Measuring the Impact of a Collaborative Planning support System on Crisis Management

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ABSTRACT

Crisis management (CM) is an aspect of command and control characterized by complexity, uncertainty, and severe time pressure. To address these challenges, CM teams can use collaborative work support systems (CWSS) to help plan their intervention and coordination activities. However, the use of CWSS is not necessarily beneficial and in some cases, can impede more than augment performance. Hence, it is essential to understand the impact of a CWSS on team performance and CM teamwork. We have developed a methodology to assess the effectiveness of CWSS by comparing the use of an interactive Smartboard with that of a traditional topographic map during team planning activities. To do so, a dynamic CM situation is simulated using a forest firefighting functional simulation - the C^{3}Fire microworld. We compared two groups of participants on the basis of performance, communication, coordination efficiency, and planning quality. Based on a preliminary analysis, in comparison to maps, the use of a CWSS seems to be beneficial to planning activities and CM coordination. At this point the main contribution of the current on-going project is to provide a method and metrics for the objective assessment of new technology in the context of CM.

Keywords

Crisis management, CWSS, planning, team cognition, microworld.

INTRODUCTION

Crisis Management (CM) refers to the exercise of direction over resources in the accomplishment of specific objectives in response to natural or human-made crisis events (e.g., industrial and environmental disasters, terrorist attacks; see Tremblay, Lafond, Gagnon, Rousseau, & Grandlund, 2010). CM is challenging due to its complex and dynamic nature. Decision-makers are confronted with novel situations characterized by severe constraints such as time pressure and uncertainty (Boin & Lagadec, 2000) and optimal decisions must be made under cognitively demanding conditions (e.g., Gonzales, Vanyukov, & Martin, 2005). These characteristics have motivated the development of tools aimed at supporting CM activities (Jain & Mc Lean, 2003). The tools vary from decision support systems, which may help to anticipate and analyze the current situation (e.g., NVision), to collaborative work support systems (e.g., Microsoft Surface). Support tools may serve different stages of CM (e.g., planning, response), depending on their purpose, in order to improve response capabilities.

Support of Planning in CM

In modern societies, CM is viewed as a five stage holistic approach: Planning, mitigation, preparedness,

Reviewing Statement: This short paper has been fully double-blind peer reviewed for clarity, relevance and significance.

response and recovery (Johnson, 2000). Although each stage is important and may have direct implications on homeland security (Morin, 2008), the current study focuses on the response stage, and more precisely, on immediate planning for an actual emergency. Planning includes assessment of the situation and needs, and the development of strategies and plans of actions, which may facilitate coordination, and reduce risks and response time (e.g., Tufekci, 1995). Planning is a collaborative activity, where a group of people have to work together in order to control a large-scale event. A collaborative work support system (CWSS) could facilitate the work of a CM team by providing visual and interactive support to communications. However, although a large array of CWSS have been developed and commercialized over the years, their development is rarely based on solid conceptual and evidence-based grounds and little is known about their impact on CM team performance. The main objective of this research is to develop a method to assess how a planning CWSS can influence team cognition and performance in a crisis management setting.

According to subject matter experts, a useful CWSS should facilitate the visualization of the real situation by including a representation of the operational field with plans, maps and pictures, as well as a representation of real objects with their associated properties (Rousseaux, 2008). When used during the planning stage, such a CWSS could augment directed attention between CM team members, information sharing, and interpersonal coordination, which are key teamwork functions (Lafond, Jobidon, Aubé & Tremblay, in press). Despite the anticipated benefits, CWSS may also have drawbacks for team efficiency and performance (Lafond, Vachon, Rousseau & Tremblay, 2010). For example, a CWSS that provides too much but less relevant information, is too complex to use, or works too slowly, could impede rather than enhance performance. In this study, the Smartboard (i.e., an interactive, electronic whiteboard), represents the CWSS for use during the planning stages of CM. Combining the simplicity of a whiteboard with the interactive capabilities of a computer, the Smartboard is a flexible tool on which one can display information relevant to the task. Used as a CWSS, the Smartboard could promote the visualization of the situation, augment directed attention, and support communication among teammates because of its large, touch-enabled surface that makes it easy to deliver dynamic information with which the team can physically interact.

Microworlds

Most research on CM is based on case studies of sudden, single impact disasters such as tornadoes, flash floods, or explosions (e.g., Auf der Heide, 2006). In these sudden-onset events case analysis, there is little experimental control, and generalization to other events is rather limited. *Microworlds* can counter these problems by offering a replicable, functional simulation of a CM situation. Microworlds are simulated task environments designed for the study of decision-making in complex dynamic situations, and provide an ideal compromise between experimental control and realism (Brehmer & Dörner, 1993). The C3Fire microworld (Granlund, 2003) selected for the present study is a functional simulation of a major fire event in a populated area in which a team of responders is responsible for various emergency response units. The simulation generates forest fires that have the characteristics of a complex adaptive system, making C3Fire well suited for simulating CM events (Tremblay et al., 2010). The C3Fire microworld possesses all of the basic elements of CM, that is, unpredictability, temporal pressure, and implication of a major event. Moreover, units in C3Fire can be divided among teammates in order to reproduce the roles provided by the FIRESCOPE (see Tremblay et al., 2010), a well known CM system. By simulating a CM event, the C3Fire microworld allows the evaluation of the impact that a CWSS may have on the management of a major situation. Being a functional simulation emulating the key elements of CM, C3Fire does not require technical expertise to operate the system. Also, within the cognitive system engineering approach (Potter & Rousseau, 2010), early phases of Research & Development and conceptual design are premature to test the work of experts.

METHODOLOGY

Participants and Design

Thirty participants, 11 males and 19 females, (mean age of 23 years) were recruited from Laval University. Participants were divided into ten 3-person teams. Each team performed a 2-hour experiment including two 10-minute practice scenarios, one 10-minute planning period and four 10-minute test scenarios. At the end of each scenario, participants were asked to complete a set of questionnaires on shared mental models (SMM) and demographic information. In order to test the specific impact of a CWSS on planning for CM, teams were randomly assigned to either the Smartboard or the paper map condition. For the planning session all participants met in the room but during the CM simulation participants were distributed in different room, and communicated via headphones and a microphone. All communications were broadcast using Teamspeak 2 software, and all interactions with the microworld or between team members were recorded using Morae Recorder software. The C3Fire map for the CM simulation was identical in the two conditions. In the CWSS condition, the Smartboard displayed the C3Fire map, including all the environmental elements of the simulation (forest, houses, swamp, lakes, etc.). This consistency allowed teams to elaborate strategies and coordination plans. Participants could interact with the map using colored pens. Each role had a predefined color, so it was possible to track individual intervention. Participants could also erase and rewrite as desired. In the paper map condition, as is habitually the case with the topographic map used by real CM teams, participants were limited to gesticulation, such as tracing invisible lines with their hands. The two conditions were compared in terms of planning quality, and also in terms of CM performance according to the mission objectives.

Metrics

To examine the details of how CWSS affects performance, we used a set of cognitive and teamwork metrics: goal-oriented performance, pattern of communications, coordination effectiveness, accuracy and similarity of shared mental models, and quality of planning. Such a range of metrics was applied to the comparison of the Smartboard with the traditional map in order to capture both beneficial effects and potential costs to using a CWSS (see Lafond et al., 2010).

Planning

Planning quality was assessed through the analysis of communication during the planning phase. We used a structured analysis grid divided into four categories that correspond to teamwork and taskwork functions: collaboration, work organization, and level of interactivity with the CWSS. Each of these categories contains several items. The assessment of collaboration through the analysis of communication was based on one developed by Cooke, Gorman, & Kiekel (2008) within a simulation of a non-combatant evacuation operations. Within the context of CM planning, work organization refers to the development of strategies and plans, goal settings, and teamwork planning. The elements of these analysis was inspired from Bowers, Jentsch, Salas, and Braun (1998) who assessed differences in communication sequences between effective and ineffective crews in two flight simulation studies. Interactions with the device were defined as the frequency of any task-relevant gesture done over the map, and any use of pens. The latter assessment was inspired from traditional usability observation checklists (e.g., Neale, Cobb, & Wilson, 2000). All communications were classified according to the items of the collaboration, work organization, and level of interactivity in the form of a behavioral checklist.

Performance

In C3Fire, as in CM situations, teams often face conflicting goals to which they must choose among different strategies to attain their prioritized goal. In other words, different courses of actions can lead to good performance. *Process gain* provides a good indication of the quality of the team’s interventions (see Tremblay et al., 2010), regardless of the strategies used by the team, and was used to measure performance in this study. Process gain is the actual performance of a team compared to the worst possible performance, or to no intervention at all. Process gain illustrates the advantages provided by the use of a CWSS by showing the extent of the catastrophe that has been avoided.

Communications

Participants interacted face-to-face during the planning stage, and through headsets during the management stage. All communications were recorded and analyzed using codification grids. Two measures were derived from communications: frequency and content. Communication frequency (i.e., the number of times each participant spoke) was used to infer role-specific workload related to information sharing. Content was analyzed to extract the object of communications (e.g., units, fire, water) and the nature of communications (e.g., transmission or request of information). These categories are also used to estimate the level of proactivity (anticipation ratio: transfer versus request of information, see MacMillan, 2004) and the focus of teamwork (goal-resources ratio).

Coordination Effectiveness

Coordination effectiveness was measured objectively by calculating the time each unit spent without a critical resource, that is, water and fuel. This measure provides an accurate image of the quality of team coordination because the refilling process for both water and fuel requires the highest level of coordination in C3Fire. This measure specifically refers to the effectiveness of resource-oriented coordination (Tremblay et al., 2010; see also Crowston, 1997). In order to obtain a scale where 'higher is better', the coordination effectiveness measure was calculated as follows:

$$\frac{\left(TotalTime / AverageTimewithoutRESOURCES_{FF+FB+WT+TU+SCOUT}\right)}{Total\,Time}$$

where FF = firefighters, FB = fire breakers, WT = water tankers, TU = transport units, and SCOUT = scouts.

Shared Mental Models

Shared metal models (SMM) were evaluated using a questionnaire of concept pairing completed by each participant. This questionnaire measures the SMM related to taskwork (Langan-Fox, Code, Langfield-Smith, 2000). The concepts used in this questionnaire were obtained from a hierarchical task analysis (HTA) of the microworld of C3Fire. Participants were presented with a two-column table, where each column represented the elements of the highest level (most general) of the HTA, that is, situation assessment and resources management. Participants had to classify the elements of the third level of the HTA (e.g. Assess risk level, Load passengers) in one of these two categories. The accuracy of the team mental model was calculated using a difference ratio (Langan-Fox, et al., 2000), which compares the actual number of differences between models, divided by the highest number of differences possible.

Preliminary Results

Preliminary results, though not statistically significant, suggest a beneficial impact on performance of using a CWSS in the planning stage of CM: CM teams who used a CWSS (SB) seem to perform slightly better (SB: *M = 2.77, SD = 0.15;* Paper: *M = 2.61*, *SD = 0.20*), and also shared a more accurate SMM (SB: *M = 0.32, SD =0.10*; Paper: *M = 0.37*, *SD = 0.12)* than the CM teams who did not use a CWSS. The use of a CWSS seems to effectively support communication: Although the CWSS group shared more information during communication than the other group (SB: *M = 73.6, SD = 28.00*; Paper: *M = 71.60*, *SD = 18.10*), much less communication was devoted to information seeking, negotiation and consensus reaching. In line with the latter trend, teams using the CWSS seem to reach a consensus more easily. More data must be collected and further research is required, however, before these conclusions could be substantiated. There was no trend of cognitive and performance costs to using the CWSS. However, there was no measure of response time or direct metrics of responsiveness. Such metrics may have detected costs such as extra time taken to carry out planning.

DISCUSSION

This paper summarizes the current results of an ongoing project assessing the effectiveness of CWSS. In the last few years, plenty of CWSSs have been designed and commercialized to improve performance of CM teams. Little controlled research has been carried out to assess the costs and benefits of using CWSS. Consequently, it is important to properly assess their effect on teamwork before implementing them in real world CM teams. The use of a microworld and objective metrics allow researchers to compare the effectiveness of a CWSS and a traditional planning device. Our results suggest that a CWSS in the form of a Smartboard used during the planning stages of CM can enhance team performance, as measured by coordination and communication The objective assessment of such devices can orient the development of CWSS, and guide decision makers in the choice of those systems.

Limitations & Future Work

According to the cognitive system engineering approach, the use of a functional simulation (microworld) is an initial step (and the only valid step) for testing systems that have not yet been used by experts. In fact, expertise could interfere if C2 centers or firefighter-commanders have never used a Smartboard in the planning process. At this early stage, experimentation with Novices should be considered more appropriate, rather than a weakness. Moreover, the level of realism involved in C3Fire preserves work domain relevance and the cognitive functioning underlying C2 required for participants – regardless of their level of expertise. The application of the metrics used in this study to field studies involving expert use of CWSS is a necessary but future step in the cognitive system engineering approach of the design process.

Extending this research to CWSSs other than the Smartboard, and to incidents other than fire would also highlight crucial information about the use of these devices. The Smartboard, as compared to the paper-based maps is not a specific system for planning in CM, as much as an interactive electronic whiteboard allowing the interaction and annotation of maps. As such, it should encourage interaction and favour communication and coordination in every teamwork activity. In sum, the methodology and metrics proposed here are applicable to other simulated environments and CWSS. In the future, a more CM-oriented system may help to validate the chosen method and metrics, and a broader view of the CWSS applicability could be built. The use of CWSS during other stages of CM situations and also the use of mobile CWSS in the field are key issues that could also be addressed with a similar methodology.

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