The Impact of Digital Display on Ground-Based Air Defence Command Post

Han Tin French

Land Operations Division, DSTO
PO Box 1500, Edinburgh, SA 5111
tin.french@dsto.defence.gov.au

Abstract

The impact of access to information through advanced information and communication technology was assessed in a study involving the Ground-Based Air Defence Command Post (GBAD CP). At present the GBAD CP obtains information about aircraft and their movements by HF radio. In the study, digital data was directly transmitted to the GBAD CP. Its effect on the situation awareness (SA) of the Command Post Officer (CPO) and Detachment Commander (Det Comd) was investigated. The Direct Questioning Technique, based on the Situation Awareness Global Assessment Technique (Endsley, 1995a), was used to measure the SA of the CPOs and Det Comds. With this method, the operators were asked specific questions relating to the situation at various times during the exercise. The questions covered three levels of SA, namely perception (level 1), comprehension (level 2) and projection (level 3). The responses were scored against the real situation by a Subject Matter Expert. The result of the study provided strong evidence that the CPOs' SA was enhanced by the digital display in terms of the air war aspects. The result also suggested that the Det Comd controlled by the CP with the digital display had higher SA than that controlled by the CP operating with radios only.

1 Introduction

One of the primary goals of a Network Centric Warfare capability is the sharing of information between various elements on the battlefield. This is made possible by extensive networking of elements in the battlespace brought about by advances in communication and information technology. The sharing of information would then result in increased shared situation awareness (SA), which in turn enables superior decisions to be made. Ultimately it is expected that mission effectiveness will be enhanced (Alberts, 2002). Although the advantages of networking have been extolled (Vergun, 2001; Scott and Hughes, 2003), there is a paucity of empirical evidence to show its impact on the Australian Army. The benefit of networking in relation to GBAD (Ground-Based Air Defence) is examined in this paper. A study was conducted to investigate the effects of digital display on the SA of GBAD CPO (Command Post Officer) and the Detachment Commanders (Det Comds) under his control.

2 GBAD CP

The Air Defence Regiment is responsible for the defence of a specified asset as stated by the higher Commander's intent. Its primary weapons in conducting the air war are ground-to-air missiles. Weapon detachments, commanded by Detachment Commanders, operate the weapons. They are placed at strategic locations around the asset being defended, with each detachment being responsible for a sector of the air-space. The GBAD CP provides the Command and Control (C2) function to the weapon detachments. It is in the CP that early warning and other information about aircraft movements, called tracks, is received by radio. A CP staff plots the tracks on a chart. The information judged to be important is forwarded to the relevant weapons detachments, also by radio.

There is a number of issues in relation to the method by which the information is transmitted to the GBAD CP. When there are many aircraft, only the most important information is passed on, usually this relates to enemy aircraft. The implication is that the GBAD CP is not made aware of friendly or neutral aircraft in the airspace. This may potentially result in fratricide. There is also latency in the information. By the time the information reaches the GBAD CP and weapon detachments, the aircraft is often no longer at the indicated location. Often track information is not updated, and the GBAD CP has to make a repeated request for the update. Finally the information received by the GBAD CP is often incomplete and prone to error. The direct transmission of digital information of aircraft movements is expected to address the shortcomings outlined above. An opportunity to collect empirical evidence arose in an exercise involving GBAD.

3 Situation Awareness Measures

3.1 SA definition

Endsley's definition of SA (1995a) is used in the study, "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and projection of their status into the near future". This definition is used widely by the research community because it is not restricted to a particular domain. It has been applied to many areas such as military, aviation, air traffic control, driving, nuclear power plant operation, medical emergency. According to the definition, SA consists of three 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.

3.2 Method

The method used to measure the SA of the GBAD CPO (Command Post Officer) and Det Comds was based on SAGAT (Situation Awareness Global Assessment Technique) (Endsley, 1995b). SAGAT was developed for computer simulation in the aviation domain. With this technique, the players' SA is measured by requiring them to answer SA questions when the simulation is frozen at random times. The responses to the questions are compared to the situation in the simulation at the time of the freeze. This comparison allows for more objective assessment of SA compared to self-rating or observer rating of SA. The SA probes include all SA elements relevant to the domain being studied, although only a randomised subset is used during each freeze. The randomisation is necessary so that the players do not anticipate particular questions and prepare for them. The questions also cover the three levels of SA. The implementation of SAGAT on a computer simulation is efficient and streamlined. During the freezes, the SA probes appear on the screen and the player provides the responses via the computer. For the work reported in this paper, the principles of SAGAT were adhered to, but the implementation was changed, as explained below.

A method to measure SA based on SAGAT, called the Direct Questioning Technique (DQT), has previously been applied in an Army context during a command post exercise involving a Brigade Headquarters in a simulated environment (French and Hutchinson, 2002) and in a field exercise with an infantry section (Guille and French, 2004). Computer simulation was not used in these exercises, so the SA questions were administered using pen and paper. Photocopies of maps were provided for questions that required the participants to show the location of particular entities on the map. The principle of SAGAT of developing a global pool of questions covering all SA elements was adhered to. However, instead of selecting the questions randomly, a Subject matter Expert (SME) assisted the selection of questions to ensure that they were relevant to the situation. In the first exercise with the Brigade Headquarters, it was found that the freezes were disruptive and time consuming. This was because the 'players' had to be taken out of the operation room, to prevent them from referring to the maps and other information in answering the SA questions. In the second exercise with the infantry section, it was decided to administer the questions during natural breaks. In the GBAD CP study reported in this paper, the SA questions were administered verbally at opportune times.

3.3 Goal-Directed Task Analysis

The SA probes, which cover all aspects of SA, are based on the information requirements for SA in the particular domain. Goal-Directed Task Analysis (GDTA) was conducted to find out what SA entails in the GBAD environment (Endsley, Bolte and Jones, 2003). As may be expected, the SA elements for the GBAD CPO are different from those of the Det Comds, due to their different functions. The GDTA requires the identification of a hierarchy of major goals and sub-goals for the GBAD CPOs and Det Comds. To obtain the information, structured interviews were conducted with Army personnel from the 16th Air Defence Regiment. For each sub-goal, the decisions that have to be made to achieve the sub-goal are then determined. Subsequent to this, the information required to make the decisions in accomplishing each sub-goal is established. Thus all the boxes shown in Figure 1 need to be filled.

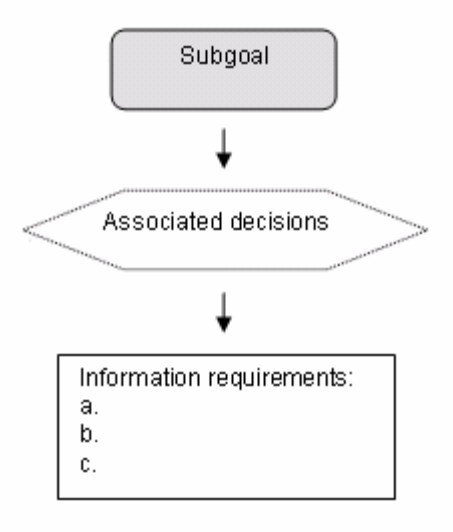

Figure 1. Subgoal-decision-information requirement structure

The results of the GDTA show that as part of his responsibility to fight the air war, the GBAD CPO needs to have knowledge of the status of the weapon detachments under its control and the way the detachments are organised to respond to enemy activities. He also needs to have good understanding of the tactical environment with regard to enemy and friendly forces in both the air and land domain. All of these, as well as matters concerning logistics, personnel in the CP, electromagnetic signature and communication are part of the GBAD CPO's SA.

Each Det Comd is concerned with similar issues as the CPO but at a more limited scale. The main focus is the tactical air environment; avoiding fratricide is one of the major goals. The Det Comd has to ensure that the system is ready to respond to enemy activities, particularly in the sector assigned to him and the adjacent ones. Clearly he has to have good knowledge of the status of the weapon and equipment as well as other issues such as logistics, personnel, communication and electromagnetic signature.

To validate the results of the GDTA for the Det Comds and GBAD CPOs, two focus groups discussions were held. During the discussions, each part of the goal structure was shown and the participants were invited to provide feedback. Issues were discussed, changes to the information on the goal hierarchy were made if required until a consensus was achieved.

The SA probes or questions were then developed based on the information requirements identified in the GDTA. The pool of questions covered the SA elements already mentioned. The questions were divided into two categories, one set contained questions directly relevant to the air war, the other was concerned with the other issues.

3.4 Data Collection

3.4.1 Command Post Officers

During the trial, two GBAD CPs were set up next to each other. Both CPs were equipped with radio communication, in accordance with the current practice. However, one of the CPs, the 'enhanced CP', was also provided with digital display. The personnel had been provided with the training to use the digital system prior to the exercise.

During the study, which lasted for four days, the researcher was assisted by an SME, an Army Major who had extensive experience in the Air Defence Regiment. Practice runs for data collection were made in the first day and a half. The data collection process began by the SME informing the CPO that he was required to answer SA questions. The researcher read out a question from the list, which had been previously agreed upon by the SME. The CPO answered the question, which was immediately scored by the SME on a scale from 0 to 10 and recorded on a pre-prepared scoring sheet. The correct answers for level 1 SA questions were obtained by the SME from the digital

display. A total of six questions, two for each SA level, was asked. The verbal interactions were taped on a voice recorder. Immediately after completing the SA probing with one CP, the researcher and SME went to the other CP, where the questioning process was repeated. Attempts were made to ask the same six questions, although this was not always possible. No particular order was applied in questioning the two CPOs.

The air war questions were asked when air raids were taking place. The operational tempo was high and the verbal method for data collection minimised the time required by the CPOs in answering the questions. It was also decided to allow the CPOs to look at the track information while responding to the SA probes, by means of the digital display in the enhanced CP and the manually hand drawn chart in the non-enhanced CP. It would have been unreasonable to expect the CPOs to commit to memory all the aircraft movements information. As the study was part of a larger exercise, the activities were not 'frozen' during the data collection and the situation kept evolving. This was another reason for ensuring that the SA probing was fast and streamlined. The issue of potential disruption to the CPOs did not occur with the non air war questions, which were asked during quieter times. During the study nine sets of air war questions and three sets of non air war questions were administered to the CPOs in the enhanced and non-enhanced CP.

3.4.2 Detachment Commanders

It proved much more difficult to collect SA data from the Det Comds. The main reason was that they were dispersed and located several kilometres away from the CPs. Restrictions on movements imposed by the exercise made it difficult to reach them. It was not possible to administer the SA probes to a Det Comd under the control of one of the CPs and then immediately repeat the process with another Det Comd under the control of the other CP. In addition the SME could not verify whether the level 1 SA question was answered correctly because he did not have the record of the events taking place. There were also other issues such as equipment malfunction and changing of personnel on different shifts. Under these difficult circumstances, five sets of questions were administered to the Det Comds under the control of the two CPs.

4 Results

The voice records containing the data were checked to ensure that the details corresponded with the written records in terms of the time of the data collection, which CPO was being probed, whether or not the assignment of the SA level was correct. Any discrepancy was resolved at this point. It was found that the data collection process took between two and three minutes.

Table 1 shows the SA scores for the CPOs in the enhanced and non-enhanced CP, and for the Det Comds under the control of those CPs. Table 2 shows the SA scores for the CPOs for the three levels of SA for the air war questions.

Table 1. SA score for the CPOs and Det Comds.

	SA SCORE*					
	CP with Digital Display			**CP without Digital Display**		
	Mean	Standard deviation	Total number of questions	**Mean**	Standard deviation	Total number of questions
CPO – air war aspects	**9.5**	1.2	51	**3.5**	3.8	51
CPO – non air war aspects	**8.6**	2.6	18	**8.6**	2.1	18
Det Comd	**8.2**	2.0	28	**6.0**	3.9	19

*The maximum score is 10.

Table 2. CPOs' score for the three levels of SA on the air war aspects.

CPO – air war aspects	SA SCORE*					
	CP with Digital Display			CP without Digital Display		
	Mean	Standard deviation	Total number of questions	**Mean**	Standard deviation	Total number of questions
Level 1 SA	**9.7**	1.1	22	**2.5**	3.3	23
Level 2 SA	**9.2**	1.5	20	**4.4**	4.3	19
Level 3 SA	**9.8**	0.7	9	**4.3**	3.8	9

*The maximum score is 10.

The frequency distribution of the scores was skewed and did not conform to a normal distribution. It was also not possible to transform the data to a normal distribution by conventional methods. Accordingly, the Wilcoxon Rank Sum test, also known as the Mann Whitney test was used. This is the non-parametric equivalent of the independent samples t-test.

It was found that significant differences exist for the CPOs' SA scores for air war aspects between the enhanced and non-enhanced CP.

- overall SA score (z=-7.400, p=0.000)
- level 1 SA score (z=-5.531, p=0.000)
- level 2 SA score (z=-3.582, p=0.000)
- level 3 SA score (z=-3.272, p=0.001)

There was no significant difference in the CPOs' SA scores for non air war aspects between the enhanced and non-enhanced CP (z=-0.176, p=0.862).

There was a significant difference in the Det Comds' SA scores under the control of the enhanced CP compared to that under the non-enhanced CP, but only at the 90% confidence level (z=-1.688, p=0.091)

5 Discussion

The results of the study show that for the air war aspects, the CPO with the digital display had much higher SA than the CPO without the display, not only for the overall SA, but also for each of the three SA levels. This is not surprising, considering that the digital display provided the CPO in the enhanced CP with a more complete and up-to-date information.

As has been mentioned before, the CPO without the digital display relied on information being provided by radio. Quite often the information was incomplete and inaccurate. For each track, ideally the information supplied should include such details as the identification (enemy, friendly or unknown), the type of aircraft, position, direction of flight, altitude. If one part of the information was not provided, the CPO did not have a complete picture. In the non-enhanced CP, when asked about the details of a particular aircraft in a zone, say the 50 km zone, the CPO often could not answer the question because he did not have the information or the information was obsolete. Indeed the CPO often had to make repeated requests for a track update with little success. In contrast, the CPO with the digital display had the complete up-to-date information in front of him, and was able to answer level 1 SA questions by looking at the display. The difference resulted in the large differentiation in level 1 SA score between the CPOs in the two different CPs.

It is apparent that the difference between the two CPs in level 2 SA (comprehension) score and level 3 SA (prediction) score was not as pronounced as that for level 1 SA. This was because the two CPs received information other than that provided by radio or through the digital display. There was a daily brief provided by the higher commander that included information on enemy activities. In addition, as the exercise progressed, there were patterns of behaviour by friendly and enemy aircraft that helped the CPO in the non-enhanced CP in his

understanding of the events. This assisted him to make threat assessments and predict what the friendly and enemy aircraft would do.

For the non air war aspects, the CPO from the enhanced CP obtained comparable SA score as the CPO from the non-enhanced CP. Again this was as expected. For the non air war aspects, the two CPs received the same briefs. The air war related information provided by the digital display was irrelevant in this case. However, the comparable scores from the two CPs indicated that there was no apparent difference in the skill levels of the CPOs in the enhanced and non-enhanced CPs. This countered the argument that the CPO in the enhanced CP might have had higher abilities than his counterpart in the non-enhanced CP which might have been the reason for the higher SA scores for the air war aspects.

Although the analysis showed that there was a significant difference between the SA score of the Det Comd under the enhanced CP, compared to that under the non-enhance CP, the result should be interpreted with caution. The difficulties in collecting the data and the lack of rigour in the data collection were mentioned earlier.

The verbal method of collecting the SA data was not inappropriate in the GBAD environment, considering that from time to time the CPOs and Det Comds had to provide a brief to their commander and answered the commander's questions. Unlike the computer simulation for which SAGAT was originally developed, where the operator was totally focused on the task during the scenario, the CPOs worked in a frenzied environment. Many matters required their attention during the day. Thus the data collection process that took two to three minutes each time did not appear to faze or interrupt them unduly.

Strong team interactions were observed in the GBAD CPs. The staff communicated freely with each other with no apparent restrictions imposed by ranks. The information provided by the radio, irrespective of its accuracy or completeness, was heard by everyone in the CP tent. This and the verbal exchanges allowed the staff in the CP to gain and maintain SA to some degree. The provision of digital information restricts the number of people who have ready access to that information and may inadvertently reduce team SA. This is an issue that has to be addressed in NCW capability.

6 Concluding Remarks

The DQT was successful in providing empirical data that showed the SA of the CPO in the enhanced CP was higher than that in the non-enhanced CP for air war aspects. It was also shown that the SA of the Det Comds under the control of the enhanced CP was higher than that under the control of the non-enhanced CP.

The advantages of networking in NCW capability have been extensively extolled. However, many human factors issues need to be addressed to ensure that the system supports the humans in the warfighting activities. These include such matters as battlespace information display; data fusion; automation and decision support systems; training; co-located and distributed teamwork, team performance, team SA, shared SA, shared mental models; collaboration within and between teams; cultural and organisational issues. As part of the research endeavour, there is an urgent need to develop metrics for shared SA, shared decision making and performance. These will assist in conferring rigour in NCW experimentation.

7 References

Alberts, D.S. (2002). Information Age Transformation: - Getting To A 21st Century Military. Washington DC: CCRP.

Endsley, M.R. (1995a). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors*, 37, 32-64.

Endsley, M.R. (1995b). Measurement of Situation Awareness in Dynamic Systems. *Human Factors*, 37, 65-84.

Endsley, M.R., Bolte, B., & Jones, D.G. (2003). Designing For Situation Awareness – An Approach to User-Centered Design. London: Taylor & Francis.

French, H.T., & Hutchinson, A. (2002). Measurement Of Situation Awareness In A C4ISR Experiment. In *Proceedings of the 7th International Command and Control Research and Technology Symposium*. Quebec City, Canada: CCRP.

Guille, M.C., & French, H.T. (2004). *Toward a Methodology for Evaluating the Impact of Technologies on Infantry Situation Awareness*. DSTO-TR-1628. Edinburgh: DSTO Systems Sciences Laboratory.

Scott, W.B., & Hughes, D. (2003). Nascent Net-Centric War Gains Pentagon Toehold. *Aviation Week and Space Technology*, 158(4), 50-53.

Vergun, D. (2001). On-Scene Report: Kernel Blitz (Experiment) 01 - An incredible Level of Situational Awareness, *Sea Power*, 44(8), 54-57.

8 Acknowledgement

The author would like to thank the personnel from 16th AD Regiment, Woodside, without whom this work would not have been possible. The invaluable assistance and support from Taryn Elliott, MAJORS John Fry, David Ferguson and Brian Yates is also gratefully acknowledged.