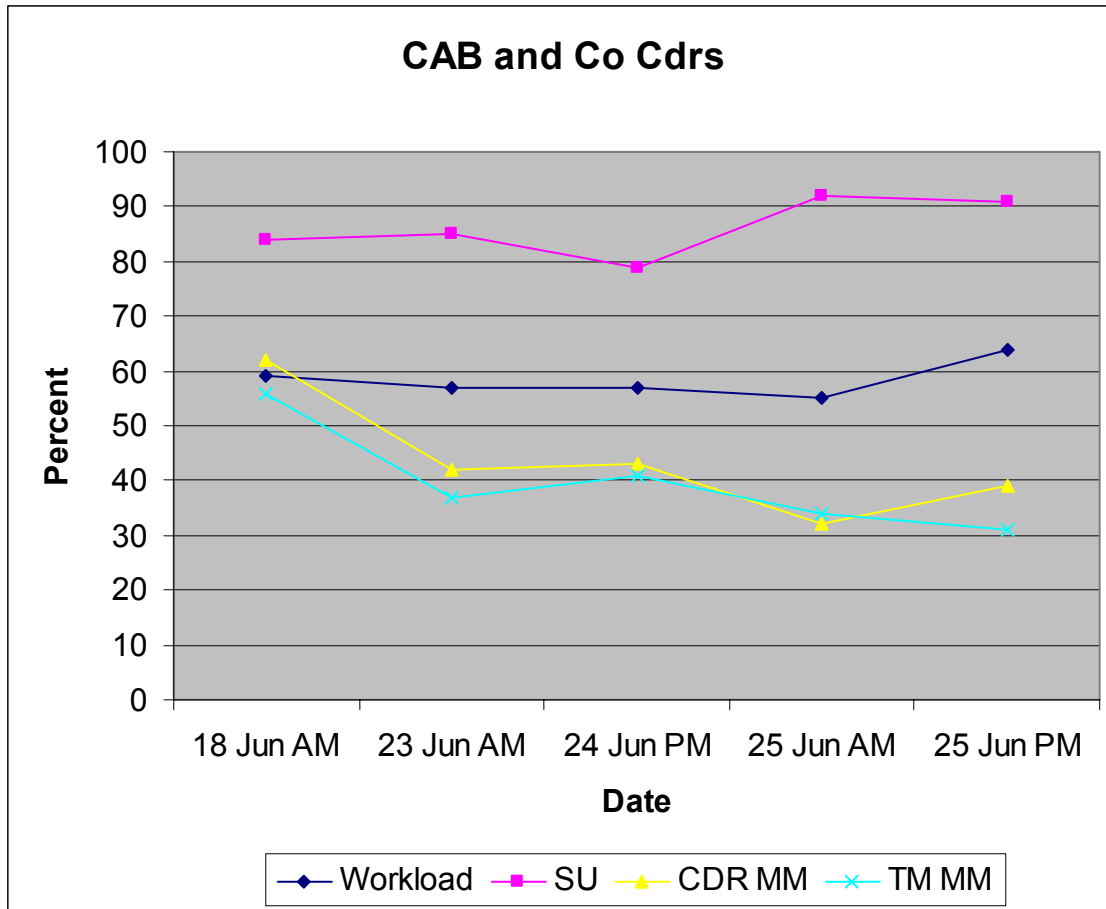
9

Figure 4. Workload and SU for battalion command team.

3.2 Mental Model Data

3.2.1 UE Command Team

As shown in figure 5, the UE command team mental model varied significantly in the first few days of the experiment, then remained relatively stable for the rest of the experiment, with a slight increase on the last afternoon. Overall though, mental model congruence was low (in the 20% and 30% range) across the staff. No data were available for the UE command team for 18 June p.m. (afternoon) because the commander did not complete the mental model.

The commander's mental model is more congruent than the team mental model during most of the experiment, which suggests that subordinate commanders' understanding of their commander's mental model is more congruent than their understanding of each other's. This suggests that the commander kept subordinates informed of what he thought were important threats to the mission better than subordinate commanders kept each other informed of their perceived threats to the mission.
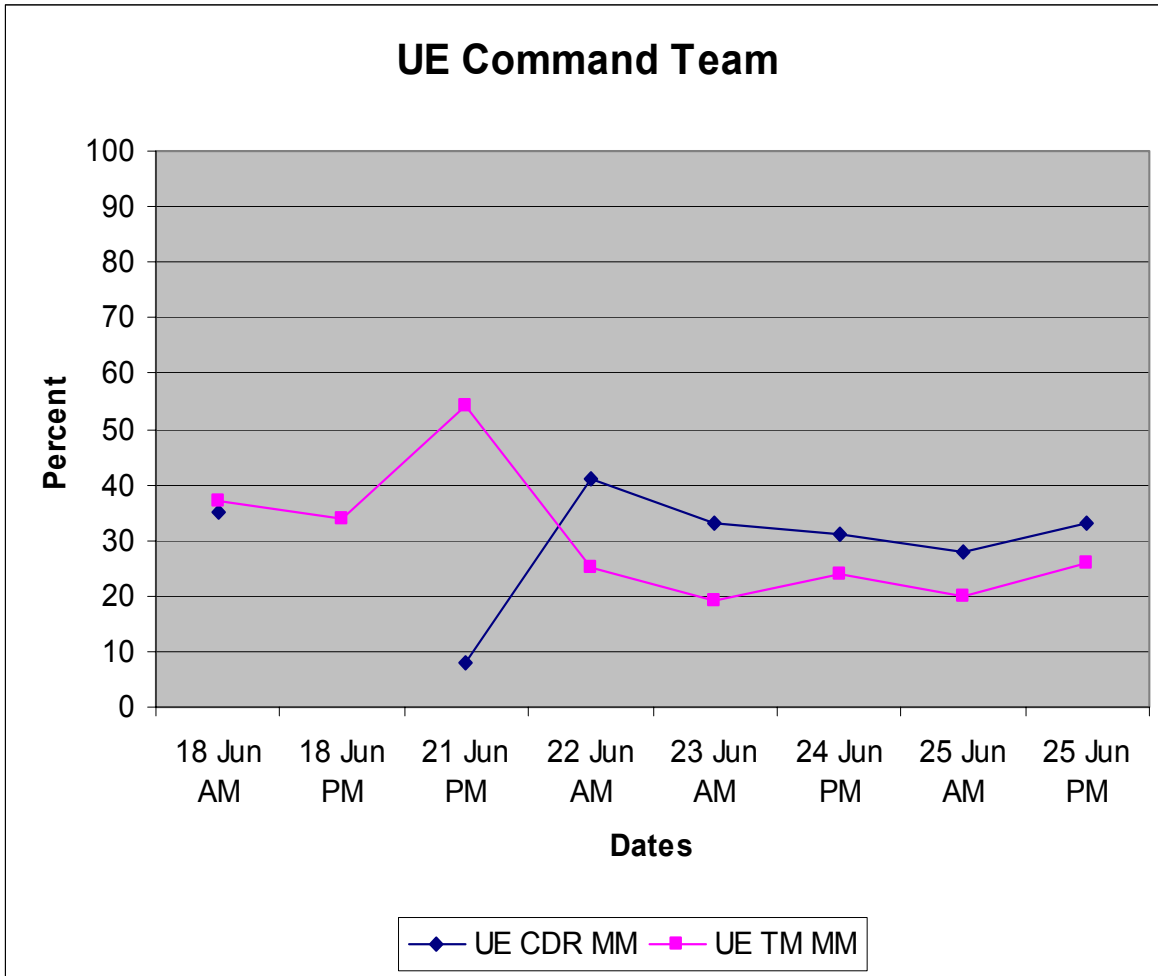
Figure 5. UE command team mental model data.

SMEs at the UE stated that the fall in the commander mental model and peak in the team mental model on the afternoon of 21 June was attributable to the same circumstance. Near the end of that day, before the survey, the UE commander was discussing what to do about the objective on an escarpment and the actions that UA commanders needed to take to achieve that objective. However, he suddenly changed his focus from the tactical level to setting conditions and shaping the battle two days away. This appeared to escape the notice of the UA commanders, who remained focused on the near-term fight. Thus, although the UA commanders had a reasonably congruent mental model of the situation, it did not synchronize with the UE commander's mental model at that time.

The slight rise in both mental models on the last day could be a result of no future planning being necessary, since the experiment was ending.

However, compared to self ratings of workload and SU, the mental model congruence data for UE and UA commanders are quite low (generally in the 20% to 30% range), never exceeding 55%. This suggests that command teams lacked a shared understanding of doctrine, tactics,

techniques and procedures (TTP), and organization, perhaps because of inadequate training or the battle command tools were not sufficient for commanders to develop congruent mental models.

3.2.2 UA Command Team

As shown in figure 6, the UA team's mental model remained relatively steady over time, suggesting that although they had a low knowledge base of understanding each other's perceived significant threats, this knowledge base remained fairly consistent over time, while their knowledge base of the commander's perceived threat varied significantly in several instances. This suggests that the commander may have had some difficulties keeping his subordinates informed of what he thought were important threats to the mission, perhaps because of the lack of established TTPs.

The data show a general decline in the commander's mental model through the end of June 23 (seize key terrain), with a sharp rise in congruence on June 24 and 25 (isolate center of gravity). Once this fight was finished, there was again a decline in mental congruence.

A possible explanation for the decline and low point on June 23 was that the UA commander spent most of the time out of his "vehicle" working on other duties (or conducting "face to face" meetings with other commanders and staff), and the deputy commander was in charge. The decline toward the end of the exercise may reflect the difficulty of the urban fight. Another interpretation for the decline is that battle "hand-off," that is, transfer, between the commander and deputy commander may need to be improved. Or it may just be an "end of test" artifact.

The CAB command team mental model shown in figure 7 shows a general decline in mental model congruence throughout the test, except for a peak (for commander mental model) on June 21 (set conditions). The generally low (in the 20% to 50% range) and declining congruence of mental models may have resulted from (a) infantry company commanders being at Fort Benning, Georgia, and not being informed about the end-of-day after-action reviews (AARs) and (b) coaching from the battalion commander (congruence for these commanders was lower, particularly earlier in the experiment). The AARs were face to face and thus, the remote site at Benning did not participate. This suggests that the remote units need to be included in the AARs and coaching from the battalion commander, so that we train as we are going to fight, as specified by doctrine.

The severe dip in commander mental model congruence on June 18 p.m. (also the UE mental model is declining at this point) may have been attributable to a perceived threat from the west of phase line lion. The UA staff thought they detected a large mechanized force preparing to attack into the flank of the 2nd CAB. However, later analysis revealed this to be a much smaller enemy force. The CAB commander then perceived the smaller force as a target of opportunity, given the CAB's ability to see and strike from a distance. However, the company-level commanders, who had less understanding of the future forces capabilities, still saw the enemy as a substantial

threat since they did not understand the capability to destroy the enemy at a distance. This suggests that lack of understanding of doctrine (resulting from a lack of training) can hinder development of congruent situational mental models.
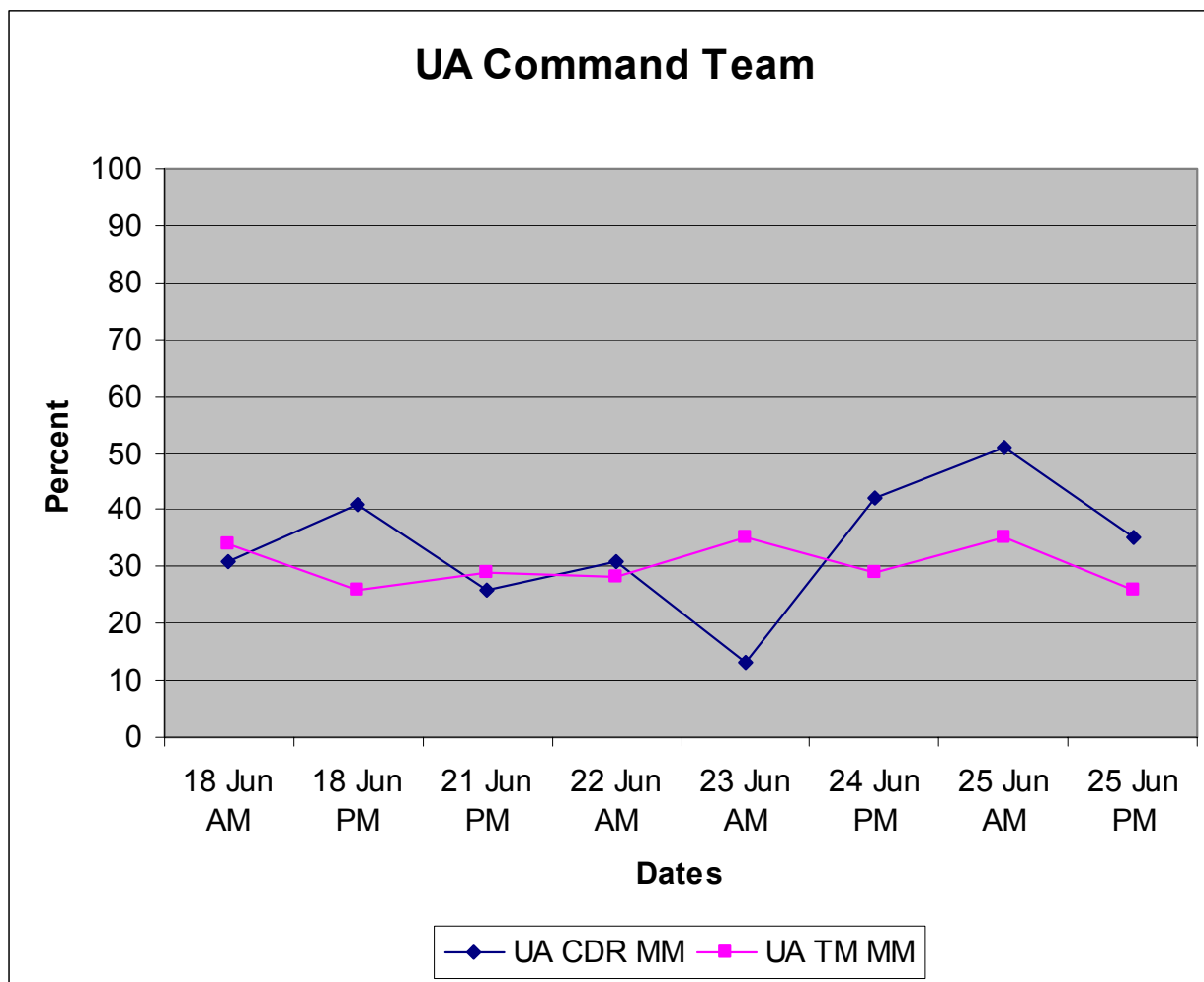
UA Command Team

Figure 6. UA command team mental model data.

The peak in commander mental model congruence on the afternoon of June 21 could be related to the 2nd CAB remaining in the tactical assembly area all day, while the 1st and 3rd CABs established conditions favorable to the 2nd CAB's assault. The 2nd CAB was involved in providing security and integrating aviation assets during this period. Since the staff had relatively little to do and their situation in the assembly area did not change, maintaining a congruent mental model was easier.

Also, there was a considerable difference in experience and therefore knowledge of the O&O concept and opposing forces capabilities between the CAB and company commanders. This lack of understanding could have exacerbated differences in mental models over time in the experiment. These data point to the need to understand the future force doctrine in order to have

congruent mental models. This finding suggests that better training of future force doctrine is needed to improve understanding, which then leads to the development of more congruent mental models.
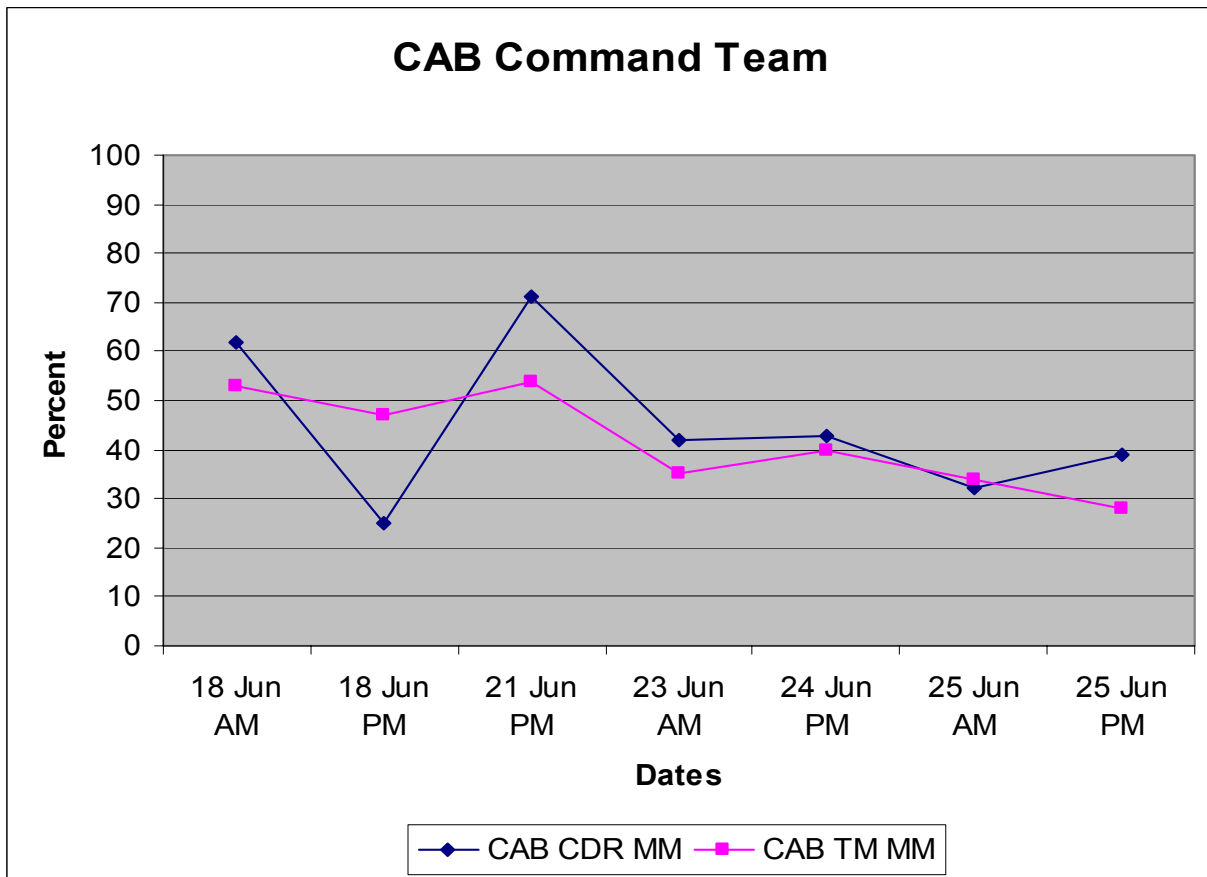

Figure 7. CAB command team mental model data.

Although commander mental model congruence occasionally reached 60% to 70%, overall mental model congruence was more frequently around 50% or lower. As discussed earlier, a variety of potential reasons for this exist, from lack of shared understanding of the O&O concept to possible need for improvement in the battle command tools (e.g., automated battle damage assessment; warnings when sensor coverage is lost from named areas of interest; improved collaborative planning software).

According to the commander's mental model across echelons (figure 8), the least experienced echelon (CAB level) usually had the highest congruence of the threat to their mission at least 50% of the time. They achieved higher and more congruent levels than any other command level. This also held true for peer mental models as shown in figure 8. In figure 8, no data were available for the UE commander team on June 18 p.m. or the CAB commander team on June 22 p.m. because the commander did not complete the mental model.
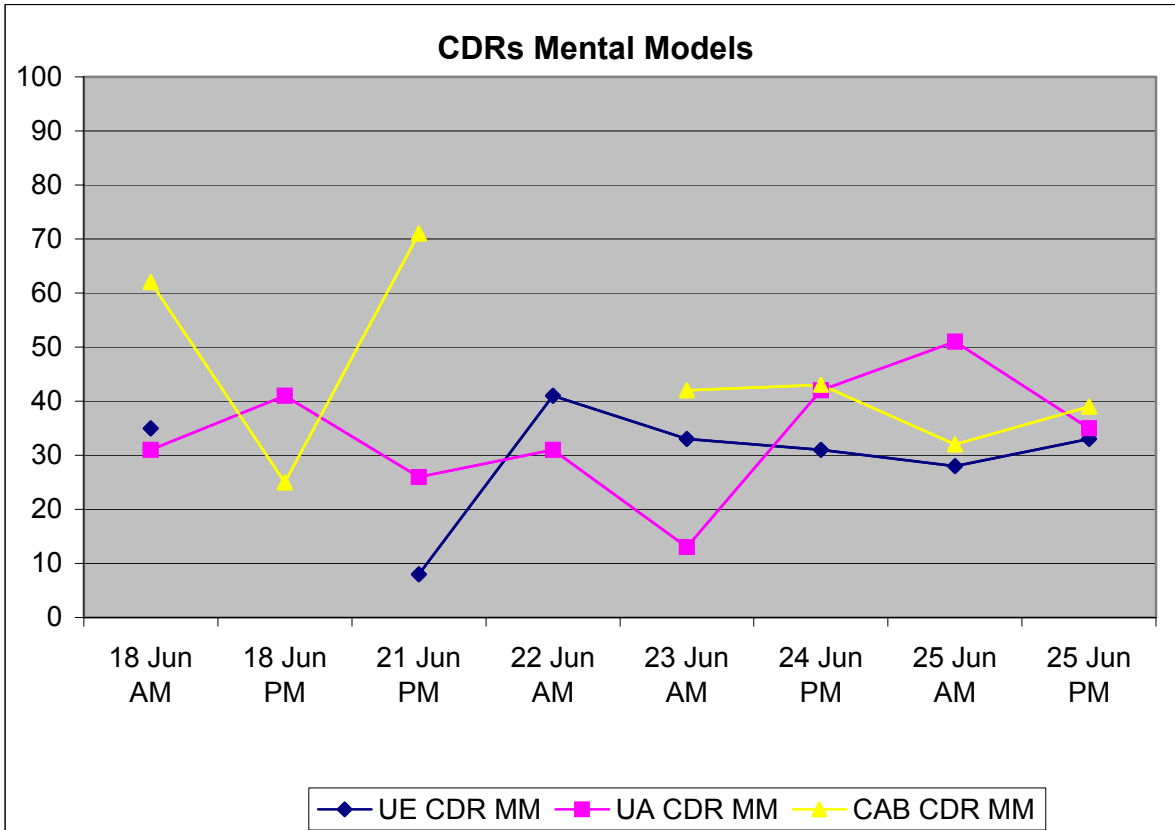
14

CDRs Mental Models

Figure 8. Commanders' mental models.

Team mental models are displayed in figure 9. In figure 9, no data were available for the CAB team mental model on June 22 p.m. because not enough members completed the team model. Although congruence is less among the same peer group, once again, the lowest echelon command group achieved the highest and most consistent mental model congruence. There are several possible explanations that may be driving this finding:

The CAB has the smallest area of influence and operations, and the most entities (sometimes down to vehicle level) to control. As such, they are much more focused on a narrow, less complex mission, allowing more congruence among the command team. Also, several company commanders were sitting in the vicinity of the CAB commander, which would facilitate coordination. Finally, one SME pointed out that the lower level commanders had the least familiarity with the scenario, unlike higher level commanders who had prior experience in other FCS UE staff-level exercises at Fort Leavenworth, Kansas. This lack of familiarity could result in the CAB-level commanders being more focused on everything about the fight in their area of interest, which in turn provided better mental model congruence.

As all command levels had the same equipment available to them to plan and communicate, the CAB was using different techniques to plan and execute the battle,

which were more efficient at relaying or transmitting the commander's mental model. One technique of interest was a relatively lengthy daily AAR. Although the UA also had an AAR, it was more restricted to the staff versus subordinate commanders, and of less duration, since the UA commander also had other exercise responsibilities.
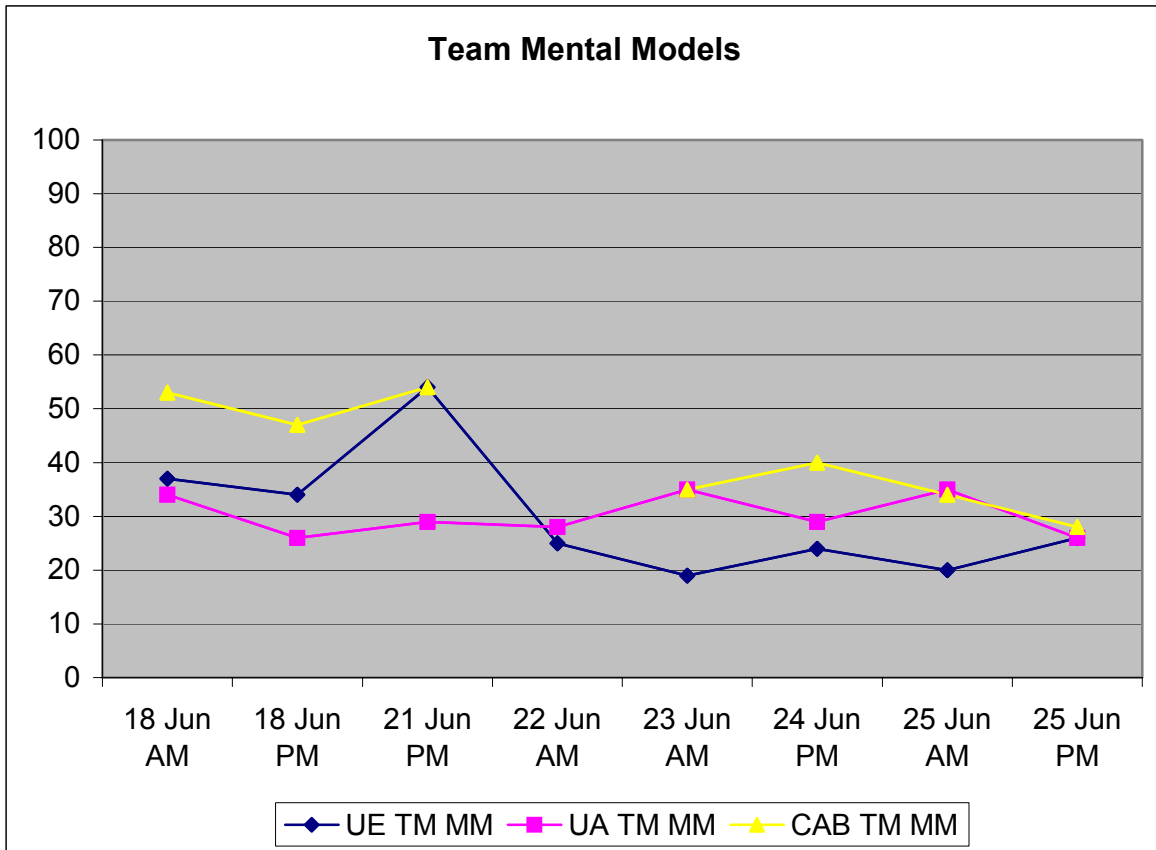

Figure 9. Team mental models.

4. Discussion

In contrast with the relatively high self-assessments of SU and effectiveness, there was relatively low shared understanding of the main threats to mission accomplishment among teams of commanders. This suggests that the ability to act collaboratively may be limited despite the networked battle command technology. SU and shared understanding take place in the heads of commanders, not on the network. Thus, for command teams to be successful, commanders must learn to periodically share their understanding of the tactical situation (Serfaty, Entin, & Johnston, 1998), as well as have an understanding of the roles and responsibilities of other team members (Mathieu et al., 2000).

It is interesting to note that the lowest level of command had the highest and most consistent levels of congruence. This could be attributable to a simpler mission plan or to the fact that the team was using techniques not employed by the other levels of the command team.

Given the confounding in the design of the experiment, it is impossible to determine the relative roles played by doctrine or the understanding of doctrine, the *ad hoc* nature of the team, the limited training, the current organization, or the limitations of the battle command technology itself.

Mental model congruence did not increase substantially over the experiment, suggesting that team learning did not occur. Again, whether this was attributable to the nature of the team, organization, training, or battle command technology is difficult to determine.

There is a major discrepancy between subjective measures of workload (low and generally decreased over the experiment), effectiveness, and SU (both were high and if anything, increased) and more objective measures of mental model congruence.

5. Conclusions

There are two conclusions that we think are most likely to be drawn from this analysis. First, numerous variables (or factors) were interacting with the battle command staff that prevented them from establishing and maintaining a coherent mental model of the battle plan and resulting fight; however, these variables do not have a similar detrimental effect on workload and SU. Second, it appears that the subjective measurements are showing more subject bias to questions on the survey.

Controlled experiments are needed for us to understand the relationship of doctrine, organization, training, and battle command tools and to isolate the influence of these factors and their effect on the battle staff in maintaining a coherent mental model of the battle plan and resulting fight. Having a dedicated team of players (e.g., those currently assigned to the UA experimental element) should help reduce the role played by variations in shared understanding of doctrine, limited training, and *ad hoc* team composition.

Smaller scaled, structured experiments with a dedicated team of players would have several advantages. Smaller scale experiments would reduce the complexity of training, since there are fewer personnel and fewer roles to train plus less complexity of development of doctrine and TTPs, since there are fewer organizational levels involved. Also, these experiments would enable better data on workload, SU and mental models. In smaller scaled, structured experiments, it would be possible to have objective measures of workload (e.g., performance of secondary tasks); SU (e.g., SAGAT, as mentioned earlier); and mental models (e.g., having team members periodically indicate their most important task, biggest problem, and resource needed). In turn,

these data would enable researchers to determine the quality of mental models, workload, and SA and how these concepts are affected by doctrine, organization, training, and materiel. Such experiments would also help us determine if mental model congruence increases over time and elucidate relationships between mental models, workload, and SA (e.g., whether differences in levels of these variables are attributable to differences in measurement techniques or to more fundamental causes).

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