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Situational Understanding, Workload, and Congruence With the Commander's Mental Model

by Bruce S. Sterling and Chuck H. Perala

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Bruce S. Sterling and Chuck H. Perala
Human Research & Engineering Directorate, ARL

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14. ABSTRACT
For the U.S. Army future force, it will be particularly important to see first, understand first, and act first. In order to do this, collaborative planning and execution are necessary. These are enabled, in part, by a shared mental model of the situation. Using a technique established by Entin and Entin (2001), we examined the relationship between discrepancies with the commander's mental model and participants' ratings of their own frustration, workload, effectiveness and situational understanding (SU). We found that the greater the discrepancy with the commander's mental model, the higher the participants rated their own frustration, and the lower the participants rated their own workload, effectiveness, and SU. The findings concerning frustration, effectiveness, and SU are explained as suggesting that those who did not have a good mental model with the commander were consequently more frustrated at their jobs, less effective, and had lower SU of the situation. The finding of greater discrepancy being associated with lower workloads was explained as a result of those who did not "have their heads in the game" (high discrepancy with the commander's mental model), being unable to provide products, information, or actions to the commander (low workload). Correlations between discrepancies in mental model and frustration, workload, SU, and effectiveness are higher during low workload and low SU. Overall, these results suggest a link between shared mental models with the commander and team performance, since performance has been consistently linked to constructs such as workload, self-efficacy, and affect. Results further emphasize the need for validated measures of mental model congruence to assess the effectiveness of changes in doctrine, organization, and materiel anticipated in the future force. Also, further research is indicated to delineate critical components of shared understanding and their impact on decision making per se, that is, what kinds of decisions are most affected and what types of errors are most likely to arise? Finally, research should assist in the development of methods to improve shared mental models.

15. SUBJECT TERMS
congruence; mental model; situational understanding; workload

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1. Introduction

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 (UAVs) and unmanned ground vehicles (UGVs) 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 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, shows 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 subordinates with better shared mental models with their commander would have better situational understanding (SU) and be more effective. It is likely that those who better understand how the commander sees the situation and what he thinks is important 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 the relationships among congruence with the commander’s mental model and individual perceived workload, situational understanding, and effectiveness. Entin and Entin (2001) have developed a method of assessing mutual mental model congruence. These researchers assess the accuracy with which team members can estimate the individual workload of other team members (Entin, 1999). In the variation employed here, the accuracy with which team members can estimate the workload of their immediate commander was assessed. Congruence with the commander's mental model was then compared to the participant's assessment of his own SU, effectiveness, and workload.

2. Method

2.1 Experimental Overview

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

The experiment consisted of one unit of employment (UE), or division-sized element, with a partial staff, and several subordinate UAs, or brigade-sized elements (three maneuver UAs, a strike [aviation] UA, and a fires UA). However, all but one UA was played constructively (i.e., only one or a few "live" participants, with research assistants assigned to control subordinate battalions), representing at most a small staff (the two maneuver UAs were played by only a UA commander). The remaining UA had a substantial staff, with all staff organizations represented at least to some extent, and six subordinate battalion-level organizations; three combined arms battalions (CABs), a non-line-of-sight (NLOS) battalion, a forward support battalion, and an aviation battalion. Most of these battalions were represented by at most 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). All but two companies were represented by a company commander only. The remaining 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. This design is referred to as a "slice" design, where at least one level of the organization is "fleshed out" from lowest to highest—in this case, platoon through UA (appendix A).

2.2 Participants

One hundred fifty-six participants assumed staff and command positions for the UE, UAs, CABs, and subordinate companies and platoons. Participants had several days of individual and collective training, but this training varied in quality, depending on the research assistant assigned to the group. Observer consensus was that many personnel were still asking questions concerning the computer interface (MC2 system) during the experiment. Nearly all participants had previous military experience and a minority were active duty Soldiers. Participants varied considerably concerning experience with FCS doctrine and concepts. Some had participated in other UAMBL experiments, while this was the first time for others. The number of participants answering the survey varied from one vignette to another.

2.3 Survey

The survey contained questions concerning workload, SU, and effectiveness (appendix B). Three questions were related to workload: frustration, mental demand, and temporal demand. There was one question each for effectiveness and SU. All questions used a 7-point scale where 1 equaled low and 7 equaled high. Participants were asked to rate their own workload, effectiveness, and SU using these scales. Then, participants were asked to estimate their commander's workload, effectiveness, and SU on an identical set of questions. The difference between the participants' estimate of their commander's workload, effectiveness, and SU, and the commander's ratings of his own workload, effectiveness, and SU comprised the measure of mental model congruence. Thus, we are not measuring the extent to which subordinates and the commander had a shared SU of the situation but the extent to which the subordinate could predict the commander's SU. The absolute value of the difference was used. In addition to the individual measures of discrepancy for each survey item, we created a measure of total discrepancy by summing the values of the discrepancies on each individual survey item.

2.4 Procedure

The survey was administered one or two times each day on the same computer that participants used to perform their duties in the experiment. It was administered immediately before the lunch break (starting from 1100 to 1300, depending on the day) and immediately before the end of the day (from around 1530 to as late as 2030). Participants were asked to estimate their workload, effectiveness, and SU since the last time they had completed the survey. Data used here were from the morning of the first "record" (as opposed to "pilot") run of the experiment and from the afternoon of the next to last day of the experiment.

2.5 Analyses

Pearson's Product Moment Correlation was used to examine the correlations between each of the measures of discrepancy with commander's workload, effectiveness, and SU, and the participants' estimates of their own workload, effectiveness, and SU. Negative correlations indicate that the higher the discrepancy between participants' and commander's mental model, the lower the participants' rating of workload and/or SU. Positive correlations indicate that the higher the discrepancy between participants' and commander's mental model, the higher the participants' rating of frustration.

3. Results

Results from 18 June (see table 1) show that discrepancies with commander's mental model of effectiveness and SU are particularly related to participants' own ratings of effectiveness and SU. The larger the discrepancy between the commander's actual ratings and the participants' predictions of the commander's ratings, the lower the ratings of participants' own effectiveness and SU. This makes sense in that if the participant does not understand the level of the commander's SU and what information the commander needs or does not need, then the participant cannot provide the commander with the information needed or perhaps provides the commander with information not needed. This would result in lower levels of participants' SU and perceived effectiveness.

Table 1. Correlations between discrepancies from commander's workload and SU and participants' workload and SU – 18 June a.m. data.

Deviation from Commander's:	Participant's Frustration	Mental Workload	Temporal Workload	Effectiveness	Situational Understanding
Frustration	.157 (154)	-.073 (154)	-.040 (153)	.095 (153)	.029 (154)
Mental Workload	.014 (153)	-.233 (153)	-.158 (152)	-.091 (152)	.054 (152)
Temporal Workload	.164 (154)	.084 (154)	.108 (153)	.049 (153)	.037 (154)
Effectiveness	.169 (152)	-.187 (152)	-.191 (151)	-.364* (151)	-.255 (152)
Situational Understanding	.082 (153)	-.126 (153)	-.086 (152)	-.339* (152)	-.383* (153)
Total Deviation	.191 (150)	-.186 (150)	-.127 (149)	-.205 (149)	-.151 (150)

* = $p < .001$, two tailed test; ( ) = Number of observations

Results from 24 June (see table 2) show the same pattern. In addition, higher discrepancies in perceptions of commander's effectiveness are related to higher levels of participant's levels of frustration and surprisingly, lower levels of workload. It is logical that a mental model that is less congruent (i.e., larger discrepancies) with the commander's results in higher frustration. However, it is surprising that a less congruent mental model is related to lower levels of workload. One observation made by subject matter experts in this experiment was "the higher the workload, the higher the SU." Thus, it is possible that those who had a mental model congruent with that of their commander were producing products or taking action in support of the commander's plan, while those who did not were perhaps being more reactive than proactive, thereby exhibiting lower levels of workload and effectiveness. Also, now the measure of total deviation with the commander's mental model is related significantly to participants' ratings of effectiveness and SU. Results show that as the discrepancy with the commander's mental model increases, the levels of frustration increase and the levels of workload, effectiveness, and SU decrease.

Table 2. Correlations between discrepancies from commander's workload and SU and participants' workload and SU – 24 June p.m. data.

Deviation from Commander's:	Participant's Frustration	Mental Workload	Temporal Workload	Effectiveness	Situational Understanding
Frustration	.272* (156)	.026 (157)	.022 (154)	-.128 (156)	-.131 (155)
Mental Workload	.009 (158)	-.060 (159)	.031 (156)	-.193 (158)	-.023 (157)
Temporal Workload	-.036 (156)	-.436* (157)	-.417* (154)	-.215 (156)	-.018 (155)
Effectiveness	.165 (158)	-.205 (158)	-.195 (155)	-.359* (157)	-.425* (156)
Situational Understanding	.144 (155)	-.165 (156)	-.155 (154)	-.289* (155)	-.458* (154)
Total Deviation	.193 (148)	-.229 (148)	-.197 (146)	-.328* (147)	-.264* (146)

* = $p < .001$, two tailed test; ( ) = Number of observations

Figure 1 illustrates the practical value of these correlations. Total deviation (discrepancy) scores for the 24 June data were first transformed into congruence scores so that the maximum possible discrepancy with the commander resulted in a score of 0 and no discrepancy with the commander resulted in a score of 100. The congruence score was then divided as closely as possible into quartiles, with the lowest (first) quartile representing the respondents with the lowest congruence and the highest quartile (fourth) representing the respondents with the highest congruence. The SU score was divided by 7 (a 7-point Likert-type scale was used), so that it ranged from 0 to 1. Self ratings of SU improve consistently from 68% to 78% as congruence with the commander's mental model improves.

The largest discrepancies came from those who rated themselves low in mental workload, effectiveness, and SU. Table 3 shows that participant ratings of themselves on workload, effectiveness, and SU correlated highly with their estimates of their commanders' workload, effectiveness, and SU. Thus, those who rated themselves low on those items also rated their commanders low. Table 4 shows that commanders rated themselves higher than their subordinates on mental workload, effectiveness, and SU. Thus, the largest discrepancies came from participants who rated themselves (and therefore, their commander) low in mental workload, effectiveness, and SU.

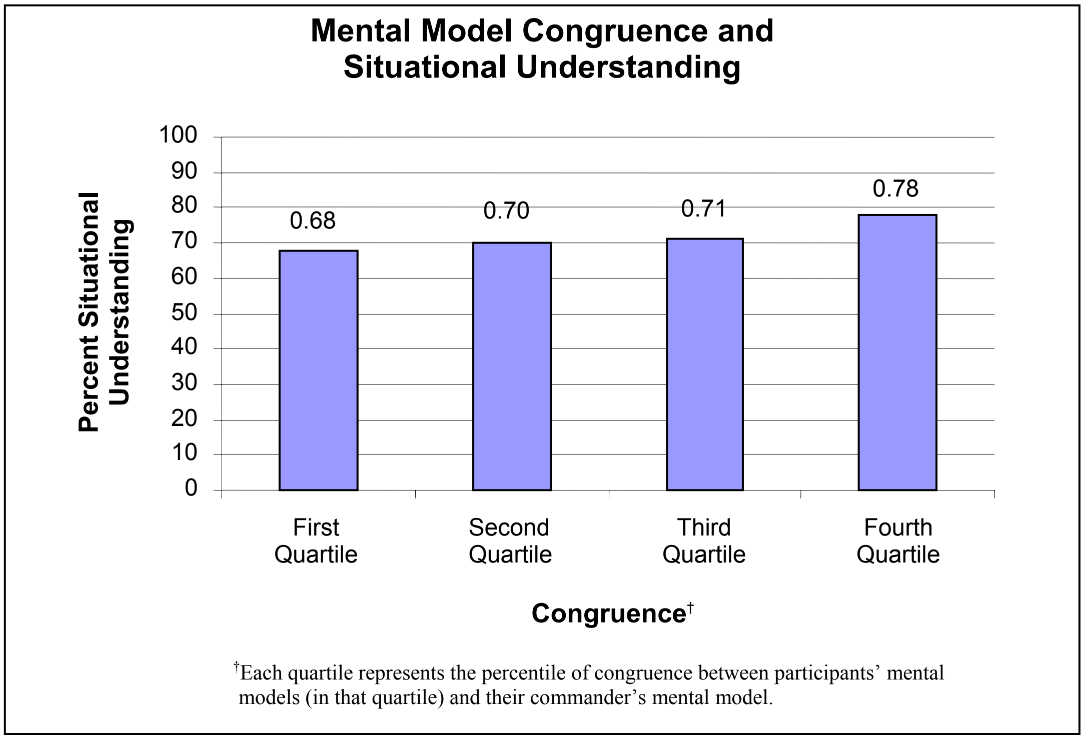

Figure 1. SU as a function of congruence with commanders' mental model.

Table 3. Correlations between participants' ratings of workload, effectiveness, and SU for themselves and estimates of their commander's – 18 June.

Frustration	Mental Demand	Temporal Demand	Effectiveness	SU
.615* (161)	.743* (160)	.688* (160)	.608* (159)	.550* (161)

* = p < .001, two tailed test;( ) = Number of observations

Table 4. Differences between subordinate and commander ratings of workload, effectiveness, and SU – 18 June.

Measure	Subordinate mean	Commander mean	Difference statistically significant (p<.001 two tailed)?	Number of observations
Frustration	3.70	3.57	No	155
Mental demand	3.24	4.04	Yes	155
Temporal demand	3.31	3.38	No	154
Effectiveness	4.51	5.16	Yes	154
SU	4.89	5.68	Yes	155

An examination of discrepancy correlations by low (table 5) versus high (table 6) workload (median split of the sum of mental and temporal workload) revealed that there were fewer statistically significant correlations between discrepancy with commander's mental model and participants' ratings of their own effectiveness and SU under high workload. This makes sense, given the results concerning where the largest discrepancies came from. That is, the largest discrepancies came from those who rated themselves low in effectiveness and SU. Thus, for those who rated themselves high, a restriction of range in the discrepancies would have attenuated the correlation between participants' shared mental model with their commander and ratings of participants' effectiveness and SU.

Table 5. Correlations between discrepancies from commander's workload and SU and participant's workload and SU – low workload, 24 June p.m. data

Deviation from Commander's:	Participant's Frustration	Mental Workload	Temporal Workload	Effectiveness	Situational Understanding
Frustration	.252 (83)	-.036 (84)	-.033 (84)	-.222 (84)	-.253 (83)
Mental Workload	.103 (84)	-.176 (85)	-.129 (85)	-.288 (85)	-.020 (84)
Temporal Workload	.030 (84)	-.211 (85)	-.107 (85)	-.064 (85)	.074 (84)
Effectiveness	.310 (83)	-.093 (83)	-.109 (83)	-.352* (83)	-.414* (82)
Situational Understanding	.235 (83)	-.046 (84)	-.070 (84)	-.287 (84)	-.533* (83)
Total Deviation	.262 (82)	-.132 (82)	-.097 (82)	-.339 (82)	-.311 (81)

* = *p* < .001, two tailed test; ( ) = Number of observations

Table 6. Correlations between discrepancies from commander's workload and SU and participants' workload and SU – high workload, 24 June p.m. data.

Deviation from Commander's:	Participant's Frustration	Mental Workload	Temporal Workload	Effectiveness	Situational Understanding
Frustration	.315 (70)	.176 (70)	.210 (70)	.050 (70)	.020 (69)
Mental Workload	-.128 (71)	.051 (71)	.310 (71)	.073 (71)	.038 (70)
Temporal Workload	.143 (69)	-.321 (68)	-.335 (69)	-.194 (69)	-.054 (68)
Effectiveness	.103 (72)	-.049 (72)	-.041 (72)	-.218 (72)	-.308 (71)
Situational Understanding	.046 (70)	-.246 (70)	-.186 (70)	-.216 (70)	-.318 (69)
Total Deviation	.169 (64)	-.138 (64)	.015 (64)	-.163 (64)	-.205 (63)

* = *p* < .001, two tailed test; ( ) = Number of observations

Another intervening variable appears to be SU. Tables 7 and 8 show that correlations between discrepancy with commander's mental model and workload, effectiveness, and SU are higher for participants who rate their own SU low (lower half of the distribution) compared to those who rate their SU high (upper half of the distribution). There are at least two ways of interpreting this result. First, when SU is high, a mental model that is congruent with the commander's may be less important, since frustration should be low and workload and effectiveness high (participants know what to do and can do it effectively without reference to what the commander thinks). The other interpretation is similar to the high versus low workload data. That is, when subordinates rate their own SU low, discrepancies with commander's ratings will be higher, since commanders tend to have higher ratings of workload, effectiveness, and SU. Thus there will be less attenuation of range and higher correlations.

Table 7. Correlations between discrepancies from commander's workload and SU and participants' workload and SU – low SU, 24 June p.m. data.

Deviation from Commander's:	Participant's Frustration	Mental Workload	Temporal Workload	Effectiveness	Situational Understanding
Frustration	.550* (49)	-.164 (50)	-.293 (49)	-.219 (50)	-.218 (50)
Mental Workload	.014 (50)	-.089 (51)	-.005 (50)	.008 (51)	-.084 (51)
Temporal Workload	.157 (48)	-.504* (49)	-.375 (48)	-.339 (49)	-.312 (49)
Effectiveness	.235 (50)	-.307 (50)	-.409 (49)	-.399 (50)	-.540* (50)
Situational Understanding	..118 (48)	-.295 (49)	-.394 (49)	-.473* (49)	-.441* (49)
Total Deviation	.399 (45)	-.312 (45)	-.394 (45)	-.366 (45)	-.388 (45)

* = $p < .001$, two tailed test; ( ) = Number of observations

Table 8. Correlations between discrepancies from commander's workload and SU and participants' workload and SU – high SU, 24 June p.m. data.

Deviation from Commander's:	Participant's Frustration	Mental Workload	Temporal Workload	Effectiveness	Situational Understanding
Frustration	.114 (106)	.116 (105)	.154 (103)	.004 (104)	.162 (105)
Mental Workload	.010 (106)	-.047 (106)	.047 (104)	-.287 (105)	-.055 (106)
Temporal Workload	-.103 (106)	-.426* (106)	-.444* (104)	-.227 (105)	.080 (106)
Effectiveness	.020 (106)	-.177 (106)	-.123 (104)	-.167 (105)	-.030 (106)
Situational Understanding	.024 (105)	-.126 (105)	-.062 (103)	.066 (104)	-.067 (105)
Total Deviation	.015 (101)	-.213 (101)	-.137 (99)	-.217 (100)	.047 (101)

* = $p < .001$, two tailed test; ( ) = Number of observations

4. Discussion

Discrepancy with the commander's mental model was associated with higher levels of participant frustration and lower levels of workload, effectiveness, and SU. Participants who did not have a good mental model with the commander felt more frustrated, performed less work, were less effective, and had reduced SU. Thus, a good shared mental model with the commander is critical to participant job performance.

One shortcoming of this study is that there is no link with exercise performance. That is, we cannot determine if large discrepancies in mental models are associated with poor performance. While discrepancies in mental models may actually result in poor performance, it is not a certainty that poor performance results in discrepant mental models. That is, if workload was high and SU was low, resulting in poor performance, it would not automatically follow that there was a large discrepancy in mental models between subordinate and commander. So long as both perceived workload as inordinately high and SU as low, there would be low discrepancy in mental model.

Since collaborative planning is increasingly important in the future force and shared mental models are necessary for collaborative planning, measures of mental model congruence are increasingly important. In future experiments where new organization, doctrine, or materiel (e.g., Soldier-machine interface) is tested, a valid measure of mental model, similar to that employed in this research, is needed. Then the effects of organization, doctrine, or materiel changes on a shared mental model can be assessed. A more valid but labor-intensive measure of situational awareness would be to measure SA directly. For instance Endsley (1993) measured SA by asking about information available to the participant. Redden, Eliott, Turner, and Blackwell (2004) used the same approach for shared understanding through examination of the role of communication. In the latter approach, the questions are administered after the simulation is complete.

Also, methods of enhancing shared mental models need to be developed. Cooke, Salas, Cannon-Bowers, and Stout (2000) postulate two types of team mental models: team mental models and team situation models. Team mental models refer to the collective task and team-relevant knowledge that team members bring to a situation. This can include knowledge of team member roles and responsibilities, knowledge of teammates' knowledge, skills and abilities, cue-strategy associations, understanding task procedures, and knowledge of typical task strategies. Team situation models refer to team members' collective understanding of the current situation at any specific point in time. Serfaty, Entin, and Johnston (1998) demonstrated that enhancement of team situation models can improve team processes in an anti-air warfare command and control simulation. They found that teams where the leader was trained to give periodic briefings of his view of the current tactical situation had better team processes (e.g., coordination) than teams where the leader was not trained to provide briefings. Team mental models could be enhanced by having the commander or other team members periodically provide information about their current most important task, biggest challenge to performing that task, and what information or resources are needed to accomplish the task. The interface could assist in providing this information by having a "window" specially designed to enter and distribute this information, and alerts could be provided to notify the user of periodic briefings.

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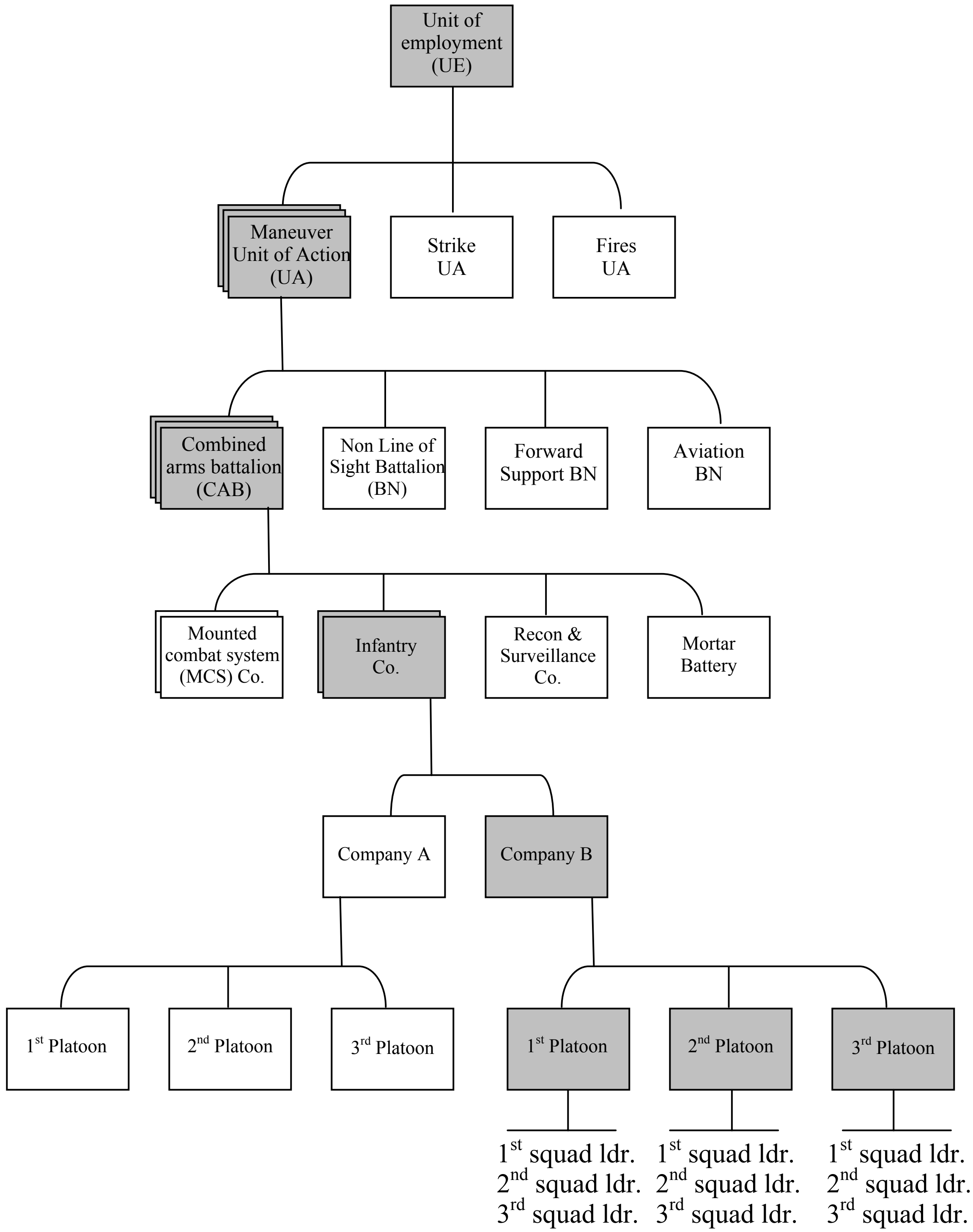
Appendix A. Organization Slice Design



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Appendix B. Survey

Rate your experience since the last survey on the scales below.

Frustration
1 Low 2 3 4 5 6 7 High

Mental Demand (how hard did you have to think)
1 Low 2 3 4 5 6 7 High

Temporal Demand (how much time pressure did you experience)
1 Low 2 3 4 5 6 7 High

Effectiveness (how effective were you are performing your tasks)
1 Low 2 3 4 5 6 7 High

Situational Understanding
1 Low 2 3 4 5 6 7 High

Click on how you think your COMMANDER answered the questions below. Do not confer with this person about your answers. If you do not know provide your best guess.

Frustration
1 Low 2 3 4 5 6 7 High

Mental Demand
1 Low 2 3 4 5 6 7 High

Temporal Demand
1 Low 2 3 4 5 6 7 High

Effectiveness
1 Low 2 3 4 5 6 7 High

Situational Understanding
1 Low 2 3 4 5 6 7 High

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