OPERATIONAL SUSTAINABILITY MANAGEMENT FOR THE INFRASTRUCTURE: THE CASE OF EMERGENCY RESPONSE

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Contents

Summary

The need for operational sustainability management of infrastructures is described in the context of emergency response. Emergency response organizations are faced with complex, unprecedented events with the potential for catastrophic losses. Advanced computing and communications technologies provide the potential to reduce this complexity by facilitating information and data processing. Integration of intelligent

decision support models into these advanced systems has further improved operational decision making. However, new models need to be developed and the traditional command and control structure of decision making be revised to accommodate greater flexibility and creativity by teams. We propose the concept of intelligent decision support for sustainability management, using the case of emergency response. The process of emergency response in light of this new concept is first discussed and opportunities for supporting the process identified. A synopsis of recent technologies and their integration with structured decision making methods illustrates how technologies can assist emergency response organizations in achieving greater flexibility in highly uncertain environments. We discuss a project at the Port of Rotterdam, where we are currently implementing these new technologies and decision making concepts for emergency management. We conclude with suggestions for implementing operational sustainability management for the infrastructure.

1. Introduction

Human beings have always been beset by threats to their well-being. Yet, with each new deadline announcing earthquake, flooding, storm, terrorist attack or other crisis, it appears that the vulnerability of our infrastructure to catastrophic events is increasing. In fact, some studies have documented that losses and potential losses in the United States from various hazards are rising at an alarming rate.

Despite the headlines, many of these occurrences are perfectly “natural” events – some of which have been happening for millions of years. Flooding river deltas is one; the threat of attack on food supplies (by neighboring tribes) is another. These events became catastrophic when we:

- move our activities in life, work, or play into high risk areas, and
- build complex, tightly coupled infrastructures to satisfy our needs and wants.

We are doing both. People are moving to suburban and exurban locations, many of which are in unpredicted flood plains, seismic risk areas, and exposed coastal locations. In addition, we are building infrastructures to support their life, work and play. In addition, advances in communications and computing technologies are being employed to create both new infrastructures, e.g., cellular communications and the Internet, and to make infrastructures safe and more productive, e.g., intelligent transportation systems.

Public posture with regard to managing hazards is interesting, yet not particularly surprising. It is apparent to even the most casual observer that public, governmental and research interest in disaster management peaks just after the occurrence of a hazardous event. At most other times, it has *appeared* that formulation of useful comprehensive disaster management plans and policies is a “back burner” item on governmental agendas. As testimony to this, it wasn’t until 1979 that the US government saw fit to consolidate its loosely connected disaster preparedness program by forming the Federal Emergency Management Agency.

The impact of disasters is in reality the interaction among three systems: the natural environment, the human community, and the built environment – the infrastructure that supports human activities. The sustainability of our infrastructure depends upon knowledge of the natural environment – for example, the research on global warming and its impact on meteorological events such as storms, droughts and floods. Sustainability also depends upon the demographic composition and distribution of population. Shifts in population require expanded infrastructures; people moving into hazardous regions like coastal areas may require new infrastructure.

One way to help ensure the sustainability of our infrastructures is by developing plans and procedures for disaster preparedness and response. These plans and procedures will form the basis for the training of emergency response personnel and organizations. However when unforeseen events occur that make implementation of the plan and procedures impossible, emergency response organizations are faced with complex events with the potential for catastrophic impacts on society and its infrastructure. Advances in communications and computing technologies provide the capability to reduce this complexity by facilitating the flow of data and its processing into information to support problem solving and decision making. In this chapter we propose the concept of operational sustainability management to help insure the sustainability of our infrastructure.

Organizational decision making can be categorized into three areas or levels; strategic, concerned with policy formulation and goal setting, including deciding on objectives, on the resources to attain these objectives, and the policies that determine how to acquire and deploy these resources; tactical, the way managers attain the resources and allocate them to accomplish the organization’s objectives, and operational, the process of carrying out specific tasks effectively and efficiently.

The need to address sustainability across strategic, tactical, and operational levels of organizational decision making has been acknowledged in the literature. Flamant et al. [1999] report on an national policy program in France for promoting sustainable regional development. The objective was to promote actions at the tactical and operational level to achieve sustainable land use management. The study addressed production systems, farm operation, and spatial structures. Kupitz and Mourgovo [1999] expect a growing reliance on nuclear energy policies due to improved operational standards and the need to adopt policies to reduce green house emissions. Harmsen and Chewter [1999] discuss design principles for future multi-functional chemical reactors that produce less waste, require less energy, are low in costs, and produce high-quality products. The key to their design approach is to translate concerns of safety, health, environment, sustainability, product quality, and finances into functions at the tactical and at the operational level. Rogers [1998] contemplates that the siting of potentially hazardous facilities should be sensitive not only to strategic risk-benefit tradeoffs but also to the process of siting, the phase of construction, the operation, and the shutdown of the facility.

Sustainability can be defined for all levels of decision making, operational, tactical, and strategic. The objective of sustainability at the operational level is to assure efficient and safe operations. Systems complying with this objective at the operational level are what we refer to as stable systems. At the tactical level, sustainability refers to organizational decision making, where conflicting plans and procedures must be made compatible in order for a system to work properly. Systems complying with tactical sustainability are what we refer to as resilient. At the strategic level, sustainability refers to organizational decision making concerned with the external environment – market forces, natural systems, etc. Systems complying with policy stability are what we refer to as durable systems. A comprehensive definition of sustainability refers, therefore, to operational stability, organizational resilience, and strategic durability. In this chapter we will focus on operational decision making as part of this comprehensive view of sustainability, and propose operational sustainability management.

Organizations charged with responding to an event with the potential for catastrophic impacts, emergency response organizations (ERO's), strive to eliminate or at least mitigate the physical destruction, losses, and human suffering imposed by disasters. Therefore, an ERO's objective is to prevent an emergency from becoming a disaster.

Emergency response organizations have benefited from technologies for sensing and monitoring, i.e., global positioning systems for locating equipment and for communications (e.g., cellular communications networks for management of field operations). Newer information technologies such as multimedia, hypermedia, virtual reality, and group decision support facilities are being assessed for their potential to aid in emergency response. However, in order to make effective use of these technologies, reasoning systems to support human cognition are required. The purpose of this chapter is to present two such systems, one for aiding the preparation and implementation of emergency response plans and another for supporting emergency responders when the plan cannot be followed and they must improvise. We first review the process of emergency response and identify opportunities for supporting it. Several prominent or promising technologies which may be incorporated into the decision making processes are then described. We then describe these two paradigms for supporting decision making in emergency response which can make use of advanced information technologies. Finally, we provide some concluding comments on the concept of operational sustainability management and its implementation.

2. The Process of Emergency Response

Emergency response relies on one or more contingency plans. The proper execution of the plans is managed by a command and control center. A commander at the scene coordinates the activities of the units fighting the emergency. The on-scene commander and support staff gather and analyze data, make decisions, and monitor their implementation and consequences. The activities required to respond to an incident are dangerous and must be performed 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 contingency plans can rarely be executed as expected, as the case of the Exxon Valdez accident showed. 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 always 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 safety and efficiency of 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.

In order to monitor and control response activities and potential external events, data about the extent and severity of the event, meteorological conditions, and current capabilities for response must be collected. These data are then assessed and processed, from which courses of action can be assessed and altered. Decisions on whether to change the ongoing operations must be made in a very time-constrained environment. Obviously, the quality of these decisions depends on the quality of the data. Consequently, the commander's ability to process these data in a form that is understandable and useful to the emergency response team must be supported. For this type of support, initial decisions can act as constraints on subsequent decisions. The response phase, therefore, concludes when a plan has been accomplished and when threats to life, property, and environment are under control.

Advances in communications and computing technologies provide the means for monitoring and control of emergency response operations. These technologies include monitoring devices such as sensors, mobile communication systems, and mobile control systems such as robot assistants. Sensing technologies provide means for response personnel to "see" inside a damaged reactor with mini-video, "feel" conditions inside a burning container with robot devices, and "track" the dispersion of pollution with satellite imagery. These technological advances, however, assist response personnel only in *sensing*; special support is required for *reasoning* in order to help emergency managers improve their decision making capabilities. Logics based on operational risk management and opportunistic reasoning are discussed below in the context of providing such support.

The operational risk management (ORM) paradigm takes into account the uncertain nature of response activities. For example, trucks may be unavailable, the 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, the fire may overrun a barricade or the use of water could increase the fire threat. Although ORM supports the emergency manager's decision making process, human cognitive limitations in operational environments must be considered as a constraint. Consequently, intelligent decision support in emergency management must always consider the human as an integral part of the decision making process. Technological and analytic support must always be tailored to the human's capabilities and constraints, and not vice versa.

In certain situations, no planned-for activity may be feasible, leading to the need to revise the plan. An emergency may evolve, so that implemented plans are no longer applicable. An emergency may be multi-faceted, requiring emergency response organizations (EROs) to combine many plans in unexpected ways. In a response involving numerous organizations, allocation of resources to certain tasks may make those resources unavailable for other tasks. Finally, resolution of unanticipated contingencies may not be immediately assignable to any particular organization. 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 emphasized for emergency management practitioners by Kreps [1991]:
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” [1993]. 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” [1993]. Indeed, there is considerable evidence to suggest that teams in decision settings like emergency management enact strategies based on recognizing characteristics of past problems in the current one [Klein, 1993]. 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 [Weick, 1993].

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 tools and should be based on an understanding of cognitive-level processes involved. Support may precede or be concurrent with the response, as discussed in the following sections.

3. Opportunities for Supporting Decision Making

3.1 Support for Operational Risk Management

Emergency response often consists of following pre-planned courses of action which are composed of standard operating procedures (SOPs). In order to enable EROs to question the quality of ongoing plans and to look for better alternatives, response plans cannot be purely sequential. Rather, response plans should be based on a broader structure which allows one to assess the impacts of unexpected events, re-evaluate a given course of action, and consider alternatives that allow response operations to continue. We therefore propose a graph theoretical approach which structures real-time risk analysis and decision making situations in emergency management.

A course of action (CA) in emergency response consists of a temporally ordered sequence of decisions and concomitant selected SOPs. Each SOP is preceded by a decision, which in turn leads to a new decision on the next SOP. Examples of SOPs are emergency vehicles approaching the accident site, the loading of a vehicle, the activities of fighting a fire, the process of closing a harbor, and the procedure of activating the response team. Each SOP is preceded by a decision; that is, every specific SOP has been chosen from a set of several possible SOPs. Some SOPs require that other SOPs be done earlier on, while others are more independent.

Emergency response commences with a decision that a significant event has occurred and, then, the need to reevaluate the present ongoing CA. The last decision is to decide if normal operations can be resumed; that is, whether the response to the accident can be considered to be over. It is important to remember that there are always different ways to respond to an emergency; in other words, different CAs could be pursued.

The environment for intelligent decision support in emergency management consists of four components.

(1) *Real-time events* (RTEs) are unexpected events which affect the successful completion of the ongoing response plan, which is expressed in terms of a CA.

(2) The *human emergency manager* controls ongoing operations, monitors the system for RTEs, and guides operations during RTEs. The guidance of operations in real-time is based on the premise that the emergency manager can better monitor the environment for RTEs and make better decisions than would be made by people in the field. Monitoring and decision making are supported by advanced information and communications technologies, such as satellite technology, environment monitoring systems, virtual reality systems and commercially available software packages that can retrieve weather forecasts.

(3) The *event system* consists, for example, of transportation networks, vehicles, surroundings (e.g., urban, rural, and environmental areas), and RTEs (e.g., natural disasters, road accidents, vehicle failure).

(4) The *communications links* between headquarters and the event system can transfer various kinds of data (e.g., location of vehicles, condition of material and cargo, extend of damage, or spread of plume) between personnel.

The tasks of the emergency manager are the following:

(1) *Monitoring* the emergency operations and looking for RTEs. An RTE is said to be *perceived* when the emergency manager considers it to have had an impact on the successful completion of the ongoing CA. As soon as enough information to determine the extend of the RTE has been gathered and processed, the RTE is said to be *located*.

(2) *Identification* of operations affected by the RTE. As soon as an RTE is located, operations that plan to use affected SOPs or those already using them are said to be *affected* by the RTE. The emergency manager would like to know which operations are affected by the RTE and at approximately what time the operations will bee affected.

(3) *Assessment* of impacts of RTEs on the success of employing a SOP. When the impacts of the RTE are assessed by the emergency manager, the RTE is said to be *assessed*.
(4) *Decision making* for affected operations. After the RTE is located, the emergency operator would like to find, if necessary, new CAs that can lead to a successful completion of the response operation. Suggestions regarding the continuation of the CA can be to continue to follow the ongoing CA because the RTE is not that severe or to use alternative CAs in order to avoid or mitigate the effect of the RTE.

3.2 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 heuristics is brainstorming, which involves uncritical acceptance of as many ideas as possible. Following certain creativity heuristics 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 [1996] results suggest that, at least at the individual level, training in creativity heuristics 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 [1993] 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 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.

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Professor William (Al) Wallace is a member of the faculty of the Decision Sciences and Engineering Systems, Civil Engineering and Cognitive Sciences Departments at Rensselaer Polytechnic Institute, and is presently Research Director of Rensselaer's Center for Infrastructure and Transportation Studies. He has held many appointments and positions abroad, including Visiting Professor, Systems Engineering and Policy Analysis, Delft University of Technology, Visiting Professor, Polyproject: Risk and Safety of Technical Systems, Swiss Federal Institute of Technology, Zurich, and a U.S. faculty member at the Dalian Institute of Technology, Dalian, China. He was a research scientist at the International Institute of Environment and Society, Science Center, Berlin, Germany. In addition, he has been a visiting professor at the University at Albany and Carnegie-Mellon University. Wallace completed assignments as Consultant, Board on Infrastructure and the Constructed Environment, National Research Council, and Expert, Civil and Mechanical Systems Division, National Science Foundation. As a researcher and a consultant in Management Science and Information Systems, Professor Wallace has over 30 years experience in and research on the development and use of information technology for industry and government. He is presently engaged in National Science Foundation sponsored research on the application of artificial intelligence to problems in incident management and emergency response, as part of a recent Information Technology Research grant, the issue of trust and knowledge management on the Internet and the vulnerability of critical infrastructure interdependencies, with particular emphasis on the

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