DESIGN FOR IMPROVISATION IN COMPUTER-BASED EMERGENCY RESPONSE SYSTEMS

David Mendonça
Information Systems Department, New Jersey Institute of Technology, 323 Martin Luther King, Jr. Blvd, Newark, NJ 07102, USA
Email: david.mendonca@njit.edu

Frank Fiedrich
Institute for Technology and Management in Construction, Karlsruhe University, Am Fasanengarten, D-76128 Karlsruhe, Germany
Email: fiedrich@tmb.uni-karlsruhe.de

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Abstract: This paper explores the design of training environments in which emergency response professionals can use information technologies to train for responding to unplanned-for situations. This approach—designing for improvisation—is fundamentally different than designing for plan execution. In this paper, we identify three dimensions of this difference and outline a set of research questions that are intended to lead to a better understanding of the role of improvisation in emergency response, as well as how it can be trained for and supported. Both questions are intertwined, since without a firm understanding of how improvisation occurs it is difficult to train for and support it.

1 INTRODUCTION

Emergencies—whether induced by nature or technology—challenge society's capabilities both for planning and response. While information technologies and advanced modeling techniques continue to expand how society can limit and manage emergencies, flexibility remains crucial to the success of planning and response operations (Mileti, 1999). The research presented in this paper is motivated by the observation that emergency response organizations need to maintain flexibility in order to address unplanned-for contingencies. It is concerned with surveying work on emergency response decision making, training and support in order to develop a set of research questions that, if answered, should advance understanding of how improvisation can be better understood, trained for and supported.

The paper proceeds as follows. The role of improvisation in emergency response is first discussed, followed by a presentation of approaches to training for and supporting it (Section 2). A discussion of these observations leads to a delineation of the fundamental differences between improvisation and plan-following, and the implications of these differences (Section 3). The discussion is synthesized into three research questions, and opportunities for future work in answering them are presented, along with some possible pitfalls.

2 BACKGROUND

Managing an emergency usually includes monitoring operations during normal conditions, selecting an appropriate procedure when planned-for contingencies arise, and revisiting the appropriateness of these procedures as other potentially disruptive events occur (Beroggi and Wallace, 1994). Emergency preparedness, on the

other hand, entails organizing for response activities before disaster occurs (Kreps, 1991). Skill in preparing and planning for an emergency should be considered distinct from skill in managing an emergency. As stated by Quarantelli (1987), "The latter does not follow from the former in the same sense as that good tactics do not follow directly from a good strategy."

Unplanned-for contingencies—events for which no planned-for procedure exists—create the need for the responding organization to develop and deploy new procedures in real-time. An unplanned-for contingency may have its genesis in numerous circumstances: an emergency situation may evolve, so that implemented plans are no longer applicable (Turner, 1995); it may be multi-faceted, requiring responding organizations to combine many plans in unexpected ways; it may occur concurrently with other situations, thus creating resource shortages or outages (Turner, 1995); and, finally, it may require activities that are not immediately assignable to a particular organization (Scanlon, 1994).

2.1 Improvised Decision Making

One approach to addressing unplanned-for contingencies is improvisation: a combined behavioral and cognitive activity that requires creativity under tight time constraint in order to meet performance objectives. Improvisation in emergency management may be regarded as a two-stage process. In the first stage, the responding organization recognizes either that no plan applies to the current situation or that an applicable plan cannot be executed. Recognizing the need to improvise involves making a judgement about the appropriateness of planned-for procedures given the occurrence of some contingency. As Klein states, "There can be errors of rigidly adhering to someone else's plan as well as inappropriately departing from the plan" (1993).

The question of *when* to improvise may therefore be conceptualized as a problem of categorization, in which the ability or likelihood of a decision maker to categorize correctly is influenced by a number of factors, such as penalties associated with making an incorrect choice and the likelihood that the response will succeed. Time pressure and risk may also influence how the choice is made (Smart and Vertinsky, 1977), in part by reducing the inclination to improvise given that the need exists to do so (Weick, 1993).

The second stage in improvisation requires the real-time development and deployment of new procedures. Standard operating procedures or routines learned from experience may form the basis for a new course of action. The improvisation may range from substitution to the construction of new procedures. In the case of substitution, the responding organization "mixes and matches" existing procedures and/or the materiel used in them. At the other end of the spectrum, the organization must develop new procedures and possibly find new materiel for use in those procedures. An example of the former case is using a school bus instead of an ambulance corps for mass evacuation. An example of the latter case is using fire trucks to provide mobile showers following a chemical exposure[1].

The question of *how* to improvise may therefore be conceptualized as a search and assembly problem, which may be influenced by factors such as time available for planning, risk in the environment and the results of prior decisions.

2.2 Emergency Response Training

Because emergencies do not happen frequently, emergency response personnel must learn how to process and reason about new, possibly never-before-seen, information quickly and accurately. Regular training exercises which induce situations requiring creative thinking under time constraint may support personnel in succeeding in such situations—not by training in how to recognize the need for and execute standard operating procedures, but by training in how to recognize and respond to unplanned-for contingencies. The need for such training has been advocated by various researchers (Kreps, 1991, Weick, 1993).

Current emergency response training is mainly based on table-top, functional or full-scale field exercises. While table-top and functional exercises are limited in their dynamics, full-scale field exercises are expensive, time-consuming to prepare and may imply health risks for the participants. Other approaches are possible. Off-the-shelf training and simulation systems may be appropriate for some organizations (Jain and McLean, 2003, Smith, 2003). Prototype technologies, including those developed as part of research programs (e.g., (Mendonça et al., 2003, Beroggi et al., 2001)) may

[1] Examples courtesy of the Port of Rotterdam (The Netherlands) Emergency Services and the New South Wales (Australia) Fire Brigade, respectively.

offer advanced capabilities beyond those provided by off-the-shelf systems, but might be insufficient for full integration into training regimes. Finally, advances in computing technologies are increasing opportunities for training in virtual environments; however, such approaches are far from standard.

An important feature of emergencies that is handled only to a limited extent in current emergency response training systems is dynamism: many available systems lack the capability to handle the dynamics which arise during emergency response operations. One example is the geographic information systems-based tool HAZUS (National Institute for Building Sciences, 2001), which is used in the United States mainly for disaster planning at the local, state and federal levels. This tool was originally developed for estimating losses due to earthquake disasters but the new release includes models for floods and hurricanes (Srinivasan, 2003). Because of the limited possibility to include dynamic information and because it is a stand-alone-tool, this system can mainly be used in a static way during emergency response training.

The use of dynamic, virtual environments has, however, been part of military training for some time. The High Level Architecture (HLA) provides a standardized software architecture for distributed simulation systems (Institute of Electrical and Electronics Engineers, 2000). Although HLA is mainly considered a standard for simulation-based military training (Lolar, 2002, Sjöström et al., 2003), it has lately been applied to civilian domains such as traffic and logistics (Strassburger, 2001). HLA-compliant training systems for field personnel like first responders or incident commanders are also being developed.

One such HLA-compliant system for earthquake disaster response (Fiedrich and Gehbauer, 2004) consists of three major components: (1) simulators for the disaster environment (e.g. for damage, casualty and fire spread), (2) simulators for the operations of human and technical equipment and (3) other auxiliary simulators. The system was originally designed as a test environment for autonomous software agents with the goal to optimize resource allocation during response operations (Fiedrich, 2000), but the application of the simulation system for training purposes was obvious. To test the system, a two day computer supported exercise with the Romanian Civil Protection Command is scheduled for October 2004.

2.3 Support for Improvisation

Supporting improvisation in emergencies can mean providing training before the emergency (as discussed previously) or decision support during the response to it. Providing support during the emergency entails the development of tools that are made available during the response. A decision aid to support improvisation must be capable of recognizing situations in which a standard operating procedure does not apply or when no standard operating procedure is executable. Given the importance of time in emergency response, the system should also support emergency managers in quickly recognizing the need to depart from planned-for procedures. Once the need is recognized, the system should support organizations in developing and deploying new courses of action.

Agent technologies enable the construction of computer programs that can reason autonomously (Boden, 1994) and thus provide an opportunity for intelligent decision support. There are a number of approaches which try to apply agent technology to areas relevant to emergency response, including earthquake disaster response (Fiedrich, 2000, Tadokoro et al., 2000), forest and bush fire firefighting (Au, 2000, Jaber et al., 2001) and flood management (Molina and Blasco, 2003). So far these approaches are not able to improvise on given situations and they use mainly plan-based reasoning: they use predefined plans which depend on constraints resulting from the current emergency situation.

3 DISCUSSION

A fundamental distinction was made in the preceding section between plan-following and real time plan development and execution. Improvisation has been proposed as one approach to addressing the latter type of situation, so it is useful to explore how plan-following may differ from improvising. Three dimensions and implications of this difference are further discussed in this section.

3.1 Processes of Improvisation

Improvisation and plan-following as cognitive activities are likely to differ in salient ways. Plan-following requires the retrieval and execution of pre-compiled routines; improvisation requires that new routines be assembled and executed in nearly real-

time, with little opportunity for verification other than through mental simulation.

Modeling the cognition of disaster response personnel serves two purposes. First, formal models may contribute to the construction of tools to support improvised decision making. Second, a catalog of cognition and behavior in cases of emergency response could be used in training and simulation (Watson and Marir, 1994).

The identification and selection of cases for study is likely to arise from the particular needs of the study. Webb *et al.* (1998) and Kreps and Bosworth (1993) present two approaches to these activities. Potentially useful data sources from field-based methods include communications logs, videotapes, questionnaires, interviews, news reports, after-action reports, testimony and emergency response plans and procedures. Training programs may represent opportunities both for further building theories of cognition, and for evaluating decision technologies.

3.2 Training for Improvisation

Training for improvisation is likely to require different approaches than training for plan-following, though the two should be seen as complementary. Training for plan-following involves exposure to a broad range of situations, and the learning of the routines that are appropriate for this situations. Training for improvisation first involves learning to recognize unplanned-for contingencies, a task that requires personnel to take a complementary perspective on training for plan-following. Second, improvising itself may require mixing and matching of planned-for procedures.

Experimentation is likely to be useful in evaluating the efficacy of training programs for improvisation in emergency response, as it has been for many other domains (Salas and Cannon-Bowers, 2001). Yet, as noted by Weick (1985), increasing realism in experimental situations leads to reduced generalizability of results. In addition, many times the emergency manager cannot control the events or activities that are controlled in a laboratory setting. Therefore, there needs to be a quasi-experimental approach that provides statistical power but enables generalization of results to a variety of emergency response settings.

In training exercises, it is necessary to define measures for assessing response performance. Factors such as human and property loss, necessary time to control the situation, environmental aspects, costs, and others are relevant. In field exercises it will only be possible to evaluate a single (namely the chosen) course of action. Because at least some of the exercise constraints can only be approximated (e.g. spread and impact of hazardous materials) a comprehensive evaluation will be difficult. In table top exercises it will be possible to discuss the advantages and disadvantages of different courses of action, making this a promising platform for training for improvisation. But nevertheless the evaluation depends very much on the experience of the trainers and the trainees and their appraisal of feasibility and quality of the actions.

3.3 Supporting Improvisation

A fundamental concern is how to provide support for improvisation following the occurrence of unplanned-for contingencies. By constructing computational models of cognition in improvisation, it may be possible to develop tools that can help responding organizations (i) recognize when it is appropriate to depart from planned-for procedures and (ii) develop and deploy new procedures in real-time. Studies based on field data offer opportunities for examining emergency response decision making in a rich environment characterized by complexity, uncertainty, risk and urgency (Vidaillet, 2001), and therefore are useful in developing and evaluating these tools.

One way to overcome some of the difficulties in supporting improvisation is to develop more and more complex plan libraries, where the tool developer tries to consider more system states and actions. A second way is to try to implement improvisation capabilities into software agent. There are also practical reasons for developing agent-based technologies to support improvisation. In the future, emergency response organizations will be either co-located or dispersed, so that technology will be necessary to enable group communications and decision making.

4 CONCLUSIONS

Three broad research questions related to each of the areas—understanding, training for and supporting improvisation—are now presented.

Question 1: How do skilled emergency managers improvise in unplanned-for emergencies? Additional research is needed in developing theory about cognition and behavior during improvisation. It may be useful to draw from other fields where

improvisation is routine in order to understand it more fully (Weick, 1998). Further exploration of the parallel with these fields may also be fruitful in developing methods for training emergency response improvisers. Field-based methods are useful for generating theory, but studies of actual responses may require a change of the public attitude towards the liability of decision makers for the consequences of their decisions during emergencies. Without this, it may be difficult to uncover reasoning or action through techniques such as interviewing.

Question 2: What are some issues concerning the design of simulation environments for training that allows improvisation? One major issue is that the consequences of improvised actions have to be simulated in some way, because otherwise it will be difficult to make the environments realistic. To reduce development costs and improve reuse of the simulators for different training purposes, it is necessary to follow a standard. Here emergency management agencies could benefit from the use of the High Level Architecture.

Question 3: How can decision makers be supported during improvisation? Two different approaches are suggested: first, simulation-based training methods may be used to train for improvisation, but technological advances must be made. Second, computer-based tools for supporting the response may be developed. At one level, these systems may facilitate data collection and analysis (a difficult problem when a contingency has not been planned-for). At another level, intelligent agents with embedded improvisation capabilities may be developed. The agents must have the capability to adjust their goals and plans in real-time and should be able to deal with imprecise and conflicting information. Although agent technology has been applied successfully to many fields, it is still not sufficiently advanced to be used in emergency training and response.

In conclusion, the rarity of occurrence of emergencies and the difficulties involved in comparing responses to them limit opportunities for studying how organizations respond to them, though recent initiatives by various funding agencies have been expanding these opportunities (Myers, 2003). A combination of both laboratory- and field-based methods intended to produce better understanding, training and support is most likely to be effective.

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