Supporting Distributed Sensemaking in Command and Control

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SUMMARY

Distributed sensemaking (DSM) is an important concept in the development of command and control for the future military operating environment. Following from earlier work developing DSM principles and DSM measures, this paper reports on a lab-based experiment which collected data on approaches to support DSM.

KEYWORDS

Distributed Sensemaking, Command and Control, Defence

Introduction

Distributed sensemaking (DSM) is the process through which teams of humans, or humans and agents/machines, who might be geographically or temporally separated from each other, seek to explain, understand, or otherwise make sense of a situation under uncertain or ambiguous conditions for informing a course of action or decision (Attfield et al., 2015). In this respect, the word 'distributed' is used in a similar manner to that in Hutchins's (1995) concept of distributed cognition or Stanton et al's. (2013) distributed situation awareness, i.e., that the activity (sensemaking, cognition, situation awareness etc.) is performed by a system in which individual agents have differing access to information. Unlike sensemaking at the individual level (Klein, 2013), DSM focuses on sensemaking through multiple agents and artefacts. For example, within a naval ship's Operations Room, different operators receive and monitor different types of information about objects within the local airspace. These might include position, range, bearing, height, radar type, and any radio communications. To make sense of these pieces of information, a coordinated discussion is conducted (referred to as an Air Investigation Process) in which each operator reports in turn, concluded by an assessment by a senior officer. Whilst individual sensemaking has been widely studied (eg Klein, 2013), DSM is a relatively immature concept (Elliott et al., 2020). This paper summarises an experiment which builds on earlier work on DSM (Baber et al., 2022) to provide an experimental investigation of approaches to support DSM.

Military teams working on the same Command and Control (C2) task can be in geographically and temporally separate locations, with access to different information and systems, and using a range of artefacts to support thinking and sharing of information. Distributed Sensemaking (DSM) is critical as the military Future Operating Environment is likely to place additional cognitive demand on individuals in teams who are conducting already complex C2 (Black et al, 2024). This could be exacerbated by increases in available information through new systems being adopted and technological advances, along with increasing potential threats and the expansion of battlespace domains to include cyber and space (Development, Concepts and Doctrine Centre, 2017).

Previous work by our team defined nine principles for DSM. They were developed by conducting a literature review around the idea of 'barriers and facilitators for DSM', and the identification of phenomena relating to tools, strategies and resources that can enhance or limit sensemaking with a focus on distributed collaborative settings. The principles, which have been used in the development of DSM interventions for this work, are: 1) Provide sufficient cues for sufficient sensemaking; 2) Support low cost information workflows; 3) Represent information quality and provenance; 4) Promote expertise/domain knowledge; 5) Allow time to acquire data/information to build an evidence-based and coordinated situation picture; 6) Use strategies for the negotiation of sense; 7) Where appropriate, use strategies for frame enumeration and elimination; 8) Provide explanatory context for actions, orders and requests; 9) Minimise the costs of achieving and maintaining common ground.

As sensemaking involves a 'quest for coherence' then an essential aspect of sensemaking in a team is the maintenance of common ground. In this study, we explored a simple intervention to support common ground, where establishing common ground involved a group discussion, based on techniques developed Berggren et al. (2017) and Santos et al. (2021). The method was down-selected from a range of interventions developed and discussed with experienced military personnel using the nine principles of DSM. The study also explored an interface design intervention which could have an impact on common ground. Both the interventions were related to the 9th DSM principle: Minimise the costs of achieving and maintaining common ground. The experiment used the C3Fire[1] microworld environment (Johansson et al., 2003) in which a grid-world simulation of forest fires requires a team to respond by extinguishing the fire and moving people to safety. This provides a sufficient challenge to teams while allowing experiments to be conducted in a relatively short (i.e., less than one hour) trial for each condition.

Method

The experiment was designed to answer several research questions (RQ) relating to DSM and its measurement. For the purposes of this paper, we focus on: RQ1: How does a simple intervention designed to support teams in establishing common ground and negotiation of sense impact upon team performance? RQ2: How does a computer interface designed to support DSM impact upon team performance?

Participant recruitment and informed consent processes were reviewed and implemented as part of the Ministry of Defence Research Ethics Committee Process (Ministry of Defence, 2022). 36 participants were recruited for the study and they worked in 12 teams. Teams were made up of either three military or three civilian participants, recruited based on availability from the UK armed forces and the Defence, Science and Technology Laboratory. Various demographic features were collected for participants but only analysis by job role (military versus civilian) is presented in this paper.

A range of measures of participant and team performance were collected during each scenario run. This paper focuses on the measure of C3Fire performance, which is the number of microworld inhabitant casualties for each C3Fire run. The experimental day experienced by the teams of

[1] www. C3Fire.org

participants, for both the common ground intervention and the associated control condition, is summarised in Table 1.

Prior to each scenario each participant was presented with a different short newspaper article. Two of the articles provided cues and clues as to locations of groups of inhabitants for that scenario and the third was a ‘decoy’ which did not contain information on inhabitant locations. Deciding the relevance of the articles was one DSM challenge for participants during each scenario run. The second DSM challenge came from the C3Fire simulation, as the participants needed to work together to understand the locations and spread of fires and the locations of inhabitants in the microworld. All of these elements had emergent properties as the simulation developed. Participants needed then to work as a team to make sense of the developing patterns to consider future courses of action and implement plans to achieve the goals of C3Fire.

The experiment had a mixed design, with three C3Fire user interface designs as a within participant factor and the intervention supporting team establishment of Common Ground (termed the ‘common ground intervention’ in this paper) as a between-participant factor. The experiment, including training, lasted a day for each team of three participants, carrying out three experimental runs using three different C3Fire scenarios following training. The sequence of scenarios and interface conditions presented to participants were rotated using a Graeco-Latin Squares design to reduce order effects. As this was a team-based study with three participants in a team, the team was treated as a single unit of analysis in terms of the high-level design, and the three team members experienced the same simulation scenarios and measures at the same time. The teams were physically distributed during the trial runs as they had their own computer interfaces and only communicated verbally from physically separated locations via a radio system.

Table 1: Overview of Experimental Day for Participants

<table>
<tr><th>Session</th><th>Common Ground Intervention</th><th>Control Condition</th><th>Duration (minutes)</th></tr>
<tr><td rowspan="2">Training</td><td colspan="2">Introductory briefing and informed consent process
Radio system training
C3Fire training
3 practice C3Fire simulation runs including a 15 minute break</td><td rowspan="2">150</td></tr>
<tr><td>Training on common ground intervention</td><td>Training on control task</td></tr>
<tr><td>Lunch</td><td colspan="2"></td><td>30</td></tr>
<tr><td rowspan="6">Experimental session 1</td><td colspan="2">Team plan for scenario</td><td>5</td></tr>
<tr><td colspan="2">C3Fire simulation run with1st interface/scenario combination</td><td>25</td></tr>
<tr><td colspan="2">Completion of study questionnaires (not reported in this paper)</td><td>10</td></tr>
<tr><td>Completion of individual element of common ground intervention</td><td>Completion of individual element of control task</td><td>5</td></tr>
<tr><td colspan="2">Feedback to team on C3Fire performance in simulation run</td><td>5</td></tr>
<tr><td>Completion of group element for common ground intervention</td><td>Completion of group element of control task</td><td>10</td></tr>
<tr><td>Experimental session 2</td><td colspan="2">Repeat of process described for experimental session one but with 2nd C3Fire interface/scenario combination</td><td>60</td></tr>
<tr><td>Break</td><td colspan="2"></td><td>15</td></tr>
<tr><td>Experimental session 3</td><td colspan="2">Repeat of process described for experimental session one but with 3nd C3Fire interface/scenario combination</td><td>60</td></tr>
<tr><td>Debrief session</td><td colspan="2"></td><td>30</td></tr>
</table>

During scenario runs participants worked together in the C3Fire microworld with the goal of saving the lives of as many microworld inhabitants as possible. Figure 1 shows the C3Fire interface which displays a grid-based map. For each trial, the team was presented with the same environment which included named forests, towns (consisting of several buildings) and campsites. However, the view of the environment differed across conditions (see next section).

Each participant controlled a set of assets in the C3Fire environment. Participants moved their assets around the environment using the computer mouse. Assets appeared on the map as coloured numbers: red: fire trucks, which put out fires by deploying water and can replenish their own water supplies; blue: water tankers, which collect water and use it to replenish fire trucks; green: rescue vehicles, which move people with the aim of preventing their exposure to fire. The three participants in each team were randomly assigned the following roles and resources: Ground chief Alpha: three fire trucks; Ground chief Bravo: two water tankers and two fire trucks; Ground chief Charlie: one fire truck and two rescue vehicles. The split of assets between participants meant that they needed to coordinate and communicate to achieve the tasks goals. A leader role was not defined.

Inhabitants in the microworld were not visible on the C3Fire map but the number of occupants of a building or campsites could be discovered by moving an asset onto the appropriate grid square. Fires, when burning, were indicated by squares turning red. If the fire was extinguished by a fire truck the square turned brown, but if the fire burnt out by itself the square turned black. Microworld inhabitants at locations which burnt out became casualties. The speed and direction of the spread of fire was impacted by wind speed and terrain type (e.g. forest vs. buildings).

The objective of the team was to minimise the number of casualties. This could be achieved by extinguishing fires or moving people to areas of safety using rescue vehicles. As the inhabitants were not visible, another key task was for participants to search to identify participant locations.

When fires started, their location was communicated to participants. Pairs of fires were started five minutes into each scenario and were extinguished after twelve minutes and 30 seconds. A second pair of fires started 15 minutes and 30 seconds into the scenario. Three different scenarios with different maps (i.e. different town/forest names), population distributions and fire start locations were created and a different one was used in each experimental run.

For the Common Ground intervention, participants were given five minutes to write (on Post-it notes) responses to the following prompt: “Thinking about the simulation run just completed: Describe three aspects of planning/acting in the C3Fire environment which are important for the team to reach their shared goal. Write each one on a separate post-it by yourself. For each one, describe why it is important.”

Participants then had 10 minutes to share responses around a whiteboard with the following instruction: “Put the post-its on the whiteboard. Discuss and review the post-its. Rank the post-its as a group in the order of importance for reaching the shared goal of saving as many lives as possible. Higher rankings go higher up the whiteboard.”. This discussion was facilitated to ensure that each step (placing Post it notes on the whiteboard, discussing these, ranking the Post it notes, and agreeing the resulting order) was performed consistently across teams. For the control condition participants had the same amount of time for personal and group reflection on each C3Fire run when just completed.

User Interface conditions

There was a within-participant independent variable of interface design. All participants experienced three different levels of interface information over three trial runs presented on their interactive maps:

- *Unit only view*. Participants could see other participant units and fire only when these were within eight grid squares adjacent to a unit they control (see Figure 1).
- *Shared unit view*. Participants could see all units controlled by all team members, but fire was only visible within the eight grid squares around each unit.
- *God's eye view*. Participants could see a full world view including all fires and units (see Figure 1).

The interface differences may increase the demands on distributed sensemaking. With the *unit only view* information is more distributed across the team, with information on unit location and fire location needing to be shared verbally by team members. In contrast the god's eye view means that unit and fire location information is shared between team members on the display.

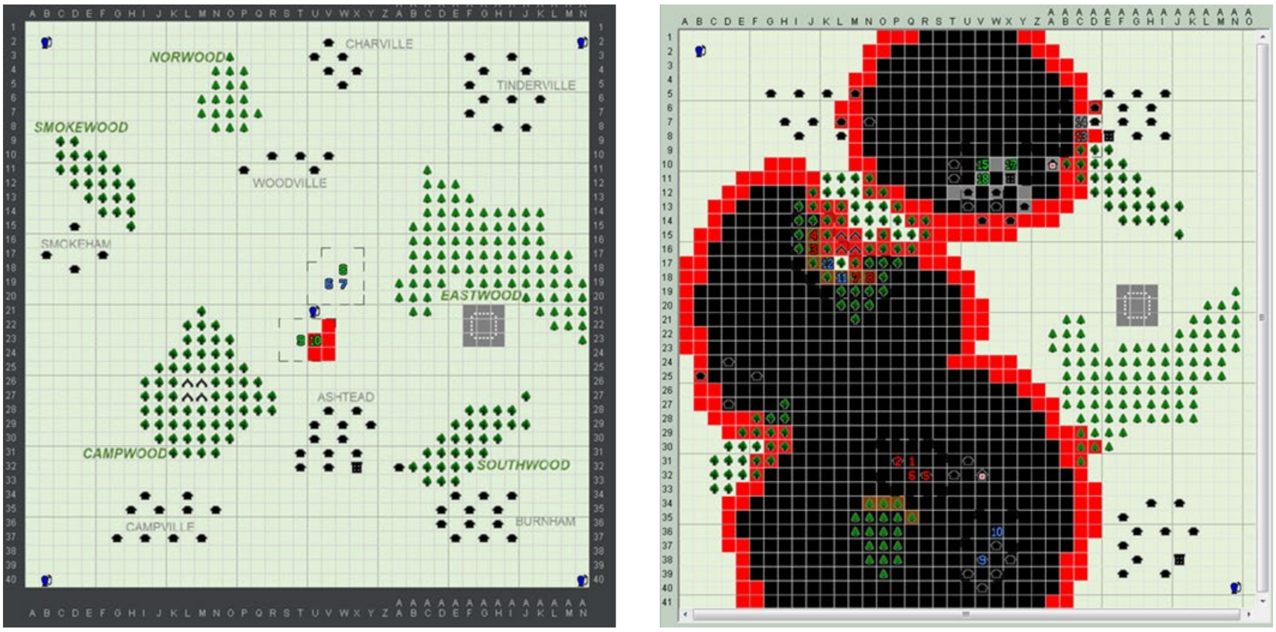

Figure 1: C3Fire Interface Unit Only View and C3Fire God's Eye View

Results

For the 12 teams who participated in the study, seven were made up of military personnel and five were made up of civilian personnel. No significant differences in performance measured by number of C3Fire casualties were found between military ($M = 31.8$, $sd = 55$) and civilian ($M = 31.4$, $sd = 37$) participant teams. Thus, any comparisons reported in the results have disregarded whether the participant was military or civilian. Originally 18 teams were planned for the study, based on statistical power calculations. It was not possible to source all these participants and therefore there is an increased likelihood of Type II statistical errors in the statistical analyses.

Common Ground and Interface Type

A mixed (common ground intervention x user interface condition) ANOVA showed no significant interaction between the two manipulations on number of casualties [$F(2, 34) = 1.023$, $p = .365$]. However, as Figure 2 indicates, there was a significant main effect for the interface view [$F(2, 34) = 4.912$, $p = .01$] showing that as the common visual information available increased, the average number of casualties decreased. Whilst there was no significant main effect for the common ground intervention [$F(1, 34) = 3.078$, $p = .088$], independent t-tests revealed there were significantly fewer casualties in the common ground intervention compared to the control condition within the shared unit interface view [$t(34) = -2.789$, $p = .004$] and god's eye view [$t(34) = -1.976$, $p = .028$]. This indicates that the common ground intervention was more successful in reducing casualties when more commonly shared visual information was available.

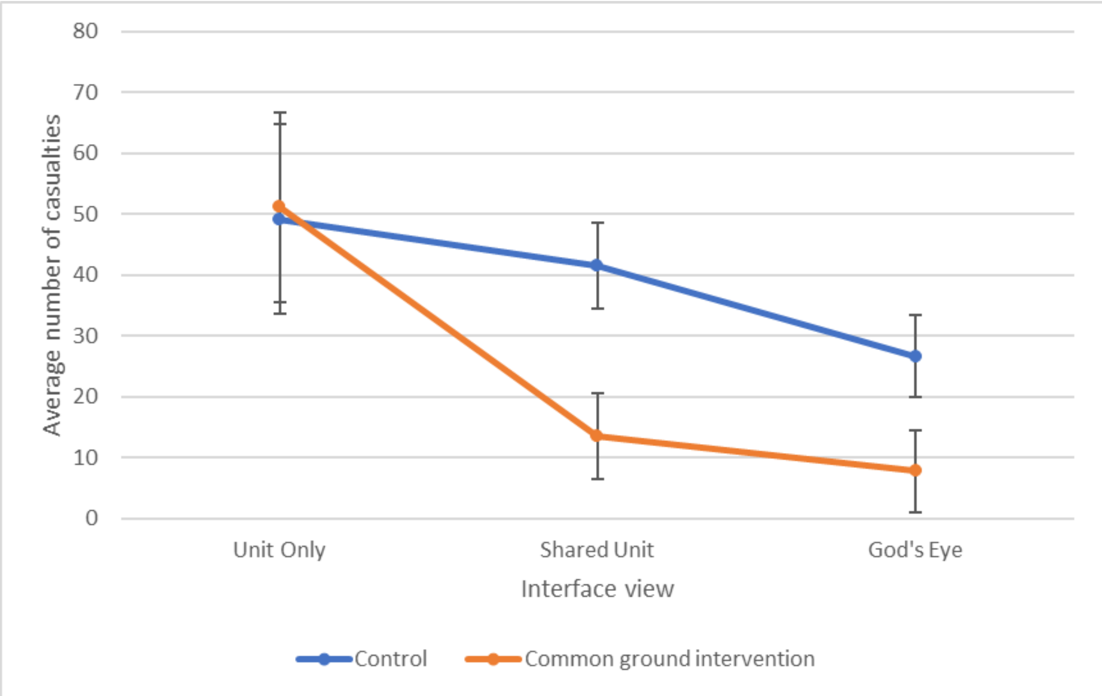

Figure 2: Average number of casualties between common ground intervention and control conditions, across the interface views. Error bars indicate standard error +/-.

Common ground and trial run

The differences in the average number of casualties between the common ground manipulation across trial runs were analysed using a mixed ANOVA. The trial runs are the three runs as experienced by participants over time (i.e. trial run three was the last run of the experimental day). As can be seen in Figure 3 there was a significant main effect for trial run [$F(2, 34) = 4.457$, $p = .015$] indicating that over time and with more practice the average number of casualties decreased. This practice effect was expected for C3Fire as previous experience using C3Fire (over several days) has identified that teams continue to improve over a large number of trial runs. This learning effect has been managed by rotating interface conditions and scenarios using the Graeco-Latin squares approach. There was no significant interaction between both manipulations [$F(2, 34)= .013$, $p = .987$].The analysis showed no main effect for the common ground intervention on number of casualties [$F(1, 34) = 3.078$, $p = .088$]. It is worth noting that at a more granular level, whilst there were no significant differences between the common ground intervention and control conditions for trial runs one and two, by trial run three the average number of casualties was significantly lower in the common ground intervention condition than the control condition [($t(34) = -1.756$, $p = .044$)].

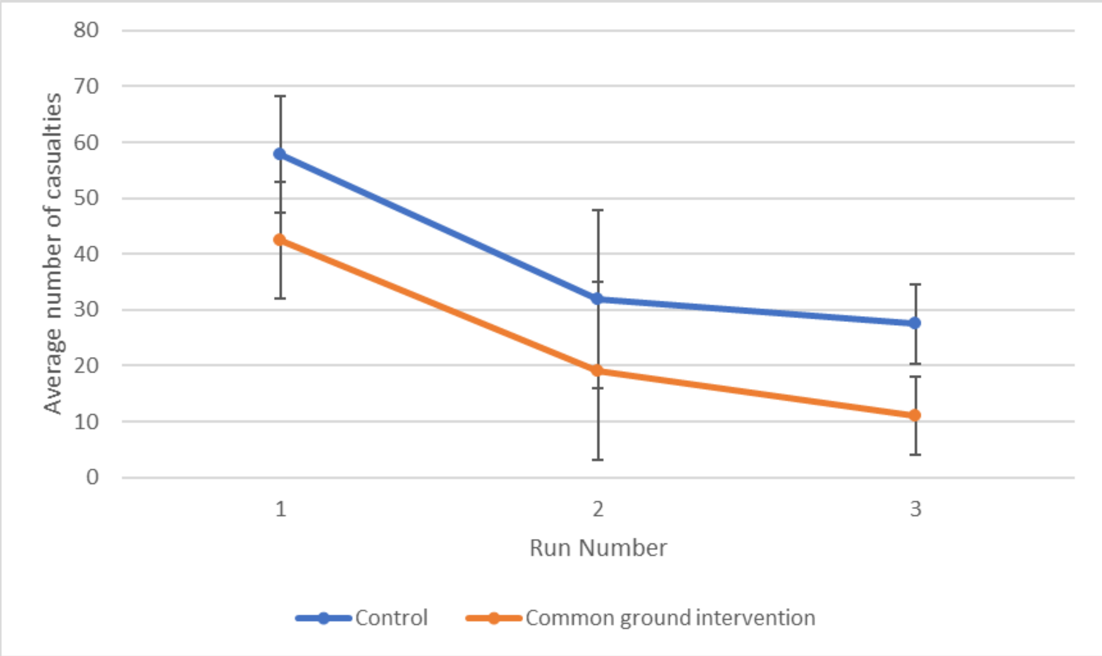

Figure 3: Average number of casualties between the common ground intervention and control conditions across trial runs in chronological order. Error bars indicate standard error +/-.

Conclusions

Anecdotally, participants felt that the common ground intervention was beneficial: e.g. “good to reflect on own performance and then to relate to team”, “not difficult/onerous”, “made planning a lot faster”, “quicker for development than more training”. Participant feedback from the wrap-up sessions suggested that the common ground intervention helped to both reflect on the past session and plan for the next session. Drawn from this, a key feature of the Common Ground intervention is that it prompts reflection on what has happened, but as the reflection relates to the goals applicable to future scenarios, this enables future planning. The approach therefore focuses directly on what is important for achieving task goals, rather than using the more common After Action Review (Morrison and Meliza, 1999) type process of identifying what went right and want went wrong and then building on this to identify future improvements.

A significant effect was identified for the three different interface conditions, with the provision of more task-relevant information on the interface leading to better performance; re-enforcing the importance of effective interface design to support DSM. Qualitative insights gained during the study highlight that having configurability for the level of information presented on the display could assist with DSM training and the management of workload for different task roles.

When reviewing differences between specific conditions, differences indicating better C3Fire performance using the common ground intervention were identified for the final trial run of the day, and for shared unit and god’s eye views. This suggests that the common ground intervention was beneficial, particularly when experience was gained, and when more visual information was available. One suggested benefit of the common ground intervention is that teams who have developed an appreciation of the problem they are facing, and gained experience in engaging in sensemaking (i.e., to reason about alternative courses of action and objectives), are more likely to benefit due to the framework the common ground approach provided to discussion (in conjunction with previous research – e.g., Baber et al., 2022). Teams who had less experience of the task or who were working with impoverished information might have less benefit from this intervention. A second explanation is that the common ground intervention helped participants in conditions with the most information available to agree on those aspects which were salient to their activity (where participants in the low information conditions, perhaps, spent more time discussing the differences in their situation awareness). This suggest that the participants with more information and common ground relating to their mission developed a more effective strategy, while participants with less information were more focused on agreeing what characterised the situation.

This work is planned to lead to the future development and implementation of tools and interventions to support DSM in the operation and design of military systems.

Acknowledgements

This work was funded by the UK Defence Science and Technology Laboratory (Dstl). The C3Fire scenarios were developed and run with the support of QinetiQ.

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