Using SYnRGY to Support Design and Validation Studies of Emergency Management Solutions

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ABSTRACT

Emergency management situations are highly complex and require the collaboration of multiple parties for adequate responses to incidents. The design and validation of effective emergency response systems is critical in order to improve the overall effectiveness of teams tasked to manage emergency situations. We report ongoing work whose objective is to increase the efficiency of emergency response solutions through iterative cycles of human in-the-loop simulation, modeling, and adaptation. Ultimately, this cycle could either be achieved offline for complex adaptation (e.g., development of a novel interface), or online to provide timely and accurate decision support during an emergency management event. The method is made possible by achieving a high degree of realism and experimental control through the use of an innovative emergency management simulation platform called SYnRGY.

Keywords

Emergency Management, Emergency Response Systems, Simulation, System Design, Validation

INTRODUCTION

Emergency management is prominently characterized by uncertainty, complexity and dynamism (Janssen *et al.*, 2010). These situations can rapidly evolve over time, often compounded by the human operator's own actions, which imposes additional stress on decision makers. Moreover, factors involved in the dynamics of emergency situations are numerous and often unknown to decision makers; rendering the prediction of how events might unfold over time extremely difficult. Indeed, the characteristics of the situations in which emergency management occurs can severely impair human decision-making; many studies have shown a negative impact on decision-making performance by the low amount of perceived information, the unpredictability of the changes in the situation, and the complexity of the situation in terms of conflicting goals and opaque relationship between actions and effects (for a review see Karakul and Qudrat-Ullah, 2008).

The design of effective Emergency Response Systems (ERSs) is a critical step towards increasing emergency management performance (Chen, Sharman, Rao & Upadhyaya, 2007). ERSs are socio-technical systems (i.e., a human and 'machine' team) that support preparation for, mitigation of, response to, and recovery from a wide range of emergency incidents (Bram & Vestergren, 2011). Cognitive systems engineering, a field of Human Factors with particular relevance to the design of ERSs, considers that cognitive functions are performed by humans interacting with cognitive artifacts in relation to a specific task. A cognitive artifact is an item that structures or takes part in cognition. For instance, a first responder may rely on a map and a GPS to find his or her way to an incident. Together, these types of cognitive artifacts perform the 'orientation' function. According to this approach, attempts to improve the decision making performance of the human operator should focus on the optimization of interactions between all three components of this socio-technical triad (Figure 1). A GPS and a map are only useful if they provide reliable representation of the city they are supposed to represent and if the presented information can be adequately understood by the human using them. The design and evaluation of ERSs should therefore take all of the interactions human-system-task interactions into account. Consequently, the improvement of ERS involves a wide spectrum of possible solutions, from human-oriented to technology-oriented.

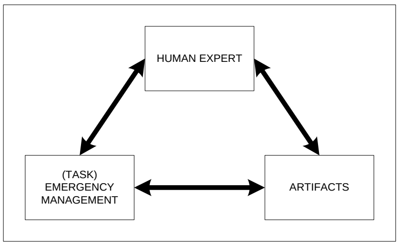

Figure 1. ERS are socio-technical systems in which human experts collaborate with artifacts to perform emergency management.

Unfortunately, the design of ERS solutions is limited by the nature of emergency management tasks in the real-world. As Bram and Vestergren (2011) noted, real-world emergency events are perceived as random and infrequent, which affords very little time for mid-event learning and observation, and even less time for adequate evaluations of potential technological solutions. Moreover, the uncertainty that characterizes real-life incidents is extremely hard to capture in training environments. This is a pity because, according to Bram and Vestergren, this uncertainty should be accounted for in order to design resilient solutions that can adapt to various contexts.

Microworlds are human in-the-loop simulations that have the potential to be effective environments for the identification and validation of resilient, adaptive solutions. These simulations mimic the complexity of real-life incidents whilst offering observation and replaying capabilities. However, in order for these simulations to be truly helpful, they must replicate the actual work performed by experts in real-life settings (Nemeth, Wears, Patel, Rosen & Cook, 2011). These simulations should also adequately capture the interactions within the ERS in an objective and reliable way (Cooke & Gorman, 2009). For instance, monitoring can be captured through the measurement of the human gaze on the map artifact. We report ongoing work on the development of a realistic emergency management simulation with measurement capabilities, and on efforts to integrate these functionalities to provide adaptive and cognitively resilient solutions (Comfort *et al.*, 2004).

METHOD

The method is an iterative cycle of human in-the-loop simulation, modeling and adaptation for ERS (Figure 2). Adaptation is the process by which the efficiency of the ERS is improved. It is the result of the previous steps and can be achieved in either offline or online modes. The method is described in detail below.

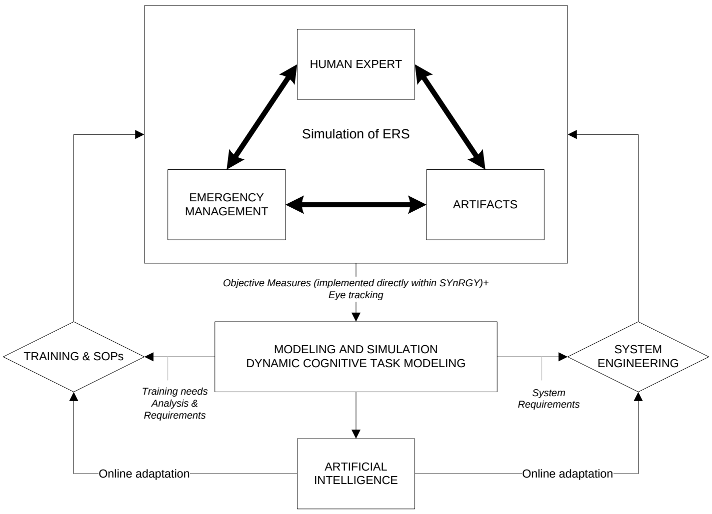

Figure 2. Adaptation to the ERS can be oriented towards technological design, or training and standard operating procedures.

Human in-the-loop simulation

The simulation approach represents a compromise between experimental control and realism (Gonzalez *et al*., 2005). Simulation allows high degrees of realism whilst maintaining appropriate levels of experimental control.

Realism

We attempt to bring the real-world into the laboratory by recruiting experts, developing and implementing a realistic scenario within SYnRGY, and providing users with real-life artifacts to accomplish their mission. The ultimate goal is to achieve the highest level of realism for all three components of the ERS socio-technical system (Figure 1). Participants recruited for our simulations are all experts in emergency management. Teams of participants from the local police service (i.e. Service de Police de la Ville de Québec; SPVQ) with experience in multi-agency operations of emergency and incident management are recruited to perform simulated emergency management tasks. In addition to expert participants, we implemented a simulation module based on the SYnRGY emergency management tool to present and manage the experimental scenario. The computer-simulation model was built to represent real-life emergency management. An emergency management scenario was developed within SYnRGY through its scenario builder capability. The scenario was derived from a Goal-Directed Task Analysis performed with subject matter experts from the SPVQ. Finally, the artifacts employed by the participants to accomplish the task are very similar to the ones used by emergency management teams (Figure 3). First, the experimental environment, equipped with capabilities typically found in operation centers, was validated by experts. For instance, the laboratory is equipped with a large shared display, several networked computers, microphones, and speakers. Second, the main computerized artifact employed by the participants to conduct their task, SYnRGY, is a real-life emergency management tool. During the simulation, participants assume one of the four roles; Emergency Manager, or Police/Fire/Medical Services Dispatchers. Participants must react to events set in the scenario to limit the damage due to incidents in a given situation. To this end, SYnRGY provides various tools for coordination (e.g. audio communication) and progress assessment (e.g. units' status monitoring panel).

Figure 3. The simulation environment is a realistic emergency management control room. It is equipped with similar artifacts than the ones used by local police service and enhanced with additional measurement capabilities.

Experimental control

There are several advantages to simulating real-world tasks within laboratory settings. First, the use of a computerized simulation to carry out the scenario allows for replicability. This feature allows for multiple teams of experts to participate in exactly the same scenario. This is critical to ensure that any observations made are not caused by idiosyncratic factors, but rather by the main experimental manipulations. Second, SYnRGY is a very flexible platform allowing for precise experimental manipulations. Indeed, most of the functions implemented into SYnRGY can easily be switched on or off for testing purposes. For instance, it is possible to activate or deactivate a function that provides users with suggestions about what resources should be allocated to respond to a particular incident. Finally, a key feature of SYnRGY is the automatic calculation of cognitive and teamwork metrics for the assessment of performance and team functioning during the execution of the task.

Measurement

SYnRGY automatically records every action performed by the participants and synthesizes the results of cognitive-based metrics (Gagnon *et al*.,2011). For instance, adaptability is inferred by comparing taskwork behaviors before and after the occurrence of critical events. SYnRGY calculates how many units are active before and after a critical incident; thus inferring the degree of participants' reactions to the incident. Combined with eye-tracking, we can extract a range of critical cognitive measures such as coordination efficiency, monitoring, and adaptability. Two ASL Mobile-Eye devices allow the capture of eye movements from two operators in synchrony. From eye-tracking we can (a) measure shared information seeking behavior among team members (i.e. proportion of time looking at the same information) and (b) extract cues that were fixated prior to a decision and perform process tracing in order to identify information requirements and also reveal potential heuristics (e.g. Lafond at al., 2009). This process is completely automatic and as a consequence does not interrupt the operators' decision making and task accomplishment. These measures target various functions of cognitive work; from individual task performance to the quality of teamwork. The purpose is to achieve a holistic view of the functions at play during an emergency management task. This holistic assessment is deemed essential for effective assessment of C2 related systems like ERSs (Lafond *et al.,* 2010).

Modeling

Holistic measurement of the cognitive work allows for a complete assessment of the ERS, above and beyond performance. The data collected during a human in-the-loop simulation can be aggregated into models with techniques such as Dynamic Cognitive Task Modeling (DCTM; Gagnon *et al.* 2011). DCTM combines typical hierarchical task analysis with process tracing techniques to generate a dynamic model of cognition and team work. Hierarchical task analysis is a decomposition of a task into a hierarchy of goals, sub-goals, operations and plans. This analysis is however limited as it is remains subjective and models an idealized process for the completion of a task. Process tracing is a systematic, objective and automated approach for collecting and analyzing quantitative data of observed events during the completion of a task. By combining hierarchical task analysis with process tracing, DCTM provides a dynamic model of how experts actually perform the task. It models the key 'functions' performed by the ERS during the completion of the task as well as the transitions from one function to another.

By focusing on the functions, DCTM is concerned with the interactions within the ERS rather than focusing only on human, task or technology. For instance, the 'situation monitoring' function is identified when a user draws his or her attention (inferred through eye-tracking) on the map tool of SYnRGY. This allows for the development of solutions that focus on precise, measured functions, rather than on components or individuals. Moreover, DCTM is dynamic insofar as it identifies the sequence of functions performed by the ERS as a whole which can later be associated with performance. This allows the identification of 'good' and 'bad' patterns of behaviors (functions). Indeed, with the increase of the number of simulations, we observe regularities in the sequence of functions performed by the ERS to complete a given task. This is achieved through standard sequence analysis techniques (Gabadinho *et al.,* 2008). We extract the sequences of functions of the best and worst teams and then compare them to identify differences. For instance, when prioritizing across incident interventions, good teams may rely on a subset of cues in a given order that is different from the one followed by poorer performing teams. This is critical as some cues may be more informative than others and hence could serve as a stopping rule in the decision making process. The differences between the sequences provide insightful indications about the procedures to follow for the execution of a given task and form the basis of the design for support in this context.

Adaptation

Observation of the interactions within the ERS and the integration of the data into DCTM provide information about the best and worst (patterns of) functions. In order to support these functions better, solutions can be developed by either adapting the technology to human behaviors and to better fit the task, train human experts in making a better use of the artifacts and understand better emergency management procedures, or finally, adapt emergency management standard operating procedures to be more in line with artifacts and human experts' behaviors (Figure 2). We plan to adapt the ERS offline in the first iterations, but eventually adapt the ERS online, during task performance. Indeed, the first iterations of simulation/modeling/adaptation will provide a 'toolbox' of cognitive solutions for supporting various functions. As the toolbox grows, it will be possible to trigger the activation of bespoke solutions matched to specific patterns of interactions within the ERS. For instance, if an algorithm detects that a team is currently prioritizing incidents (through measured behaviors), a panel summarizing relevant cues in the right order for effective prioritization could be activated at this precise moment. Another solution could be to adapt procedures and training so that humans performing emergency management are taught to look for specific cues first when prioritizing.

CONCLUSION

This paper describes an iterative method for the design and evaluation of effective ERSs. The objective is to develop efficient ERSs with realistic simulations of emergency management in a controlled experimental environment. Ongoing work is focused on the identification of critical functions associated with emergency management and on the development of a 'cognitive toolbox' to support them. This is made possible with the holistic and objective measurement and modeling of cognitive and team functioning during simulated scenarios involving experts. This work goes beyond traditional user-centered design and evaluation processes (e.g,. ISO 9142-210) insofar as our emphasis is on simulating real-world incidents in a realistic yet controlled experimental environments in order to capture dynamic and detailed representations of task accomplishment. We argue that this is necessary for this type of design study. Our work emphasis on the use of objective measures of cognition and their integration within a realistic emergency management platform. This integration will allow for online user-centered adaption of the ERS. With the development of several solutions, SYnRGY will become a toolkit for the support of decision making in the context of emergency management. Future work will focus on the development of 'intelligent' algorithms that can identify functions during a simulation and activate the required support tools in a timely manner.

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