Extending the capabilities of the C^3Fire microworld as a testing platform for research in emergency response management

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ABSTRACT

The present paper describes the C^3Fire microworld and the testing capabilities it provides for research in emergency response management. We start with a general description of C^3Fire and report extensions that add a new subtask (search and rescue) relevant to the context of emergency response and a vocal communication system. We then describe how various organizational structures can be designed using this task environment and several metrics of major interest for research in crisis management, related to task performance, communication, coordination effectiveness, monitoring effectiveness, recovery from interruptions, detection of critical changes, and team adaptation. The microworld constitutes a highly flexible testing platform for research in team cognition, cognitive systems engineering and decision support for crisis management.

Keywords

Emergency response, microworld, research methodology, team cognition, metrics.

INTRODUCTION

Crisis management (CM) refers to the exercise of direction over resources in the accomplishment of specific goals and objectives in response to natural or human-made crisis events (e.g., industrial accident, pandemic, environmental disaster, terrorist attack). CM can be seen as encompassing a spectrum of activities and different terms that include command and control (C2) and emergency response. Public safety and national defense organizations are faced with the challenge to develop organizational structures and technologies that promote the agility to deal with the unpredictable demands of CM situations. Complex and dynamic situations such as these are cognitively demanding and heavily engage a variety of cognitive functions such as situation assessment, monitoring, problem solving, causal learning and planning (Gonzalez, Vanyukov, & Martin, 2005). Furthermore, effective teamwork is of critical importance to ensure adaptable and responsive CM (Salas, Cooke, & Rosen, 2008). The study of team behavior and effectiveness has seen much progress through laboratory and field research, although both approaches have limitations. One particularly promising approach that seeks to escape both the "narrow straits of the laboratory" and the "deep blue sea" of the field study involves finding a compromise between experimental control and external validity by using computerized microworlds for human factors research and cognitive systems engineering (e.g., Gray, 2002). Microworlds are task environments that are used to study behavior under simulated conditions within a laboratory setting. They retain basic or essential real world characteristics while omitting other aspects deemed superfluous for the purposes at hand. Microworlds offer the great advantages of experimental manipulation and control, without stripping away the

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complexity and the dynamic nature of the task. Being a functional simulation emulating the key elements of the task, the computerized task does not require technical expertise to operate the system, allowing researchers to obtain larger samples typically necessary for hypothesis-testing. Microworlds have been mainly used to study learning, dynamic decision making, complex problem solving and team cognition (e.g., Funke, 2001; Jobidon, Tremblay, Lafond, & Breton, 2006). Moreover, microworlds can provide very cost-effective testing platforms for concept validation early in the technology development cycle and for requirements analysis for the design of technology in the domain of emergency response (Johansson, Trnka, & Granlund, 2007; Schraagen & van de Ven, 2008). For instance, when designing an adaptive dynamic resource allocation system for emergency response management (Airy, Mullen, & Yen, 2009), human-in-the-loop testing using a microworld could be of considerable value to assess how well humans will deal with such a system.

The present paper highlights the benefits and the testing capabilities of the C³Fire microworld (Granlund, 1998; www.c3fire.org) for research in emergency response management. We begin with a general description of C³Fire and report extensions that add a new subtask (search and rescue) relevant to the context of emergency response and a vocal communication system. We then describe how various organizational structures can be designed using this task environment and several metrics of major interest for research in crisis management.

C³FIRE

The C³Fire microworld puts a team of people in charge of various emergency response units during a major fire event in a populated area (Figure 1). C³Fire is a highly flexible research tool allowing the experimenter to design various scenarios and customize both the content of the interface and its layout (Figure 2). The structure of the team and the resources on the field can be configured based on the objectives of the study. Team size is usually between three and nine members. Team members communicate through an email system integrated within C³Fire. The information tools and the user interface of the members of the team can be individually defined. The fire model in the simulation generates a forest fire that has characteristics of complex adaptive systems (i.e., self-organization and non-linear growth). The situation evolves autonomously over time and as a function of human intervention. The resources that can be integrated in the simulation are units such as firefighters, fire-breakers (i.e. bulldozers), search and rescue units, water tankers, fuel tankers and helicopters.

Units in C³Fire are partially autonomous agents. Specifically, they need to be dispatched to specific locations to do their work. Players must select the unit and drag its icon to the desired destination (the unit number will appear in white at the destination, designating the intention). Firefighters automatically attempt to extinguish red (fire) cells with water when they are dispatched over one. The firefighter can either succeed (extinguishing the cell, which turns brown), run out of water, or may be too late and the cell burns-out (i.e., turns black). A fire-breaker (i.e., bulldozer) can be instructed to create a fire-break in a cell (by double-clicking on it) thus preventing the fire from spreading to it. Water tankers replenish the firefighters' water reserves, and can refill their own reservoir at specific locations. Movement costs fuel and the amount depends on the unit type. Fuel tankers refuel emergency units when their reserves run out. Units spend a configurable amount of time mobilizing and demobilizing before and after performing their function. One key change from previous versions is the addition of emergency response units (i.e. search and rescue vehicles and helicopters), which increases both the complexity of the task and its ecological validity from a CM perspective. In order to support research, monitoring is integrated in the simulation and in all the information tools used by the participants (Figure 3). During a session, the C³Fire system creates a log with all events in the simulation and all computer mediated activities, such as communication and individual work. The logged information is detailed enough for quantitative analysis and playback of the whole sessions.

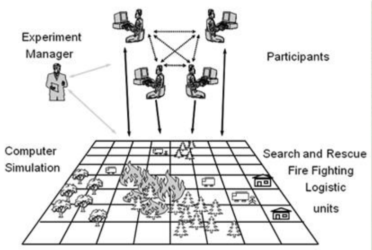

Figure 1. C³Fire, organization and simulation.

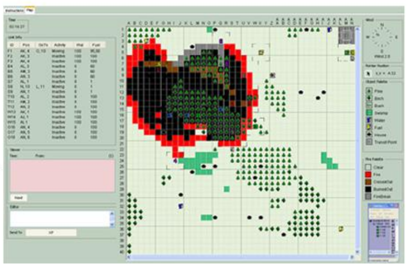

Figure 2. Example C³Fire interface

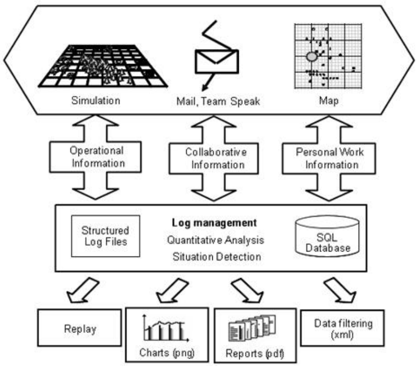

Figure 3. Monitoring in C³Fire

The C^3Fire simulation takes place on a geospatial grid of adjustable size representing the map of the surrounding area. The interface can show various information elements, arranged as desired by the experimenter (see Figure 2). This includes the scenario time, the unit information panel, the viewer for receiving text messages, and the text editor for sending text messages. The unit information panel can show relevant data about the emergency response units (ID, position, movement destination, current activity, water reserve, fuel reserve). Wind strength and direction can be represented by a compass placed on the screen. The pointer position indicator provides the present coordinates of the mouse pointer when it is located over the map. The fire palette and the object palette act as a legend for the icons and colors on the map. The parameters of a scenario are defined in two XML files. The first XML file defines the static or general properties of the situation such as the size/position of elements on the interface, the specific coordinates of objects (houses, trees), the number of players and number/types of units that they control, plus other parameters set by the experimenter to set time-pressure and complexity (movement speed, range of vision, size of water reserves, fire's propagation, burning time of various objects, etc). This flexibility is particularly useful for customizing and fine-tuning task difficulty and for allocating various roles to each player. The second XML file determines the start/end time of a scenario and specifies various scripted events such as new fires, changes in wind strength and direction. The ability to add sudden and unexpected events to a scenario is an important feature that allows researchers to study team adaptation.

THE NEW SEARCH AND RESCUE FUNCTIONALITY

In previous versions of C^3Fire, the two main goals were to stop the fire from spreading and to protect houses in the area. Here, we report an extension to C^3Fire adding a third possible goal which is to evacuate any remaining people from their houses and bring them to a transit point. The purpose of this extension is to create a situation that is closer to the real-life challenges in emergency response, and to create a task with multiple competing goals. One important goal with the new feature is to increase the possibility to study coordination and collaboration. The CM team needs to coordinate the firefighting activities with the rescue activities. Coordination needs to be achieved both at the global planning level and at the operational level. Indeed, the presence of simultaneous goals and conflicting priorities constitutes a key stressor in CM, which sometimes requires making hard choices when constrained by limited response capabilities. The new search and rescue module adds several subtasks: identify critical geographical areas where people need to be evacuated, plan evacuation, search geographical areas, and transport people to transit points, hospitals, or schools. The new functionality is optional and customizable. The C^3Fire environment can now be configured to have civilians in the geographical area that must be evacuated. Units can be endowed with a search capability (to find people) and a transport capability (to bring people to a designated location). A message appears in the Viewer panel when people are found. Loading/unloading speed and transport capacity can be configured at will. The geographical environment can be configured to contain transit points, health centers, hospitals, etc. Figure 2 gives an overview of the different parts of the interface and the operational environment (according to one possible layout). The central map is interactive, allowing selection of a particular unit in order to give it a new movement order. Reconnaissance vehicles typically have a wider field of view and are useful for situation monitoring, detecting new fires, and for locating survivors in houses. Transport units are needed to collect the survivors and bring them to a transit point (upper right of the map in Figure 2).

INTERACTION BETWEEN PARTICIPANTS: TEAMSPEAK EXTENSION

In addition to sending text messages to other team members, participants can now communicate verbally with others via headsets using the TeamSpeak software (TeamSpeak Systems GmbH). Participants must hold down the zero key on the numeric pad before speaking into their microphone. Depending on the TeamSpeak configuration, participants can either communicate with everyone via an open channel or sub-groups can be defined. Although an on-screen window is not necessary for TeamSpeak interaction, this interface feature can be helpful simply to highlight the identity of the team member currently speaking (see lower-right of Figure 2). The verbal communication system extends C^3Fire information exchange capabilities and increases the ecological validity of simulating teamwork in CM (see Jobidon et al., 2006).

TEAM TYPES AND ROLE ALLOCATION

Various team structures can be designed in C^3Fire by assigning the control of various unit types to different participants and providing different information sources to participants, thus giving them one or many roles to accomplish. Depending on the role/unit assignment, team members may be relatively independent or may need to exchange information or resources with others (Lafond et al, 2010). Team structures can thus vary from traditional stove-pipe (hierarchical) structures to edge (flat) organizations. Team members may be collocated in the same room or distributed across multiple laboratories. The roles in C^3Fire can be set to correspond to the key staff required in crisis management systems such as in the Californian FIRESCOPE (Office of Emergency Services, 2007) or the Incident Management System for Ontario. According to these systems, the Incident Command is formed by three officers and four chiefs, who can be supported by diverse specialists if needed. The units in C^3Fire can be divided so that the role of each participant corresponds to the role of the chiefs or specialists who comprise the Incident Command, e.g., Operation Section Chief (responsible for firefighters and fire breakers), Planning Section Chief (controls water tankers and fuel tankers), Search and Rescue Chief (scout, helicopters and rescue units), and Situation Unit Chief (responsible for information).

METRICS

At the end of a session, C^3Fire creates a log of the events that occurred over the course of the scenario (state of units and cells over time). Morae software (TechSmith) can be a useful complement to the C^3Fire logs in order to record verbal communications, video clips of user information (displayed on each station), and interactions with input devices (mouse/keyboard). These logs capture all the information needed to assess team performance and processes. Below, we define key metrics that can be used to assess team effectiveness.

Performance. C^3Fire reflects CM demands since it provides a multi-objective task that may encompass conflicting goals. Depending on the scenario, the overall objective can be directed toward a series of sub-objectives: Limiting the spread of the fire, saving civilians, minimizing the number of burnt houses, or a combination of these. The achievement of each of these sub-objectives can be measured independently or weighted with regards to their priority. A potentially useful approach for the measurement of each of these sub-objectives – made possible by the use of a microworld – can be to compare the "worst case" scenario to the observed results in order to have a clearer idea of the accomplishments of the team. This means running the simulation without human intervention in order to quantify what would be the actual loss at the end of the scenario if no actions were made. Then, a ratio between the latter estimate and the one obtained when a human team performed the tasks can serve as a quantitative measure of crisis management efficiency.

Performance = (extent of actual losses) / (extent of losses without team actions)

Communication. Participants can communicate via text messages or headsets (using the TeamSpeak software). Two measures derived from communications can be associated with team processes: Frequency and content. Analyses based on the frequency of communications can be used to infer role-specific workload related to information sharing. Content of communications can also be extracted and categorized on the basis of theoretical models of teamwork (e.g., Rousseau, Aubé, & Savoie, 2006) and of task analysis trees of functions and sub-tasks (see Lafond, Tremblay, Dubé, Rousseau, & Breton, 2010). Indeed, observation grids can be derived from such models. The validity and reliability of the content analysis is assured by calculating a coefficient of agreement (kappa statistic) between observers. Such data can then feed matrices of transitions in order to provide insights on the cyclical and dynamic aspect of teamwork models (see Cooke & Gorman, 2009).

Coordination effectiveness. In C^3Fire, this is based on the time each unit spends without a critical resource, i.e., water for firefighters or fuel for water tankers. This measure specifically refers to the effectiveness of *resource-oriented coordination*. This type of coordination refers to processes that serve primarily to manage dependencies between activities or resource dependencies (Crowston, 1997). It provides an excellent indicator of the efficiency in performing the water or fuel refill process, which requires coordination between two types of units.

Coordination effectiveness = (total time - average time unit spent w/o essential resource) / total time

Monitoring effectiveness. This metric refers to the team's ability to identify idle units in a timely manner and issue a new movement order (units waiting for water or fuel refills are not considered idle).

Monitoring effectiveness = (total time - average unit idle time) / total time

Recovery from interruptions and team adaptation. An ecological feature of C^3Fire is that it allows the introduction of task interruptions and of critical changes can create significant modulations of workload during a scenario requiring re-planning to adjust (LePine, 2005). Team response to these interruptions is itself an important research topic (Tremblay, Vachon, Lafond, Gagnon, & Breton, 2009). Two different means to study response to task interruptions are possible in C^3Fire: Resumption lag and event-based analysis. Resumption lag is based on the time needed to recover from the interruption. It is operationalized as the time taken to give the first order after the end of the interruption. Event-based analysis refers to the comparison of the aforementioned metrics before and after the interruption.

Detection of critical changes. Participants are informed to mention aloud any detection of a critical change in the environment such as the change of wind direction or onset of a new fire. The time between the actual onset of the change and the first mention of a critical change by a team member corresponds to the detection lag.

CONCLUSION

The present work described extensions to the C^{3}Fire microwold for research in emergency response management, namely the search and rescue functions and a vocal communication system (TeamSpeak). The analysis of communications (both textual and vocal) is instrumental in revealing the dynamics of teamwork and testing models of collaborative work. The microworld constitutes a testing platform for research in team cognition, cognitive systems engineering and decision support for CM. Critically, C^{3}Fire is designed to: 1) achieve an optimal compromise between internal and external validity, 2) show flexibility in scenario configuration (spectrum of units and roles – including newly added search and rescue functions), allowing researchers to capture emergency response and crisis management and rapid response planning (e.g., OPP), 3) be highly configurable for testing many different team types (collocated vs. distributed) and structures (hierarchical vs. edge organizations), and 4) readily provide metrics for assessing teamwork effectiveness (including macrocognitive functions and microcognitive processes in team cognition) as well as quantitative measures of task performance. Further developments being considered for C^{3}Fire include the simulation of toxic spills and flooding, including the addition of emergency units necessary to deal with these types of emergencies.

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