Measurement Of Situation Awareness In A C4ISR Experiment

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Abstract

This paper describes an attempt to measure the situation awareness of Brigade Headquarters staff during a command post experiment conducted to quantify the benefits of a C4ISR system. The experiment involved human players who have been given the task of conducting specific military operations within a scenario. The motivation for developing measures for situation awareness was to gain the ability to evaluate the impact of decision support tools and visualisation aids. The ability to measure situation awareness also provides a tool for studying command performance, specifically command appreciation of the situation.

The method used to measure situation awareness was SAGAT (Situation Awareness Global Assessment Technique) (Endsley, 1995b). This involved the freezing of the exercise at random times, during which the subjects had to respond to questions relating to the three levels of situation awareness (perception, comprehension and projection). SAGAT has been employed in the air domain for many years. Its implementation in the land force has been at the lower echelon activities. This work was undertaken to assess the viability of the method in a C2 environment at the Brigade level. It was concluded that the technique is potentially very useful. Possible improvements in the implementation of the technique are discussed.

1. Introduction

Command and Control systems networked with surveillance and reconnaissance assets and embedded intelligence capabilities (C4ISR) are complex human activity systems. They consist of people, tools, processes, procedures, organisational structures operating in a dynamic environment. The commander and his staff interact with each other, aided by the available tools to achieve specified goals. They operate within the organisational structure in accordance with doctrine and standard operating procedures. The dynamic situations created by the adversaries and environmental conditions are often unpredictable, and generate time pressures and surges of high workload. The players have to make decisions under the conditions of uncertainty and ambiguity. The consequences of their decisions and actions further affect the dynamics of the situation. The volatile nature of the variables makes a C4ISR system a difficult 'beast' to investigate. A holistic approach to studying C4ISR systems such as that depicted in the

‘Sensemaking Conceptual Framework’ (Leedom 2001) and in the work described by Worm (2000) is clearly desirable. However, research that addresses an element of the system to a greater depth is also valuable. As the understanding and insight of each of the parts is incrementally developed, a clearer picture of the total system will emerge.

This paper addresses the issue of individual situation awareness, which is one element in the cognitive domain of the ‘Sensemaking Conceptual Framework’ (Leedom 2001). The focus of the research has been the development of a methodology to measure situation awareness. The ability to measure situation awareness of the command team would serve as a tool for studying command performance, specifically command appreciation of the situation.

The motivation for conducting the research arose from the observation that the development of decision support tools and visualisation aids to assist Command and Control (C2) staff perform their tasks has been largely technology driven. The effectiveness of these tools and aids is difficult to evaluate. A recent study (Henderson 2000) concluded that technological support systems could reduce the effectiveness of a command team. Situation awareness measures provide one way of assessing whether or not the introduction of a particular tool improves or degrades command appreciation performance. One of the strengths is that they can be used for diagnostic purposes, allowing the positive and negative aspects of the tool to be identified.

This paper provides a report on our first attempt to measure C2 staff’s situation awareness in a command post exercise, Hydra Drive 2001 (HD01). In Australia, the Land Operations Division (LOD) of the Defence Science and Technology Organisation (DSTO) has conducted several experiments in the last few years, one of the aims of which was to quantify the benefits of C4ISR support systems. These experiments involved military players who were given the task of conducting specific military operations within a scenario.

HD01 was intended to be the first of a series of command post experiments, which served as a baseline. In this experiment, the Brigade Headquarters (Bde HQ) staff conducted planning and execution of their plan with few technological aids. In subsequent experiments, information technology tools will be introduced to support the command team.

A framework of measures for the total C4ISR system has been developed (Seymour et al. 2001). It consists of five hierarchical levels of measures, namely data, information, knowledge, decision and effects. Each of the lower level measures feeds into the higher ones. The third and fourth level, knowledge and decision respectively, belong to the cognitive domain. The first and second level, data and information, belong to the information domain, whilst the top level, effects, is in the physical domain. Knowledge, which constitutes the third level measure in the hierarchical framework, was interpreted as situation awareness.

During HD01 the Bde HQ staff’s situation awareness was measured. This was our first attempt to implement the method for measuring situation awareness. As such the purpose of the work was on identifying the strengths and weaknesses of the method and what it might reveal, rather than on the results themselves.

2. The concept of situation awareness

Although situation awareness is a phrase that is used frequently by the armed forces, there is not a universal definition accepted by the military from different nations. Nevertheless, the concept of situation awareness is generally understood to mean ‘knowing what is going on’, implying the possession of knowledge and understanding to achieve a certain goal. The existence of a goal or goals is important as it defines the scope of the information on which to focus in order to gain situation awareness for achieving the goals.

In the current work, the definition of situation awareness put forward by Endsley (1995) has been adopted: “situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future”. This definition divides situation awareness into three distinct levels. The first level involves the perception of elements in the environment. Level 2 involves the understanding of the significance of these elements in the current context and level 3 is the projection of the future status of the elements.

A person’s capacity for gaining and maintaining situation awareness is dependent on many factors including the goals that need to be achieved, the complexity of the situation, the operator’s workload and level of stress. The operator’s abilities, experience and training also influence how he or she deals with the external variables. It has been assumed that technology support, generically termed situation awareness tools, necessarily increases the operator’s situation awareness. However, unless the tools have been designed in such a way that it facilitates the operator’s understanding of the situation, advanced technology may indeed degrade performance.

In the model developed by Endsley, situation awareness is separated from and is regarded as a pre-requisite for decision making. A high level of situation awareness does not automatically guarantee high quality decision, as decision making is influenced by factors such as risk-taking propensities, experience, etc. One might expect that good situation awareness will increase the probability of good decision.

Endsley’s definition of situation awareness has been used extensively by the research community in various domains. The decomposition into three levels provides a useful construct for investigating situation awareness.

3. Situation awareness measures

3.1 Techniques for measuring situation awareness

Various methods have been developed for measuring situation awareness particularly in the aviation domain. These include performance based measures, subjective techniques and questionnaires/queries. An example of a performance based measure for a Brigade Headquarters may be the battle outcome, such as the loss exchange ratio. Such measures are attractive because they are objective, non-intrusive and are generally easy to obtain. However, in a complex environment, they lack sensitivity and diagnostic value since factors other than situation awareness are likely to contribute to performance. Subjective ratings of situation awareness by the participants may be inaccurate because the subjects may not be aware that they are missing information. Observer ratings may be more valid if the observers know the situation intimately and if they are trained in observing the participants' behaviour. The non-intrusiveness of observer ratings works in its favour. Questionnaires administered after an exercise can be misleading due to the delay between the time when the events occurred and that of questioning.

Because of the limitations in the various methods outlined above, the direct questioning technique based on SAGAT (Situation Awareness Global Assessment Technique) (Endsley, 1995b) was used. SAGAT involves freezing the simulation at random times during which subjects are questioned. The responses to the questions or probes are compared to the situation in the simulation at the time of the freeze. This comparison makes the technique less biased than self-ratings or observer ratings of situation awareness. SAGAT contains a set of probes that are relevant to the domain being studied. These probes, which cover all three levels of situation awareness, are based on the situation awareness requirements for the task. From the set of probes a random subset are asked during a freeze. This randomisation is necessary so that participants do not selectively pay attention to the issues raised in the previous freezes. Randomisation also emphasises the need to cover all aspects of the situation in the probes, rather than only asking highly significant questions.

Unlike the air domain, at present only a few researchers have developed and implement methods to measure situation awareness for the land force. In a virtual MOUT (Military Operations In Urban Terrain) simulation at the platoon level, situation awareness was measured using three different techniques, SAGAT, SABARS (Situation Awareness Behaviorally Anchored Rating Scale) and PSAQ (Participant Situation Awareness Questionnaire) (Matthews et al 2000). MARS (Mission Awareness Rating Scale) appeared to be promising for use in assessing subjective situation awareness (Matthews et al 2002). Redden and Blackwell (2000) applied a method based on SAGAT in a free-play exercise involving platoon commanders operating in the urban environment.

It is to be noted that the use of SAGAT in the current work differed from the original technique (Endsley, 1995b) in two respects. First, in HD01 it was applied in a live exercise, rather than a computer simulation. Second, in conducting their tasks, the subjects worked in a team environment in which the situation awareness of different aspects of the tasks is shared between the team members.

The development of the situation awareness probes for SAGAT involved a three stage process (Figure 1). Interviews were conducted with Army Officers to elicit the cognitive processes in conducting their tasks. Analyses of the interview results identified a list of the information required for situation awareness. This was in turn used to formulate the situation awareness probes.

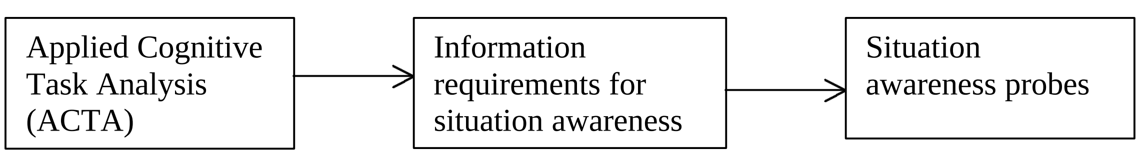

Figure 1. The process for the development of situation awareness probes.

3.2 Applied Cognitive Task Analysis (ACTA)

The information requirements for situation awareness needed to be identified for the development of the probes. To this end Applied Cognitive Task Analysis (ACTA) was employed. The method, developed by Klein, involves a task diagram, knowledge audit and simulation interview (Crandall et al 1994). The task diagram outlines the direction of the knowledge audit by identifying cognitive aspects of the task. The knowledge audit explores the cognitive aspects of the task in detail and identifies cues, strategies and differences between novices and experts. The simulation interview involves analysing a specific scenario. It elicits cues, strategies, common errors and an assessment of the situation as the subject works through the simulation. The knowledge audit and the simulation interview take approximately one and a half hours each. Two people conduct an ACTA interview; one person leads the interview and writes responses on a whiteboard, and the other takes more detailed notes. The latter may probe particular questions in more depth as sometimes the interviewer is focussed on the structured questions.

After some practice with non-military personnel, ACTA interviews were conducted with fifteen SMEs (Subject Matter Experts) who were or had been in the Australian Army. The rank ranged from Captain to Lieutenant Colonel, as well as Warrant Officer. The analysis of the interviews produced a compilation of the information requirements for the three levels of situation awareness. At the lower organisational level, platoon and company activities of patrol, attack and defend were covered. At the higher level, the information requirements for the Bde HQ staff, which included the commander, intelligence, operations and logistics officers, were obtained.

3.3 Information requirements for situation awareness

The information requirements for situation awareness obtained through ACTA were sorted according to level one situation awareness (perception), level two situation awareness (comprehension) and level three situation awareness (projection into the future). As a result, extensive lists of situation awareness requirements for patrol, attack, defend and for various functions within a Bde HQ were generated. Table 1 provides an example of the list of information requirements from interviews on conducting surveillance throughout a patrol.

Table 1. Information Requirements - Conducting Surveillance Throughout a Patrol

Level 1	Level 2	Level 3
Perception Enemy – location, strength, weapons, equipment and dress, past movement, doctrine Friendly – friendly locations, locations of other platoons, disposition, patrol borders, mission and intent, higher commander's intent Assets available – ammunition, rations, water, resupply details, casualties	**Understand the significance of**: Enemy – location, strength, weapons, equipment and dress, past movement, doctrine Enemy picture / situation (1 and 2 levels up) Friendly – friendly locations, locations of other platoons, disposition, patrol borders, mission and intent, higher commander's intent (1 and 2 levels up) Assets available – capability to do the next task	**Projection** Anticipate enemy movement and future intent (likely actions and methods) Anticipate friendly movement and future intent (likely actions and methods) Anticipate availability or the lack of availability of assets

Although level one and two contain many similar elements, at level two their significance and implications are understood. Level three involves anticipating the enemy's actions and one's own response to enemy actions. This incorporates many information requirements for situation awareness that are task specific.

3.4 Situation awareness probes

As mentioned previously the information requirements for situation awareness form the basis of the probes. The probes include the three levels of situation awareness. Careful attention must be paid to the appropriate phrasing as well as the content of the probes. The questions must be couched in military language and must be presented with clarity. They must also be specific. An Army Officer assisted with the development of the probes for a Bde level operation. Some examples are shown in the following table.

Table 2. Examples of situation awareness probes.

Probe	Category	Situation awareness level	Response form
Mark on the map the location of (subordinate unit 2 levels down).	Blue	1	Map
Which of your subordinate units is under the most direct enemy pressure?	Enemy	2	Text
What is the enemy's Centre of Gravity?	Enemy	2	Text
Mark on the map the location of (unit) and mark its projected movement for the next 3 hours.	Blue	3	Map
What is the enemy's next significant action likely to be?	Enemy	3	Text

4. Hydra Drive 2001

In HD01 the Bde HQ were staffed by personnel from the Army Reserves, many of whom had not attended formal courses in the Military Appreciation Process (MAP). A few weeks prior to HD01 the Bde HQ staff started to receive training on MAP and worked as a team.

HD01 was undertaken over a period of five days, in which the participants conducted the four phases of the MAP. The first three phases, consisting of mission analysis, Course of Action (COA) development, and COA analysis took approximately two and a half days to complete. The decision and execution phase, in which the battle was played out, took a little over one day.

As has been mentioned HD01 was a baseline experiment, thus the Bde HQ operated with traditional materials and tools. Paper maps, acetate overlays, paper message logs, voice radios were used, with computers being employed only for their word-processing and spread-sheet functionality.

The constructive wargame “ModSAF” was used to support the experiment. The enemy was played by two Army officers who directed ModSAF entities in the scenario. The Bde HQ staff did not control ModSAF entities directly but issued orders to the Lower Control (LOCON). The latter executed the orders on the wargame and provided the Bde HQ with situation reports, contact reports and so on. The Higher Control (HICON) played the Brigade’s higher headquarters and provided the Bde HQ with additional stimulations as appropriate. The Bde HQ staff had received and studied the documentation relating to the scenario, operations and the tasks they had to conduct at least one week before the start of the exercise. Thus they were able to become immersed in the simulated Bde HQ environment and in their tasks relatively quickly.

As well as situation awareness, other human factors aspects of the Brigade HQ’s activities were examined: radio messages, team interactions, information handling and communication, tool use, commander’s activities and commander’s intent (Demczuk et al, 2001). The tools examined included battle maps, radios, overlays, computers, whiteboards, and manuals. An expert team consisting of three Army officers assessed the performance of the HD01 participants based on the activities relating to the MAP sequence. In addition, ethnographic analysis and scientific debriefs were conducted.

4.1 Situation awareness measures in HD01

During the five day exercise eight freezes were effected to administer the situation awareness probes. The timing of these freezes was constrained to fit with that for other measures as well as the need to be as least intrusive as possible. For each freeze a pseudo random set of probes was drawn from the complete set.

As well as covering the three levels of situation awareness, the probes comprised questions relating to the enemy, friendly (blue forces) and the ground. It was anticipated that different probes would be used for the different functions within the HQ, for example some probes might be relevant to the Intelligence Officer but not to the Operations Officer. However, a closer inspection of the probes revealed that they were relevant to all staff.

A short time before each freeze an expert panel reviewed and contextualised the probes, which generally consisted of five to six questions. This process ensured the probes were relevant and allowed probes to be specific (eg asking the location of a specific unit). In addition, the players were asked to rate the level of confidence they perceived for each of their responses to the questions.

During each freeze it was necessary to move the Bde HQ staff to a separate area where they answered the probes with no access to their battle maps and other information. The probes involved a combination of written responses and marking locations on a photocopy of the map. Having completed their responses the participants returned to the Headquarters and the exercise was resumed. Each freeze lasted approximately eight to ten minutes.

Responses were scored by comparing the answers to the probes with the “ground-truth”, that is the situation at that point in the exercise. This was achieved using battle maps from ModSAF and the expert panel.

4.2 Results

Responses were analysed in terms of the corresponding level of situation awareness, the subject matter of the probe (blue, enemy or ground), the function of the respondent (Commander, Chief of Staff, Personnel/Logistics Officer, Intelligence Officer, Operations Officer) and the confidence level associated with each response.

As this was our first attempt to apply SAGAT in a C2 environment, the endeavour should be regarded as a pilot study. The purpose was to see if the method was viable. We were interested in identifying the strengths and weaknesses of the method and in looking for ways to improve it in the future. It is acknowledged that the method has not been validated. The results in HD01 were obtained from a small sample, too small to be subjected to a rigorous statistical analysis. Only descriptive statistics is used.

Figure 2 shows the overall situation awareness (combining situation awareness levels 1, 2 and 3) over the eight freezes. There was a general increase across the seven freezes. This was in line with the expectation that the staff’s situation awareness should develop as the exercise progressed. There was, however, a marked decrease in situation awareness in the eighth freeze. This could be attributed to an end effect due to the timing of the final freeze. This occurred immediately after the battle finished, the consequence of which may have been that participants lost interest in the state of the battle.

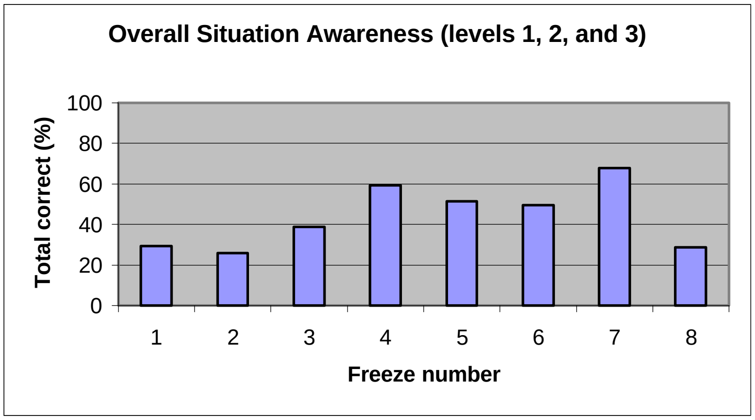

Figure 2. Development of overall situation awareness.

An examination in terms of specific situation awareness levels showed that correct responses for situation awareness level one (perception) and level two (comprehension) varied between twenty percent to just over sixty percent across the eight freezes, however for level three (projection) they varied over a much greater range, from less than twenty percent to more than ninety percent. It is conjectured that the large variation in the responses to level three (projection) questions is attributed to the level of difficulties of the questions. A decrease in level two and level three situation awareness was observed in the eighth freeze. The effect on the overall situation awareness was highlighted in the previous page.

Situation awareness of the blue force (friendly force) increased across the first seven freezes as expected but again showed a decline in the eighth freeze (see Figure 3).

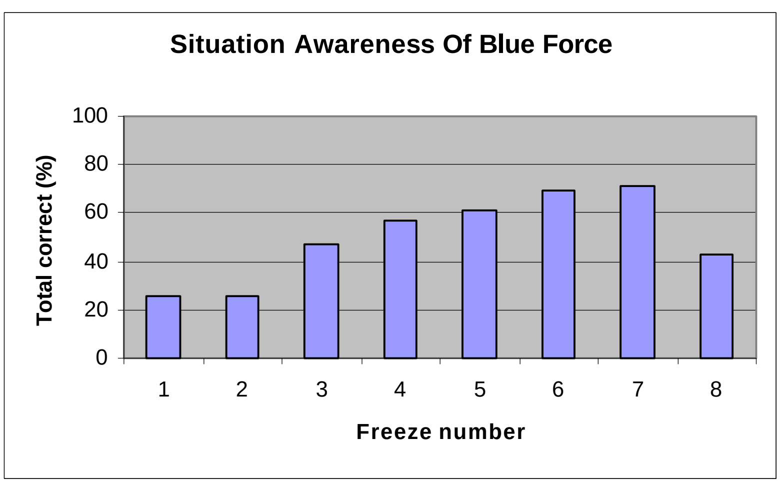

Figure 3. Development of blue force situation awareness.

Situation awareness of the enemy showed the same pattern initially, with an increase over the first three freezes. There was a decline over the subsequent freezes except in the seventh freeze. There were insufficient data to draw any conclusion on the probes relating to the ground or terrain. Overall, there was slightly more awareness of the blue force situation than there was of the enemy situation.

Situation awareness was also assessed in terms of the different functions within the Bde HQ. The responses of the Commander (Comd), Chief of Staff (CofS), Personnel/Logistics Officer, Intelligence Officer and Operations Officer functions were compared. Of most interest was the Commander's situation awareness. Despite spending a substantial amount of time outside the HQ, the Commander answered more probes correctly than any of the other functions for all three categories (blue force, enemy and ground). This suggests that the Commander's occasional distance from the HQ was not detrimental to his situation awareness. The Intelligence Officer and Operations Officer showed a similar understanding of blue force despite their different functions. However, the Intelligence Officer answered more enemy questions correctly than the Operations Officer. This is consistent with the Intelligence Officer's role.

Figure 4 illustrates the situation awareness of the blue force over freezes for the Commander, Chief of Staff (CofS), S1/4 (Personell/Logistics Officer), S2 (Intelligence Officer) and S3 (Operations Officer) functions.

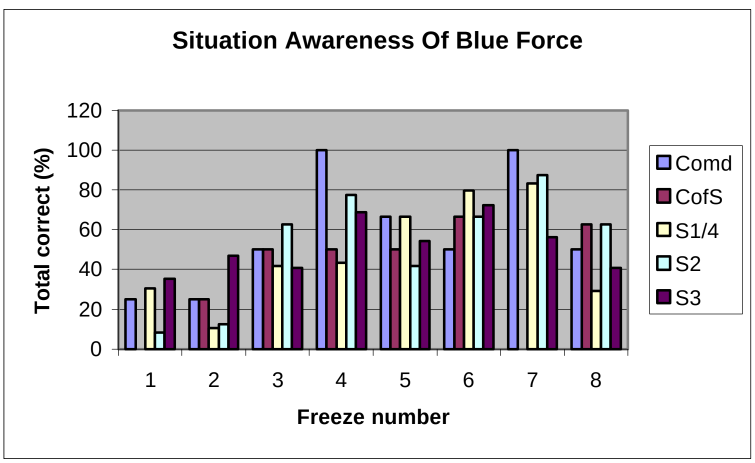

Figure 4. Comparison of the different Bde HQ staff's situation awareness of the blue force.

For each of the situation awareness probes, participants were asked to rate their confidence with their assessment as 'not confident', 'confident' or 'very confident'. The results indicate that over freezes the number of 'not confident' responses declined. (see Figure 5).

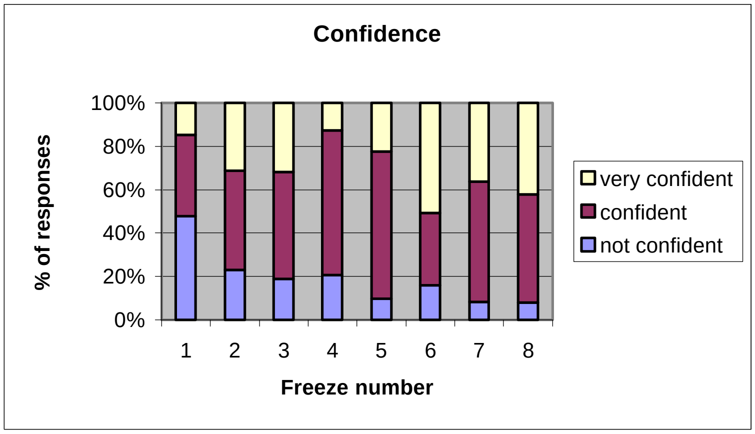

Figure 5. Level of confidence in responses.

In summary, the results revealed a general increase in situation awareness as the exercise progressed although there was a decline in the eighth freeze. Interestingly, participants were mostly confident or very confident with their responses during the final freeze. This perception contradicted the finding that many of their responses were incorrect.

Overall there was slightly more awareness of the blue situation than the enemy or the ground. Strater et al (2001) found that novices focused more on their own situation than the enemy. This is consistent with the results from HD01, the participants being relatively new to the MAP.

4.3 Discussion

HD01 provided an opportunity to pilot test an adaptation of SAGAT for measuring situation awareness. Limitations of the technique, of its implementation, and the way the exercise was conducted are discussed below.

The need to take participants out of the Bde HQ took eight to ten minutes and was more disruptive than anticipated. This caused participants to tire of the process quickly. The timing of the freezes was restricted by the activity within the headquarters and needed to be co-ordinated with freezes to collect data for other measures. It would be advantageous to have shorter freezes making them less intrusive and less predictable in terms of their timing. This would be possible if the attempts to collect other data are minimised.

Due to the relatively low tempo of activities within a Bde HQ it may be possible to take players out the headquarters to respond to situation awareness probes one at a time without pausing the exercise. Although this would be detrimental to situation awareness in domains with a higher tempo such as air traffic control, in this setting leaving the headquarters for a few minutes would be comparable to a coffee break. The disadvantage would be that one could not compare all of the staff members’ situation awareness at a particular point in time.

The reservists who participated in HD01 were relatively new to the MAP. This may have caused some difficulties with the terminology used in some of the situation awareness probes. In addition, they had not worked as a team prior to training for the exercise. This may have affected the way the team functioned and shared information, resulting in lower individual awareness of situation outside of the player's main area of responsibility.

The expert panel was relied upon to score the responses to the situation awareness probes. This meant that in some cases, particularly for the probes relating to the higher situation awareness levels, the results were less objective than had been expected. Open-ended questions, which could not be entirely avoided, were a problem. The use of multiple-choice questions would overcome the difficulties. The creation of multiple-choice questions, which had to be contextualised, would require an intensive effort from a SME.

An insufficient number of probes caused repetition, potentially focussing the attention of the Bde HQ staff on specific aspects of the situation. A broader range of probes relevant at the Brigade level will be required in future.

5. Conclusions

The implementation of SAGAT in HD01 showed that potentially it is a very useful technique for measuring situation awareness in a C2 environment. It is not an easy technique to employ in a free-play situation; it needs intensive effort on the part of the experimenters as well as Subject Matter Experts throughout the activities in terms of reviewing, contextualising and administering the questions, and scoring the responses.

The weaknesses of the method encountered in the exercise and the means to overcome them have already been discussed in the previous section.

The information obtained from the responses to the questions is valuable for its diagnostic value. The analyses of the results in terms of situation awareness levels (perception, comprehension and projection), or in terms of categories (enemy, blue forces, ground), as illustrated in Section 4.2, can reveal the specific issue that the subjects may have in conducting their tasks. For example, if level 1 situation awareness in terms of the enemy picture is low, one might consider the possibility that the information is not getting through to the players or that the information is not presented in the correct manner. If level one situation awareness is high, but level two is low, training may have been an issue.

A great strength in measuring situation awareness using a method based on SAGAT is the objectivity. The probing method taps directly into the subject's knowledge of the situation at the particular time. When decision support tools and visualisation aids are introduced to the headquarters, their impact on the subjects' situation awareness can be measured directly. The strengths and weaknesses of the tools can be identified.

In the long term, a more efficient way of implementing the method may be afforded by an intelligent agent-based method that will allow the probes to be administered by the computers used as part of the C4ISR system. This allows the subjects to enter their responses to the situation awareness probes on the computers they are using, thus disruption is kept to the minimum. The agent can then score the responses against the correct answers, thus streamlining the whole process.

Some of the difficulties encountered during HD01 could be overcome by designing more focussed and more controlled experiments, if possible at a smaller scale, that specifically investigate the key issues of situation awareness. Under these conditions, the researcher can be expected to have a better control in the way the battle develops and be able to administer the probes at the appropriate times. As well, because the experimenter has access to the "God's eye view", establishing the ground-truth and therefore the correct answers to the probe should be less of a problem.

The technique used for measuring situation awareness in the C2 environment has yet to be validated. A plan has been developed to conduct controlled experiments for that purpose. The reliability and sensitivity of the measures will also be examined. The experiments will also provide the opportunities for implementing other situation awareness measures to explore any relationship between the different measures.

Finally, a valid method for measuring situation awareness would provide a valuable tool to answer many research questions. For example what critical information is needed for the player to gain and maintain situation awareness? How does a commander maintain a high level of situation awareness even though he may spend a majority of his time away from the HQ? How does the individual situation awareness compare with team situation awareness measures based on behavioural observation? Can the situation awareness be correlated with decision making and decision errors? We hope to be able to address some of these issues.

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