Assessing Human Factors in Command and Control: Workload and Situational Awareness Metrics

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Abstract

The effects of digitized command and control on commanders' workload and situational awareness (SA) were experimentally investigated in a simulated battlegroup scenario. Military participants acted in pairs to lead the planning and execution of a land reconnaissance operation, controlling the deployment of various units and sensor assets to find and fix an enemy. The subjects performed two versions of the exercise: one in which all communications between the HQ and its battlefield units occurred using the standard voice radio net, and a second version in which most of the interactions were either augmented or replaced with digital technology such as data-link, text messaging and automatic location reporting. During the execution phase, the command teams responded to various measures of workload and SA, described in the paper. These data, backed up with subject debriefings, provided several key insights into the impact of digitization. For example, it appears that the automatic presentation of enemy positional data reduced the depth to which commanders mentally processed incoming sighting information, thus reducing their sense of confidence in understanding the enemy picture. The pros and cons of the measures used are discussed, along with lessons learned.

Introduction

To maximize the probability of mission success, the military commander must construct and then implement effective courses of action, and do so at a faster pace than the enemy. In the heat of battle, however, critical decisions may have to be made under conditions of great uncertainty, the inevitable 'fog of war'. One of the main factors affecting the tempo of action is the commander's need to reduce uncertainty, to visualize the battlefield and to anticipate future events by achieving accurate and up-to-date situational awareness (SA).

Battlespace awareness results from the fusion of explicit elements of information about factors such as terrain composition and enemy capabilities. Pre-battle intelligence assessments provide the commander with assumptions about the battlefield environment and the threat situation. As the battle progresses, intelligence, surveillance, target acquisition and reconnaissance (ISTAR) processes are further used to continuously track the situation. If there are dramatic or unexpected changes, a new iteration of the decision-making process may be called for.

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Good SA is achieved and maintained through the effective use of sensor assets. Part of the commander's role in this is to direct the sensor capabilities of the units and assets under his command, specifying the information that should be obtained to support his plan of action. Co-ordination and communication within this complex process has normally been achieved by voice radio contact between soldiers on the ground and the commander's HQ. Sub-unit leaders (e.g., company commanders) are required to provide the HQ with verbal status reports, often in coded form, detailing things like present location, progress on task objectives, and any enemy sightings. In the army context, the HQ staff will track the course of events by marking up the latest known positions of own forces and enemy sightings on a transparent sheet overlaying a large map of the battle area (Figure 1). However, the flow of information in this labour-intensive process tends to be sporadic and fragmented, providing the commander with only scattered snapshots of the battlespace. With the increased tempo of modern operations, there is a need for faster and easier communications.

Fig 1: Marking up the current battlefield situation

Battlespace digitization

Digital communication and information technologies promise to revolutionize the way in which military commanders conduct operations in the battlefield. Digital communication and data processing technologies could radically improve the intelligence-handling aspect in particular by automating much of the data encoding, decoding and exchange between the soldier on the ground and the command centre. In theory, an integrated digital infrastructure should give the commander significant advantages in terms of faster communication, greater message security, easier intelligence sharing and speedier decision-action cycles, enabling him to think and act more quickly than the enemy.

It is also commonly argued that greater use of digitization can bring psychological advantages, reducing human workload and enhancing situational awareness, thereby improving the performance efficiency and effectiveness of the commander and his staff. Despite the promise, however, we must take care to minimize the risk of new, perhaps unforeseen complexities arising for the human user through the introduction of the new technology. Experience in various domains shows that bringing new technology into an 'old system' can introduce unforeseen side-effects on workload and SA, such as a sense of being out-of-the-loop, which can have an underlying negative effect on performance. One conceivable risk, for instance, is the possibility that by dramatically increasing the sheer volume of low-level data available to HQs and their sub-units, this could actually confuse rather than enhance the SA of commanders as well as their subordinates. Or if the rate of incoming data is high, the HQ staff could conceivably be over-burdened with the task of having to make sense of it all, thereby raising workload levels.

The issue to be addressed here is twofold. First, there is a need for proper experimentation to investigate such issues in a valid C2 context. Second, there is a need for reliable measures of workload and SA in the conduct of C2 tasks within such experimental research. With these issues in mind, we describe an experimental study of digitized command and control in a battlegroup HQ using a synthetic environment (SE) and other battlefield simulation technology. We focus on the techniques that were used to assess the subjects' workload and situational awareness, the results that were obtained and the lessons learned for future research of this nature.

The ISTAR-SE Experiment

Battlespace simulation

BAE Systems is developing a synthetic environment (SE) capability to simulate complex military systems of systems. The facility combines a battlespace communications model with distributed interactive simulation, enabling simulator systems located at different places to operate in an integrated fashion within the same computer-generated environment, including representative terrain, vehicles, buildings and so on. These capabilities were exercised in an initial proof-of-concept study, set up by the company's Future Systems Group, to implement a functional simulation of battlespace digitization in a realistic ISTAR context involving reconnaissance tasks. The ISTAR-SE experiment, as it was known, also served as an opportunity to develop ways to investigate human factors issues such as workload and SA.

Methodology

An army tent was set up to simulate a battlegroup HQ. The HQ was connected by both telephone and intranet links to facilities at various sites, where staff played different roles within the simulation. Inside the tent, military officers acted in pairs, one as battlegroup Commanding Officer (CO), the other as an assisting Operations Officer (Ops). Fourteen military participants took part, providing seven teams in all. They were aged 25-37, and consisted of two lieutenants, four captains and eight majors, with an average service length of 10.5 years. About half had served in actual conflict. All were drawn from a training course being held at the Royal Military College of Science (RMCS), Shrivenham, UK. In addition to the military subjects, two research staff inside the HQ played the role of radio operators, relaying messages between the subjects and other role-players.

Each commander led the planning and then execution of a 2-hour land reconnaissance operation as part of an advance-to-contact mission, controlling the deployment of various units and sensor assets to find and fix an enemy. A special feature of the exercise was that the battlegroup commanders had direct control over the use of the available reconnaissance assets. These consisted of various configurations of ground armoured reconnaissance vehicles and an unmanned air vehicle (UAV), all operating within the same synthetic environment.

The subjects performed two versions of the exercise:

(a) a ‘conventional’ version in which the sole means of communication between the battlegroup HQ and its battlefield units was a standard voice radio net, and

(b) a ‘digital’ version in which

- all interactions were conducted via a digital data-link,
- electronic text messaging replaced voice radio,
- blue unit positions were automatically relayed at regular intervals to the HQ, and
- a computer-generated map display in the HQ provided the commander with a graphical picture of the latest known red and blue unit positions (Figure 2).

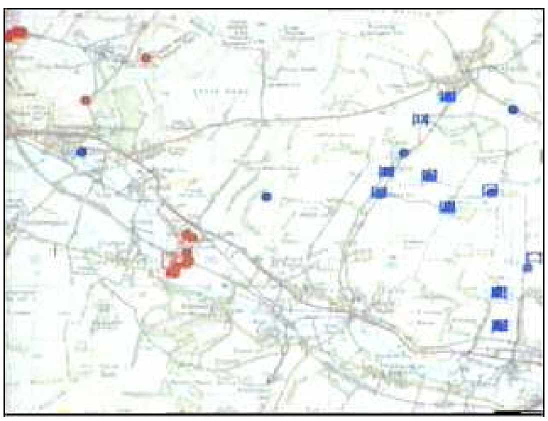

Fig 2: Electronic map display showing own unit locations (blue) and enemy sightings (red)

Human factors measures

To investigate issues of operational effectiveness and its correlates, the Human Factors data obtained in the experiment consisted of the following measures of performance, situational awareness (SA) and mental workload:

- Timing data (time to first enemy sighting, task completion time)
- Expert observer's performance assessments
- Subjective SA self-ratings
- Objective SA analyses
- Subjective workload self-ratings
- Subjective workload analyses

In addition to these measures, transcripts were made of the subjects' comments positive, negative or otherwise   during structured debriefing sessions.

Situational awareness

Subjective SA ratings were taken at 40 minute intervals using the Crew Awareness Ratings Scale (CARS; see McGuinness, 1999; McGuinness and Foy, 2000). This is a generic 8-part questionnaire addressing both the mental content and mental processing of SA with regard to four separate functions:

1. **Perception**, the assimilation of new information
2. **Comprehension**, the understanding of information in context
3. **Projection**, the anticipation of possible future developments
4. **Integration**, the synthesis of the above with one's course of action

For each of these four functional aspects, subjects were asked to rate:

a) The **content** of that aspect: Is it reliable and accurate?
b) The **processing** of that aspect: Is it easy to maintain?

Note that the ratings were given on a 4-point scale ranging from (1) the ideal case to (4) the worst case. Note also that, given the emphasis on ISTAR assets, it was decided at the outset to focus on the teams' awareness of the *enemy* picture. With hindsight this turned out to be an error, as will be discussed below.

The subjective ratings of SA were supplemented by the use of customized 'mini situation reports' or *mini-sitreps* to provide a more objective analysis of the CO's current understanding of the actual situation. Each mini-sitrep asked the CO to briefly summarize:

- Current enemy positions
- Assessment of enemy intent
- Assessment of current operation
- Assessment of future developments/outcomes
- Any deviations from or changes to original plan

These were given to the CO twice per exercise, at the same time as he was asked to give subjective SA ratings.

Workload

To assess the subjects' mental workload in the two conditions, two approaches were taken. One was to record a profile over time of subjective workload self-ratings taken at regular intervals (2 mins). This instantaneous self-assessment (ISA) technique provided profiles of subjective workload as it fluctuated over the course of the exercise for each individual. Two response entry devices or 'button boxes' were installed in the HQ, one for each subject. These consisted of five coloured buttons, each representing a different level of workload:

- red = max
- yellow = high
- white = fair
- green = low
- blue = min

The second approach was to obtain a further post-exercise breakdown of subjective workload using the NASA-TLX (Task Load Index) tool. This provided insights into how the workload was specifically experienced by the subjects, e.g. as primarily mental demand or physical demand.

Secondary-task measures of workload and physiological indices such as heart-rate variability were not used, as these were deemed to be overly intrusive for this particular study.[1]

Debriefs

The subjects' experiences and opinions were further explored in structured, post-trial debriefing sessions. These provided useful insights into the experience of performing with C2 digitization.

SA results

Recall that the CARS subjective ratings are for awareness of the enemy situation. These measures showed that the content ratings gradually improved, perhaps earlier for the CO than for the Ops Officer. Ratings for SA processing, on the other hand, were fairly consistent over time. For an overall breakdown of the different aspects of SA (perception, comprehension, projection and integration), see Figure 3. Note that Commanders (perhaps not surprisingly) were particularly strong on "knowing what to do", i.e. the integration aspect.

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[1] In subsequent experiments with the Army, however, we have made use of wrist-mounted motion monitors to provide profiles of physical activity over time.

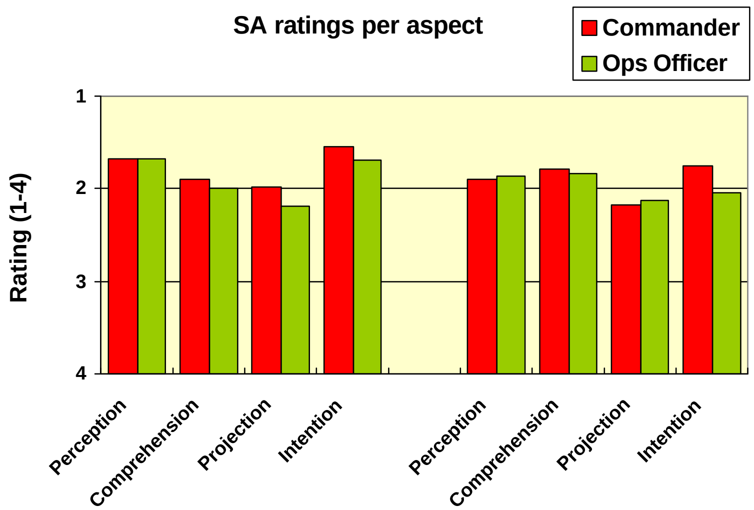

Fig 3: CARS ratings for each aspect of SA

There were no major differences between the digitized and non-digitized conditions in terms of CARS *processing* ratings (i.e., the ease or difficulty of making sense of the data). However, CARS *content* (i.e., confidence in awareness) was generally rated slightly higher in the digital condition by both team members. The only exception to this was for the CO ratings of *comprehension* content (understanding the enemy picture), for which the ratings were higher under the conventional condition. This was found to be the opposite of the Ops' ratings, and suggests that the COs felt less confident in their understanding of the enemy picture with the digital systems. It appears from the debriefs that the automatic presentation of enemy positional data reduced the depth to which incoming information had to be mentally processed, thus reducing the commanders' degree of involvement with the information flow and reducing their sense of confidence in the enemy picture.

Although no dramatic subjective advantage was reported for digitization as far as the self-ratings of enemy awareness are concerned, there were sometimes impressive differences in terms of the commanders' ability to report the enemy situation. Figure 4 shows an example of sitreps obtained from one CO under each condition, and highlights a difference in the precision of reporting under each condition. (Note that commanders did not refer to sighting logs when writing their sitreps, but did confer with the Ops officer.)

	Conventional	Digital
Area 1	*"Couple of BMPs"*	*"1x BMP, 5x mortars, 1x tank"*
Area 2	*"BMP, truck"*	*"4x unknown vehs, 2x BMPs, 1x tank"*
Area 3	*"unknown veh"*	*"3x BMPs, 2x mortars"*
Area 4	*"need more info"*	*"4x ATWs, 3x BMPs, 2x tanks, 1x inf"*

Fig 4: Examples of sitreps
(type and number of enemy sightings per area of interest)

There was no reference to this apparent benefit in the debriefs, so it is unlikely to reflect a difference in the memory of the COs. Rather, the sensor operators tended to make their sighting reports more precisely worded when using electronic text messages, so the COs had more exact information to go on. That is, the digital system influenced the users' reporting behaviour. It is also possible that information is more easily eroded when messages are received and passed on by voice. Some are misheard, some are forgotten, some are lost – problems that are unlikely with digitization.

Workload

The ISA workload ratings given during the exercises varied substantially amongst individual subjects (e.g., Figure 5). This is partly because the distribution of workload between the roles of the CO and Ops varied between teams, with some teams distributing the workload evenly between the two roles and others placing more workload on one team member. However, a general trend that did emerge indicates that the workload of the Ops tended to increase quite early during the mission and then drop off again towards the end of the mission, whereas the workload of the CO tended to increase steadily as the mission progressed. This is attributed to the fact that the CO was required to prepare a final report that summarised the enemy situation and proposed the future Course of Action.

Fig 5: Example workload profiles for one team.
Top = CO, bottom = Ops.

Generally, the subjects felt that the workload experienced during the experiment was relatively low. In the debrief, subjects stated this was because many of the other functions that would normally be performed were not represented in the experiment. For example, the CO/Ops Offr would normally have to liaise with a Battery Commander regarding the use of artillery; he would also liaise with a BG Engineer regarding the use of the BG engineering assets. These activities would normally be performed in addition to managing the reconnaissance assets and would tend to increase the levels of workload experienced.

Generally, the COs' level of workload exceeded that of the Ops Offrs. Subjects with more relevant experience tended to assume the role of CO in the experiment and perhaps the lack of experience of some of the Ops Officers may have added to the workload experienced by the COs.

The main TLX factors contributing to the workload experienced during the trials were *mental demand, temporal demand, effort* and *frustration*. From Figures 6 and 7, it also appears that the overall workload of the COs was lower in the digitized condition, however the overall workload of the Ops Offrs was about the same for both conditions.

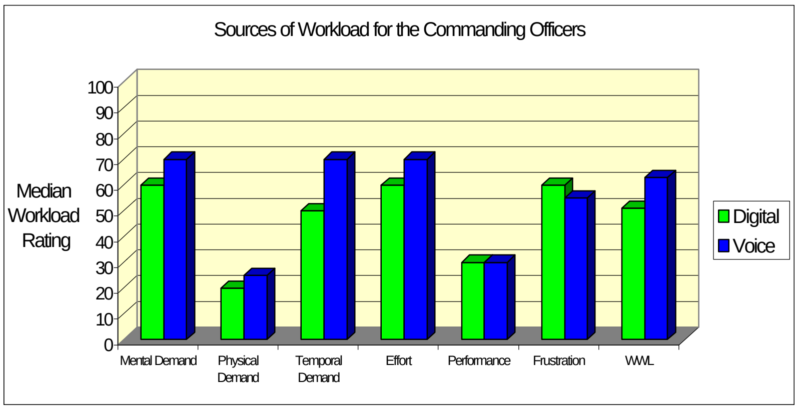

Fig 6: Sources of workload for COs in both conditions

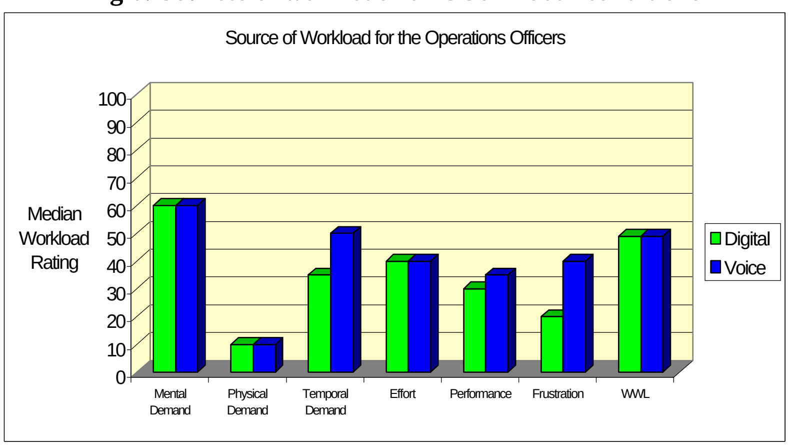

Fig 7: Sources of workload for Ops in both conditions

Lessons learned for digitization

The main benefit of digitization was the direct visibility of the current locations of own forces, including the ability to access those positions immediately and accurately. All subjects liked being able to see a visual display of the actual blue positions. Other findings:

- Being able to obtain an instant and accurate readout of a unit's grid reference eliminated the need for a lot of radio traffic taken up with acquiring loc-stats.

- Some voice reports were misheard, some were forgotten, some were lost. These problems were virtually eliminated with digitization.
- Digitization relieved the command team from having to mark everything up on the map.
- Some communications were speedier with digitization in that senders did not have to wait for an opportunity to transmit, and incoming reports did not have to be received in sequence.
- Conversely, outgoing messages appeared to be slower by text than by voice.
- Digital, non-voice interaction was good for assessing and controlling the situation in routine, low-tempo phases. However, it became a liability in critical, high-tempo phases.
- The Commanding Officer could not impose authority via text messages. In other words, he was unable send his orders immediately or to convey any direct sense of urgency, and unable to be 'assertive'.
- Text messaging could not give the listener a sense of the psychological state of the sender (e.g., relaxed or stressed).
- The Commander could not readily check/confirm the orders that were being sent out as intended; there was no implicit audio feedback as with voice radio.
- The digital system presents the Commander and Ops Officer with a pre-processed picture of the situation and this reduces the need for complex mental processing. While this probably reduces workload and the risk of error, it also reduces the depth of processing performed by the users, which leaves them potentially less involved/engaged/immersed in the situation.

Overall, users would not want digitization to replace voice radio communications, but to supplement it.

Evaluation of measures

Two problems emerged with the SA assessments. One was that we should have addressed more than just the enemy situation in both the subjective and objective data collection. It transpired in the debriefs that digitization may have had a particularly positive effect upon awareness of the friendly (blue) situation. We were unable to confirm this with the SA data we obtained. The second problem was that due to extraneous circumstances we lost access to the resident subject-matter expert (SME). This meant that we were unable to analyse the subjects' mini-sitreps (the intention had been to compare completed reports with objective ground truth as observed and interpreted by the SME). Being unable to do so was unfortunate as there sometimes appeared to be distinct differences between the conditions in terms of the COs' ability to report the enemy situation accurately.

The ISA technique was useful in generating workload profiles and allowed closer scrutiny of the distribution of workload throughout the missions. Some difficulty was experienced initially with the technique because of the placing of the ISA button boxes in the HQ. Consequently, in the pilot studies some subjects failed to provide ratings when prompted. This problem was resolved in the main trial by emphasising during the briefing that the

ISA prompts should be visible to the subjects at all times.

Conclusions

The design of the experiment provided, on the whole, a sufficiently realistic framework within which the subjects could adequately employ their C2 skills and responsibilities. With regard to digitization itself, the reported pros and cons were more or less as anticipated, but there were also some surprises. The workload and SA metrics used were mostly (though not completely) successful in providing both data and insights into the impact of digitization. Individuals' workload and SA data were often an extremely useful focusing point for discussion in the debriefing sessions. With hindsight, less emphasis should have been placed on assessing awareness of the *enemy* situation; a broader look at commanders' battlespace awareness may have been more informative. The main issues to emerge from the structured debriefs were:

- the information flow during routine phases versus high-intensity phases;
- commanders' appreciation of blue and red positions;
- commanders' awareness of the psychological state of recce asset operators;
- commanders' ambient awareness of incoming and outgoing messages;
- commanders' mental processing of incoming battlefield data.

Our aim in this study was to devise ways of exploring the human factors issues of battlespace digitization within a realistic simulation. The methods used served this purpose well, and provided useful insights into the implementation of digitized communications. In conclusion, we hope to have demonstrated methods and techniques for the systematic investigation of human factors issues in a C2 context, along with the sorts of insights to be gained from the results of such research.

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