Decision support for improvisation during emergency response operations

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Abstract: Emergency response organisations are faced with complex, unpredictable events with the risk of catastrophic losses. To assist emergency response organisations in responding to these events, new models must be developed and the traditional command and control structure of decision making must be revised to accommodate greater flexibility and creativity by teams. In this paper we propose the concept of decision support for improvisation in emergency management. The concept is based on the paradigm of operational risk management and is motivated by the observation that emergency response organisations must be prepared to improvise during response activities. The process of emergency response in light of this new concept is first discussed and opportunities for supporting the process identified. We conclude with a review of a project at the Port of Rotterdam, where we are currently assessing this new decision making approach for emergency management.

Keywords: Emergency response; operational risk management; improvisation; blackboard-based decision support.

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1 The process of emergency response

Emergency response relies on one or more response plans. The proper execution of plans is typically managed by a command and control centre. A commander at the scene coordinates the activities of the units responding to the emergency. The on-scene commander and support staff gather and analyse data, make decisions, and monitor their implementation and consequences. The activities required to respond to an incident are often dangerous and must be carried out under time pressure.

Activation of emergency plans is based upon assessment of the potential impacts of an accident and the courses of action needed to eliminate or at least mitigate this impact. These response plans can rarely be executed as expected, as the case of the Exxon Valdez accident showed [1]. Flexible approaches to emergency management are therefore required. Any such approach must be able to deal with an uncertain and changing environment and allow for revision of planned courses of action. Moreover, the approach must be able to support emergency managers in improvising when no standard operating procedure can alleviate the catastrophe.

Unanticipated events affecting planned activities may arise during response operations. Examples include traffic congestion delaying the arrival of the response team and bad weather preventing needed response equipment from arriving on-site. In such situations, the commander must be supported in assessing the potential impacts of these events and deciding whether to continue following planned courses of action or to pursue alternate activities in order to maintain the safety and efficiency of the operations. Performing these tasks requires that real-time monitoring and control of response activities, as well as of any external events that have the potential to affect these activities, be considered as integral parts of effective emergency response.

The operational risk management (ORM) paradigm [2] takes into account the uncertain nature of response activities. For example, fire trucks may be unavailable, weather conditions may change unexpectedly, or chemical dispersants may not work as planned. ORM also accounts for the fact that this uncertainty may change the risks associated with various courses of action. For example, a fire may overrun a barricade or the use of water could increase the threat of fire. Although ORM supports the emergency manager's decision making process, human cognitive limitations in operational environments must be considered as a constraint. Consequently, decision support in emergency management must always consider the human as an integral part of the decision making process. Technological and analytic support should be tailored to the human's capabilities and constraints, and not vice versa.

In certain situations, no planned-for activities may be feasible, leading to the need to revise the plan. An unexpected event may evolve; so that implemented plans are no longer applicable. An unexpected event may be multi-faceted, requiring emergency response organisations (EROs) to combine many plans in unexpected ways [3]. In a response involving numerous organisations, allocation of resources to certain tasks may make those resources unavailable for other tasks. Finally, the resolution of unanticipated contingencies may not be immediately assignable to any particular organisation. In these circumstances, EROs must be prepared to improvise: that is, to rework their knowledge in a novel way in time to fit the requirements of the current situation.

The need for skill in improvisation was emphasised for emergency management practitioners by Kreps [4]:

> "Without improvisation, emergency management loses flexibility in the face of changing conditions. Without preparedness, emergency management loses clarity and efficiency in meeting essential disaster-related demands. Equally importantly, improvisation and preparedness go hand in hand. One need not worry that preparedness will decrease the ability to improvise. On the contrary, even a modest effort to prepare enhances the ability to improvise."

Klein stated that "The need for improvisation is a continual aspect of team decision making. There can be errors of rigidly adhering to someone else's plan as well as inappropriately departing from the plan" [5]. Yet, as noted by Weick in his seminal study of the Mann Gulch fire, "What we do not expect under life-threatening pressure is creativity" [6]. Indeed, there is considerable evidence to suggest that teams in decision settings like emergency management enact strategies based on recognising characteristics of past problems in the current one [5]. A sobering conclusion of Weick's study of Mann Gulch is that, under certain conditions, teams may force their conception of the emergency to fit one they know how to address [6].

The foregoing results point to the need to support emergency managers in responding to real-time events in situations requiring either modification or creation of courses of action. Methods for providing these types of support should be embedded in decision support tools and should be based on an understanding of cognitive-level processes involved.

2 Support for improvisation

The decision task of a team facing an unanticipated contingency is to generate a creative response, which addresses the contingency and can be implemented in the time available. Support for this task in domains other than emergency management has generally been in the form of heuristics, either embedded in software or not. One of the most common creativity-enhancing methods is brainstorming, which involves uncritical acceptance of as many ideas as possible. Following heuristics that support brainstorming seems to result in more ideas, but there have been few investigations into the relevance of such ideas to the task, the capability of one heuristic to produce results which differ from another's, or the feasibility of brainstorming in severely time-constrained situations. Nonetheless, Massetti's [7] results suggest that, at least at the individual level, training in brainstorming may support task-relevant creativity and that the embedding of heuristics in a creativity support system does not hinder task-relevant creativity.

Improving understanding of cognitive processes in improvisation is a vital first step in developing decision aids to support improvisation and is a research strategy with a firmly established tradition. In raising outstanding questions for field research in crisis decision making, Klein [5] discussed the need for an improved understanding of how teams improvise successfully. Researchers have begun to study improvisers in diverse fields, including business and the arts. Other recent work appears in a series of papers on improvisation in the September-October 1998 special issue of Organization Science entitled ‘Jazz Improvisation and Organizing’. An important point in much of this research is that, in order to understand the process of improvising, we should study decision making in situations which require, or at least permit, some degree of improvisation.

3 A theoretical framework for improvised decision making by teams

Hayes-Roth and other researchers have created computational models of improvisation, which have been used either to model or support improvised decision making by humans. In a series of early experiments in human planning, Hayes-Roth and Hayes-Roth [8] observed that human planning could be multidirectional and opportunistic. It is multidirectional in that humans seem to plan at various levels of abstraction and seem to be able to move between those levels, displacing some goals in favour of others. Planning is opportunistic in that “goals that fit into a developing plan are integrated, and goals that belong together are clustered into subplans, often without regard for how the subplans will integrate with the overall plan” [9]. Opportunistic planning is closely akin to ‘coordination by feedback’ which takes place in Emergency Operations Centres [10], where decision makers must be prepared to make decisions based on feedback they receive from the field.

Hayes-Roth and colleagues developed a series of blackboard-style architectures based on these experiments. For example, the Guardian system has been tested on the tasks of monitoring and diagnosing emergency room patients in real-time and been favourably evaluated [9]. More recently, Hayes-Roth and colleagues have explored directed improvisation: that is, the “simultaneous invention and performance of a new ‘work’ under the constraints of user-specified directions.” Directed improvisation has been implemented by extending and modifying the blackboard architecture BB1. The Virtual Theater, a collection of BB1-based software characters embodied as agents, is the testbed for the directed improvisation paradigm [11].

3.1 Blackboard-based decision support

The emergency response organisation (ERO) in a blackboard-based system can be comprised of a number of humans and software agents. In the Virtual Theater, a human provides high level directions to software agents (‘characters’) whose task is to improvise a course of action while abiding by those directions. Directions may be abstract, such as ‘go to x’. A character considers behaviours that are consistent with the user’s directions and with the character’s perceptions of other characters’ actions. The character then selects (‘realises’) the most preferred behaviour for the current situation. A realisation of the preceding direction might be ‘hop to pedestal’. Throughout the performance, characters welcome possibilities and pursue promising ones.

The models embodied in the Guardian and Virtual Theater systems share similar features. A model in either system is realised as an agent (a type of doctor or patient’s advisor in Guardian and a virtual actor in the Virtual Theater). Each agent has a two-level architecture comprised of a physical controller and a cognitive controller, both of which are based upon a dynamic control model. The dynamic control model allows for concurrent and asynchronous control of an agent's perception, cognition and action. The dynamic control model constructs control plans which specify a sequence of tasks, parameter values and constraints. One step in a sample control plan in Guardian is to perform, as quickly as possible, the task of diagnosis, taking a blood pressure reading of 140/90 as input and giving a clinical judgement as output. A repertoire of behaviours, which take blood pressure as input, is available. A behaviour embodies "the potential application of particular methods to particular tasks in particular contexts." In Guardian, the context is the knowledge the agent has about the patient; an example method is to use case-based reasoning to determine the cause of the condition. Every behaviour in turn has triggering conditions that are satisfied by particular events, such as a sudden increase in blood pressure. A scheduler selects from triggered behaviours the one that best matches the plan. Finally, an executor performs the chosen behaviour. Again, because planning is opportunistic, execution of an active plan can be suspended when the need arises. A listing of the behaviours followed by an agent is its control plan.

A human team member communicates via the blackboard system with other team members, whether they are real people or software agents. When communication is from software agent to human operator, the simplest type of operator control occurs when an action recommended by the system is rejected or approved. Higher levels of communication allow for provision of more general commands. In either type of communication, the blackboard performs the function of a team mental model since it holds decision makers' representations and is shared by members of the team.

3.2 Adapting and encoding approaches to improvisation

To provide decision makers with support in improvising, a blackboard-based agent must be instantiated with knowledge and reasoning processes appropriate for the domain. Possible sources for this instantiation include field and laboratory studies. The Disaster Research Center (DRC), currently at University of Delaware, conducted numerous, occasionally large-scale field studies involving interviews with emergency responders and affected persons. DRC's interview methods were semi-structured. According to Quarantelli [12], training of interviewers emphasised that DRC wanted the overall picture of the disaster, which necessarily involved seeking multiple perspectives on the disaster response. Indeed, these multiple perspectives offer an opportunity, in the context of improvisation, to investigate how members of a responding organisation perceived and responded to actions of other members. In the following scenario, excerpted from a case in DRC archives, an instance of improvisation during emergency response is presented and the decision maker's approach to improvisation is represented in a simplified control plan.

3.3 Case study: chemical plant fire

A fire department in a small north-eastern town responds to an incident at a chemical plant involving an explosion and fire in Unit One and resultant threat to Unit Two. Although other organisations respond to different facets of the incident (e.g., Civil Defense provides shelter), the fire department is responsible for containing the fire. Table 1 shows the process trace and control plan for the deputy chief.

Table 1 Process trace and partial control plan for the deputy chief

Line	*Process Trace*	*Partial Control Plan*
1	Receives notice of threat to Unit Two and decides to respond to the threat.	
2	Asks where are the helpers?	
3	Asks how close are we to having an incident at Unit 2?	
4	Looks for helpers, finds and organises the response team at coffee wagon.	
5	Team sets up water canons between the fire and Unit 2 and proceeds to douse Unit 1.	
6	Notices fire threat has lessened and stabilised.	
7	Snowstorm begins.	
8	Decides that nothing else can be done except douse Unit 1.	
9	Receives gas masks.	
10	Team starts maintenance or picking operation (i.e., lifting debris and dousing resulting gap with water) in Unit 1.	
11	Crane becomes available.	
12	Crane used to lift roof of Unit 1.	
13	Crane breaks down.	
14	Commissions two other cranes.	
15	Notices flooding and the impediment of ice due to dousing.	
16	Water supply exhausted.	diagnose (zero flow, empty well)
17	Realises hoses cannot be moved without damaging them.	plan treatment (evidence of empty well, relocate operation)
18	Removes tips from frozen hoses. Sets up operations at nearby hydrant.	implement treatment (relocate operation, move new hoses to hydrant) interpret sign (positive flow from hoses, normal) *interpret sign (frozen hoses in path, obstruction hazard)*
19	Returns to maintenance plan.	interpret sign (reduced smoke and fire, fire under control) implement treatment (fire under control, maintenance plan)
20	Requests a forestry truck to transport hoses to station.	*plan treatment (obstruction hazard, remove obstruction)* *implement treatment (remove obstruction, get forestry truck)* dispatch (forestry truck, transport plan) transport (hoses, station)

The incident occurs in winter: temperatures are below freezing; a blizzard during operations leaves ten inches of snow. DRC personnel interviewed numerous members of the local fire department, including the deputy chief, soon after the incident.

In the course of the emergency response, the deputy chief (DC) is dispatched to the plant and told by the plant manager to ‘stop that fire from coming in’ to Unit Two from Unit One. DC has no set plan for addressing the emergency but is familiar with plant operations and recalls that Unit 2 is similar in structure to Unit 1. The summary of this episode in the case is in two parts. First, a process trace describes, to the extent possible and in natural language, the signals which DC received and the behaviours in which he engaged. Secondly, a hypothesised partial control plan summarises the tasks undertaken by DC as self-reported in the case, as well as task input and output (shown, respectively, as the first and second items in parentheses). In documenting the control plan, a number of processes (i.e., tasks) which DC employs have been inferred from the interview.

Some features of DC's problem-solving strategy are immediately evident. Progress towards the goal of stabilising the fire is hampered numerous times (e.g., lines 13 and 16), requiring temporary suspension of the picking plan and attention to other tasks (commissioning other cranes; arranging for removal and replacement of the frozen hoses). DC's decision to remove the frozen hoses using a forestry truck is an instance of improvisation: a presumably pre-existing action (removing an obstruction) is modified only by adding a novel means of effecting it (i.e., commissioning a forestry truck). It may be that DC's ability to improvise here is contingent upon his having a capability to recall an object based on its functional capabilities. A decision aid in a similar situation might take the direction 'transport hoses' as input and offer one or many plans as output. Alternatively, the direction to 'remove an obstruction' might produce a different plan (such as 'drag hoses to side') as output.

As this example demonstrates, new behaviours and ways of realising them must be defined in order to encode instances of improvisation during emergency response. The Deputy Chief's improvisation concludes when he recommences with a planned-for course of action (i.e. the maintenance or picking plan). With completion of the coding, the various behaviours, including the conditions under which they were triggered, would be stored for later retrieval.

4 An assessment of decision support for improvisation

We are in the process of assessing our capability to support improvisation with emergency responders from the Port of Rotterdam in the Netherlands. In so doing, we are following the approach taken in our past work: to assess decision support systems in field settings that closely resemble those of actual crisis situation [13].

The Port of Rotterdam is one of the largest cargo and container ports in the world. In addition to intense cargo handling activities, a large number of processing facilities and storage sites for hazardous materials are located at the port, including storage places for ammonia, chlorine, liquefied natural gas, and propylene. The port area falling within the hazard area of port activities is about 600 square kilometres and contains about one million people.

The Rotterdam harbour area has developed a Regional Operational Base-Plan (ROB) to protect the physical and social health of the population. The two most important decision making authorities for ROB are the Command Place Incident (CoPI) and the Regional Operational Team (RegOT). CoPI members are commanders of the fire brigades, police, ambulance, hazardous materials specialists, and press. The head of CoPI is the fire brigade commander. CoPI members meet at a centralised location, usually a specially equipped vehicle. The decision making regime for emergency management is defined in the Coordinated Regional Incident-Management Procedure (CRIP). CRIP has four alarm levels, corresponding to increased levels of severity in risk, and becomes active for incidents involving hazardous materials, large-scale technical emergency response, or any other accident where at least one of the CoPI members calls for a coordinated response to an incident.

The port authority is currently investigating alternative methods for supporting communication and decision processes [14]. To this end, the port authority has acquired various advanced communications and information technologies, including a group decision support facility (GDSF), a multimedia authoring tool to design exercise scenarios, a large flat panel display for digital video conferencing, and several digital cameras to record incident scenarios and monitor the exercises.

The port's GDSF will be used by the CoPI during emergency response, allowing the commanders to brainstorm, categorise their ideas, and arrive at a consensus decision. The incident description will be embedded in a multimedia system and will include all databases, animation, video, audio, and textual and graphical instructions. Feasible courses of action can be presented and evaluated according to the decision makers' preferences. During training sessions, unanticipated events could be generated at any time by the exercise staff, forcing the commanders at the CoPI to assess the impact of these events and, if necessary, to alter the current courses of action or develop new ones. The port has identified the need to train response teams in recognising and adapting to unplanned-for situations. The port has therefore broadened its focus from training teams solely to follow SOPs to training teams to be better improvisers.

The port authority just completed a series of field exercises using new information and communications technologies and training approaches. The commanders gathered as a CoPI and made decisions supported by a GDSF. Each CoPI exercise team consisted of five to seven commanders. Six sessions, each lasting two to three hours and involving two exercises, were conducted. A decision support system was used in all cases as part of the GDSF. The logic embedded in the system varied from none to recommended procedures. Our preliminary analysis of the results showed that teams with the assistance did investigate new courses of actions.

5 Concluding comments

As was assumed in our previous research, advanced information and communications technologies will become an indispensable part of modern emergency response operations. Our focus lies, therefore, on how to complement these new technologies with intelligent decision support systems that improve the decision making process with the result being more efficient and effective emergency response.

The impetus for this research is the observation that organisations need to maintain flexibility in order to respond to unanticipated contingencies [4,6]. The thesis of this research is that support for emergency response organisations (EROs) in exercising this flexibility can be provided by a computer-based system and that the system's design system ought to be informed by an understanding of the cognitive processes involved in responding to unanticipated contingencies. When these situations arise, EROs must be prepared to improvise: that is, to rework their knowledge in a novel way in time to fit the requirements of the current situation.

The principal contribution of the proposed research is twofold: a better understanding of the process of improvisation in emergency response and a system whose design is driven by this understanding. A unique characteristic of this research is its reliance on cognitive-level analyses of improvisation and adapted for use in a decision support system in emergency response. The research also advances methodologies for the study of improvisation in jazz and emergency response.

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