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Establishing Functional Requirements for Emergency Management Information Systems

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ABSTRACT

The advancement of computer technologies has led to the development of a number of emergency management information systems (e.g., EIS, CAMEO, IEMIS). The design of these systems have tended to be technologically driven rather than oriented to meeting information management needs during an emergency. Of course, emergency management needs vary depending on the characteristics of the emergency. For example, in hurricanes, onset is typically slow enough to allow emergency mangers to simulate evacuations dynamically while in chemical disasters onset may be sufficiently rapid to preclude such simulation(s). This paper describes a system design process in which the analysis of widely recognized emergency management functions was used to identify information requirements and the requisite software and hardware capabilities to deal with rapid onset, low probability, high consequence events. These requirements were then implemented as a prototype emergency management system using existing hardware and software to assure feasibility. Data, hardware, and software requirements were further developed, refined, and made more concrete through an iterative prototyping effort. This approach focuses attention directly on meeting emergency management information needs while avoiding unneeded technological innovations.

INTRODUCTION

Public safety officials, corporate officials, and the public are increasingly aware and concerned about rapid onset, low probability, high consequence technological hazards. An example of this class of event is the sudden release of large quantities of toxic substances into the atmosphere placing nearby populations in imminent danger and leading to substantial numbers of casualties. Events of this type require immediate response in terms of identification of the problem and decision making to: alert command and control elements, mobilize appropriate emergency resources, protect populations at risk, alert the public, manage resources, contacts, lists, and procedures, and handle reentry and recovery.

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A review of existing Emergency Management Information Systems (EMISs) available from public or private sources shows that all have significant limitations which impede their effective use for rapid onset, low probability, high consequence events (Feldman and Dobson 1990). Existing EMISs tend to focus much more on the character and nature of emergency events than on organizational issues such as planning, resources, procedures, communication, and coordination. In part, these limitations are a consequence of the way these systems were developed and, in part, they stem from the nature of organizational data which tends to be soft and difficult to capture and maintain. Often these systems were developed for other purposes or in response to available technology rather than in response to the requirements for dealing with emergencies. This does not mean these systems are without merit for emergency planning or for use in emergencies but it does mean that a careful evaluation of these events might lead to the selection of quite different features and/or a different way of implementing particular functions or requirements.

This paper describes the development of an emergency management system based on the identification of information requirements derived from an analysis of widely recognized emergency management functions (Reed 1990). These information requirements are then examined in terms of the requisite software and hardware capabilities. The approach used here describes the requirements for an EMIS to respond to rapid onset, low probability, high consequence events, and identifies how technology might be used to aid decision making. This process involved:

- examining the nature of rapid onset, low probability, high consequence emergency events;
- evaluating the constraints and limitations that these impose;
- using a standard list of emergency management functions to generate requirements;
- evaluating generic requirements;
- organizing requirements around the stages of an emergency event; and,
- prototyping to demonstrate the feasibility of meeting the requirements.

Often these steps were carried out concurrently.

THE NATURE OF CHEMICAL ACCIDENTS

Chemical events are characterized as "rapid onset" because the elapsed time between an accident and when populations may be exposed to agent can be very short. There are many reasons why rapid exposure may occur. In many parts of the country, population has grown in proximity to industrial sites which use or store hazardous chemicals. Another reason is that vehicles used to transport hazardous substances must use the major highways which pass through major population centers.

The problem is illustrated by the Army Chemical Stockpile Program (Carnes 1989; Carnes and Watson 1989). At three of the chemical stockpile sites, chemical agent borne by a 3 m/s wind can reach more than 10,000 people in less than 30 minutes and at two other sites agent can reach 10,000 people in about 40 minutes (Rogers, et. al. 1989). Lethal concentrations of agent could reach these same people at faster windspeeds but this would require a larger release of agent, an extraordinary circumstance, because agent disperses more rapidly at higher windspeeds. The point of these illustrations is to show how quickly chemical agent(s) can reach the public and how limited the time is for officials to assess the severity of the hazard, to make decisions to warn the public, to warn the public, and for the public to take protective actions.

The Army's unitary chemical stockpile sites also provide an example of what low probability may mean. It is estimated (Chemical Stockpile 1987)) that if there were 10,000 disposal programs such as the Army program, only 3.2 of those programs would have an accident resulting in one or more fatalities. If there were 10,000 storage programs lasting 25 years each, 25 of these programs would experience 1 or more fatalities. The estimated probability of one or more fatalities for the continued storage of the existing unitary stockpile is estimated to be about 2.4 chances in 25,000 years. The probabilities associated with the use of chemicals in industrial and transport setting are less certain.

High consequence events are those events that could result in substantial numbers of fatalities and/or loss of property if not handled properly. The potential for casualties from a release at the chemical stockpile facilities is an example.

While the circumstances will vary, there is potential for rapid onset, low probability, high consequence accidents throughout the US and in the rest of the world. In actuality, such events are fairly common (see Figure 1). Sorensen (1987) examined chemical accidents resulting in an evacuation of the public in the five-year period, 1980 to 1984, based on either United Press International (UPI) or the Associated Press (AP) news wire accounts as reported by NEXUS. An update of this data shows that there were more than 50 chemical accidents a year involving the evacuation of at least 10 people.

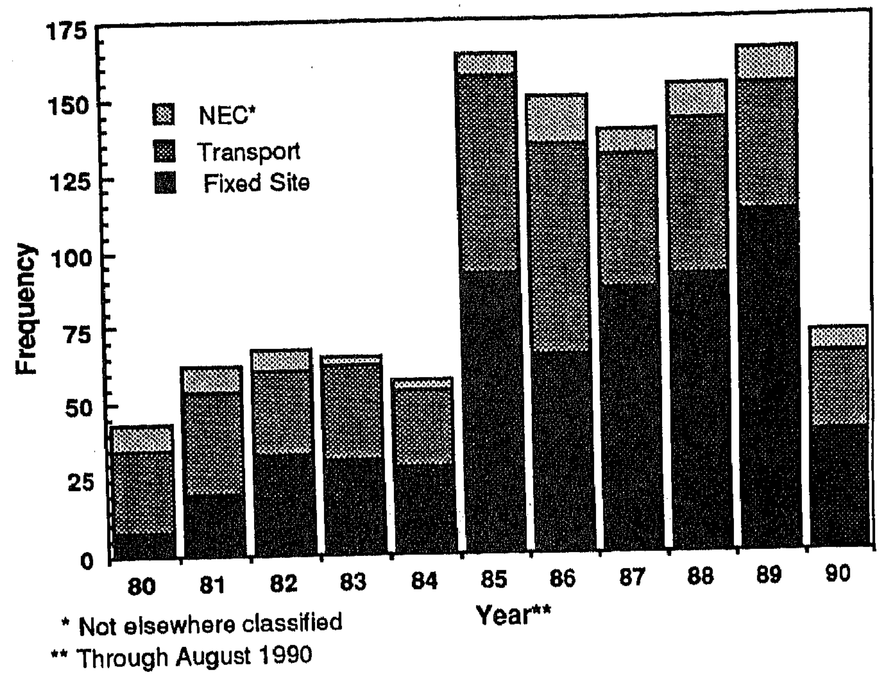

Fig. 1. Frequency of chemical accidents with evacuation in the U.S. in the 1980s

Subsequently this data has been updated and the new data show that the frequency of chemical accidents reported by AP/UPI has more than doubled to over a hundred accidents a year (for years where complete data is available) since 1984. The reasons for this increase are unclear but a possible reason is that the accident in Bopahl, which occurred in December, 1984, may have caused a change in reporting practices. In addition, public officials may be more willing to recommend or order precautionary public evacuations in the post Bopahl era.

CONSTRAINTS AND LIMITATIONS

The character of these rapid onset, low probability, high consequence events, impose constraints and limitations which must be dealt with in any EMIS. For example, current state of the art chemical agent monitoring technology does little to speed recognition of releases which would allow more time for decision-making. In general, monitoring technology is not suited to providing either an instantaneous identification of a chemical substance or instantaneous readings of concentration of an agent in the atmosphere. In the case of the chemical agents, it takes several minutes for current sensor technology to detect agent at low levels. Given the costs and sensitivity of the monitoring technology, its usefulness is limited almost exclusively to closed environments, such as buildings, where chemical concentrations will be high. This means that first warning of a problem is likely to come from a person or an alarm activated by a person rather than from an automated sensor and alarm and that the type of agent and quantity of agent may not be immediately known.

Often, chemical agent type can be deduced quickly from the location of a release or from knowledge of who is reporting an accident. Typically chemical operations segregate storage and processing so that a single agent is present or being processed at a particular location during a given period. Thus, if you know the location of the problem or the work team involved, you can tentatively identify the agent.

Determining the amount of chemical involved is somewhat more problematic. It is not possible to measure releases with any precision and in certain circumstances (such as releases accompanied by a fire or explosion), it may be difficult to make an immediate visual determination of the number of containers involved. Thus, the amount of material released must be deduced from the accident's circumstances. In the case of the chemical stockpile program, the assumed amount of agent released will be based on an estimate derived from the contents of the containers or munitions as developed in a risk analysis performed for the EIS (Fraize et.al. 1989).

Some sense of the path and rate of travel for any agent plume is needed to protect populations-at-risk and to avoid mobilizing populations-not-at-risk. A reasonably accurate prediction of plume travel requires a precise source term, extensive meteorological information, information about the effects of local terrain, extensive computational resources, the accurate input of all of this information, and time to complete the requisite calculations. These conditions are difficult if not impossible to meet at a reasonable cost and in the time frame imposed by real world events. Even if the data were available and the predictions could be made almost instantaneously, political realities are such that emergency decision-makers will cautiously seek to insure that all populations are adequately protected and to account for factors such as wind shifts due to approaching fronts and diurnal cycles. Thus, simple models or estimates of plume width and down wind distances based on look-up tables are entirely adequate for initial decision making in an emergency. More sophisticated plume models may be used in the post-accident period to help evaluate the situation and to aid in recovery and reentry.

The ability of a population to protect itself depends on the amount of time that it has to implement and complete protective measures and the efficacy of the protective measures (Rogers et. al. 1990). The amount of time that a population has to implement protective measures is the amount of time it takes for agent to reach the population. During this period, officials must decide to warn the population and activate the warning system, and the public must recognize the danger, decide to act, and successfully complete the requisite action.

The most efficacious protective action under ideal conditions is removing people from contact or chance of contact with chemical agent. Models can be used to predict evacuation clearance times and to predict locations within the traffic network where measures can be taken to reduce clearance times (Southworth 1990). Unfortunately, the accuracy of evacuation models, like the accuracy of plume dispersion models, depends on the validity of the assumptions on which the models are predicated and on the quantity and accuracy of the data that are available. Also, evacuation models require significant computing resources and/or significant amounts of solution time. Thus, current state-of-the-art evacuation models are of use for planning but input requirements and run times make them inappropriate for real-time use in rapid onset emergencies.

Furthermore, evacuation is not always feasible for nearby populations. In such a case, in-place sheltering (including expedient, enhanced, and pressurized sheltering), or some form of sheltering with evacuation after plume passage, in the case of institutional populations, may be the best way to maximize protection. Because no alternative provides perfect protection, the trade-offs in protection effectiveness between evacuation and these alternatives must be considered. Considering these trade-offs increases the decision time and further complicates the decision process.

There is insufficient time to run evacuation models and protective action software for a variety of populations, evaluate the output, and decide on protective actions in an emergency situation. As part of their pre-emergency planning, communities need to build decision matrices with predetermined actions for specific circumstances. These decision matrices may be incorporated into the automated system and can be the basis for decision-making about protective actions in the initial stages of an emergency.

Unlike hurricanes where there may be time for members of household units to assemble and to evacuate together, the rapid onset of chemical agent emergencies may result in people finding themselves separated from other household members. Providing resources that will enable people to quickly establish contact with one another after a chemical agent emergency will help to reduce anxiety along with pressure for reentry or unauthorized attempts at reentry into evacuation zones.

Beyond being able to locate evacuees, an evacuee register is needed to be able to establish who has evacuated, to speed the available assistance to those who need it, and to track assistance that has been offered and accepted.

A number of constraints and limitations related to rapid onset, low risk, high consequence events have been identified. These constraints set a framework within which an automation system can be developed. The principal constraints have to do with how soon accurate information about the extent of an incident will be available and how quickly that information can be evaluated. Many important decisions, such as protective action decisions, need to be predetermined and the automated information system should support decision-making by providing for rapid and accurate retrieval of information.

THE CAPABILITIES OF AN EMIS

Table 1 summarizes the generic functional requirements associated with an EMIS and the potential applications of each. The generic functional requirements represent the critical areas where EMISs provide assistance to emergency managers. Near-real-time capabilities are required to handle data collection from agent monitors, meteorological stations, critical facility operations, and other indicators of potential problems. Manual data input is required to handle the detection of hazard from human observation of events in connection with the stockpile, emergency operations and response, and also to serve as back-up to real-time monitors should they fail.

Table 1. Generic system requirements and potential applications

Generic Requirement	Primary Application(s) / Technology or Provision System
Near-real-time data	pressure of the chemical processing facility; agent monitors; meteorology monitors; seismology; transponder movement during transport; traffic flow monitors
Manual data inputs	event detection; resource tracking; back-up real-time data; traffic reports
Mapping	site; site area; installation; community
Reporting	chain of command; event logging; alarms
Relational Data-base	locational GIS; inventory; resources; personnel; protocols; population exposure; institutions; command authority; warning devices; protective action effectiveness (public & institutions)
Analysis	accident classification; monitor protective action capacity
Modelling	meteorology; dispersion; protective action; traffic flow
Procedures	traffic access and control; notification; protective action selection; monitoring; shelter registration; sampling; decontamination; reentry teams; public affairs
Communications	facility with EOC; field with EOC; FAX or other equivalent written message
Ring-down	chain of command; emergency personnel; institutions; plant operator
Warning device activation	siren controller; tone/alert radio controller; telephone ring-down; pagers
Time monitoring	alarm critical events/activities; record times in event log; track critical events
Support	word processing; drawing; charts

Mapping displays are required to locate key emergency response inventory, resources, and personnel. In addition, mapping capability allows emergency officials to locate populations at risk, potential exposures, and sample coverage.

The EMIS should not only activate alarms when critical tasks and activities are required, but record information flows and decisions as they occur. This record should be permanent, unalterable, and show the progression of events throughout any emergency.

An EMIS must have a relational database for tracking resources, personnel, and equipment, as well as for monitoring exposure, population response, and command structure.

Analytic and modelling capabilities are required to calculate expected exposure(s) and the estimated effectiveness of various critical functions, such as protective actions. These models and analyses are critical in the monitoring of an accident and the emergency response it engenders.

Procedures are essential to guiding emergency operations during the response and reentry phases. These procedures are likely to be the product of a task analysis that will help emergency managers avoid failures to perform critical functions during specific operations. The associated checklists also provide a record of performance and help assure compliance with existing guidelines.

Communication and ring-down provide specific mechanisms for establishing and maintaining effective communication among people involved in response. Warning device activation is time critical. Controlling the activation of public warning devices/channels from the EMIS is an important system function.

The ongoing monitoring of time, elapsed time, and criticality is essential for an effective EMIS. In addition, the system must provide easy linkage to more routine operations such as word processing, drawing, and other graphics for effective communication.

THE DATA REQUIREMENTS ASSOCIATED WITH THE PHASES OF AN EMERGENCY

From an automation standpoint there are three qualitatively different phases to emergency decision making. The planning and analysis phase deals with the modelling and data acquisition and manipulation that are required to prepare for an automated response during an emergency. In the planning stages data requirements are high as data are transformed through analysis into planning information. There is heavy reliance on a wide variety of data such as population statistics, road capacities, and the location, type, and population of institutions, etc.

The operation and response phase includes the ongoing day-to-day operation of the automation system as well as

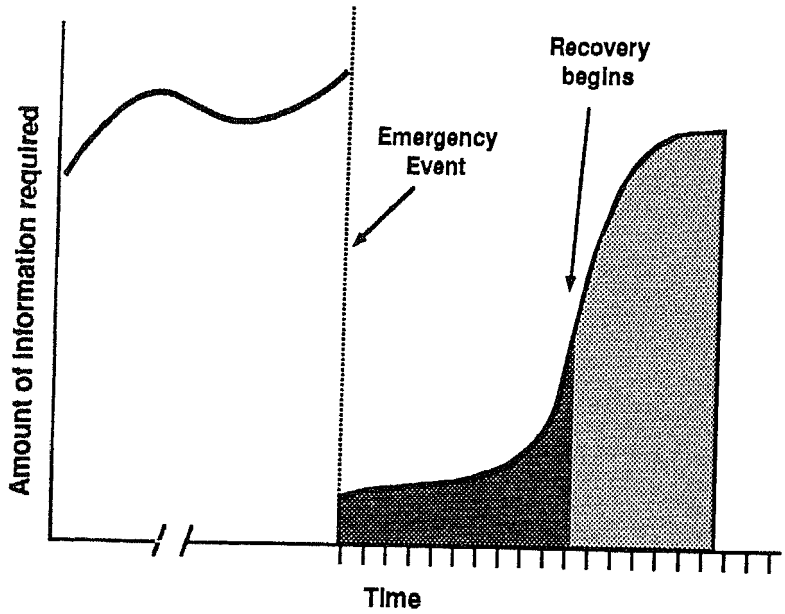

Fig. 2. Information requirements before, during, and after an emergency

operation of the system in an emergency. Operation and response rely much less on quantities of data and analysis and more on the management of information, searching for things, sorting things, etc. In an emergency the real-time information and data requirements become much smaller and very specific. Information is needed about the accident, environmental conditions, procedures, resources, and lists.

Recovery and reentry deal with automation requirements for operations after the initial response to an event has been made and the objective is to return to routine operations. Much new data is required in this phase. This includes an analysis of plume path, analysis of the levels of residual chemical agent, recording of exposures of fatalities, etc. Figure 2 illustrates conceptually how data requirements change with phases of the accident.

Figure 3 emphasizes the processes involved in the various phases of an emergency. At the planning stage, meteorological models, source terms, evacuation analysis, and protective action modelling are combined to produce a protective action decision matrix. Also in the planning phase, the procedures, the resources and the contacts/lists that are needed during an emergency are assembled. These activities are data intensive but they do not require real-time systems.

The response and operation stage takes on a very different character. Here, information about meteorology, agent, the status of the processing facility, and the character of storage activities is constantly being updated. In a crisis, this information is used as a basis for interrogating the protective action decision matrix to determine what should be done. In addition, the procedures, resources, and contacts and other lists of resources assembled during the planning phase are utilized. A very important part of this phase is the alerting and notification process. To a large extent, this stage makes use of existing data.

The final phase, recovery and reentry, involves new sets of issues. These include the logistics of caring for, sheltering, and locating those who have been temporarily or permanently dislocated and minimizing conditions which may adversely affect public health upon reentry. Impact and hazard assessment, which is concerned with identifying exposures, fatalities and property damage and determining when the emergency is over, are also important. Together with other information about plume travel and accident conditions, these are used to make the reentry decision. There also is the issue of compensation which is influenced by all of the preceding issues. This stage is primarily concerned with gathering primary information in real-time. The data collected during this period can significantly reduce nuisance and disruption for the people impacted by speeding decisions about reentry, etc.

PROTOTYPING IN SUPPORT OF FUNCTIONAL REQUIREMENTS

The functional requirements of an EMIS need not only be identified but also validated and tested for feasibility. Prototyping is one method of validating and determining the feasibility of requirements. A prototype implements concepts in software to see how the concepts work in the real world. Several different prototypes may be developed and either combined or discarded. Prototypes are not early versions of software but working models which can lead to refinements of function, concept, and detail design.

A prototype of a system for dealing with rapid onset, low probability, high consequence events associated with Army chemical stockpile sites has been developed by ORNL. This prototype utilizes an Apple Macintosh computer and Hypercard software. This medium was chosen because it is particularly well suited to the problem. Hypercard's object-oriented programming language allows rapid development of the modules. For example, approximately 15 modules, some of which incorporate real data, were constructed in a period of about six weeks with about 3 person months of effort. Changes and additions can be made quickly in this medium. Further, Hypercard permits linkage of disparate elements. The prototype development was done more or less concurrently with the effort to develop functional requirements. This resulted in a great deal of intellectual exchange between the effort to develop the functions and the prototyping effort.

It is not possible to fully describe the prototype within the limitations of this paper. However, it is possible to explain the power of the approach by briefly describing one of its modules. Figure 4 shows a card from the emergency response stack. The base map underlying this is a scanned map of one of the sites. The scroll box in the upper right hand corner is a dummy list of institutions preceded by the coordinates of these

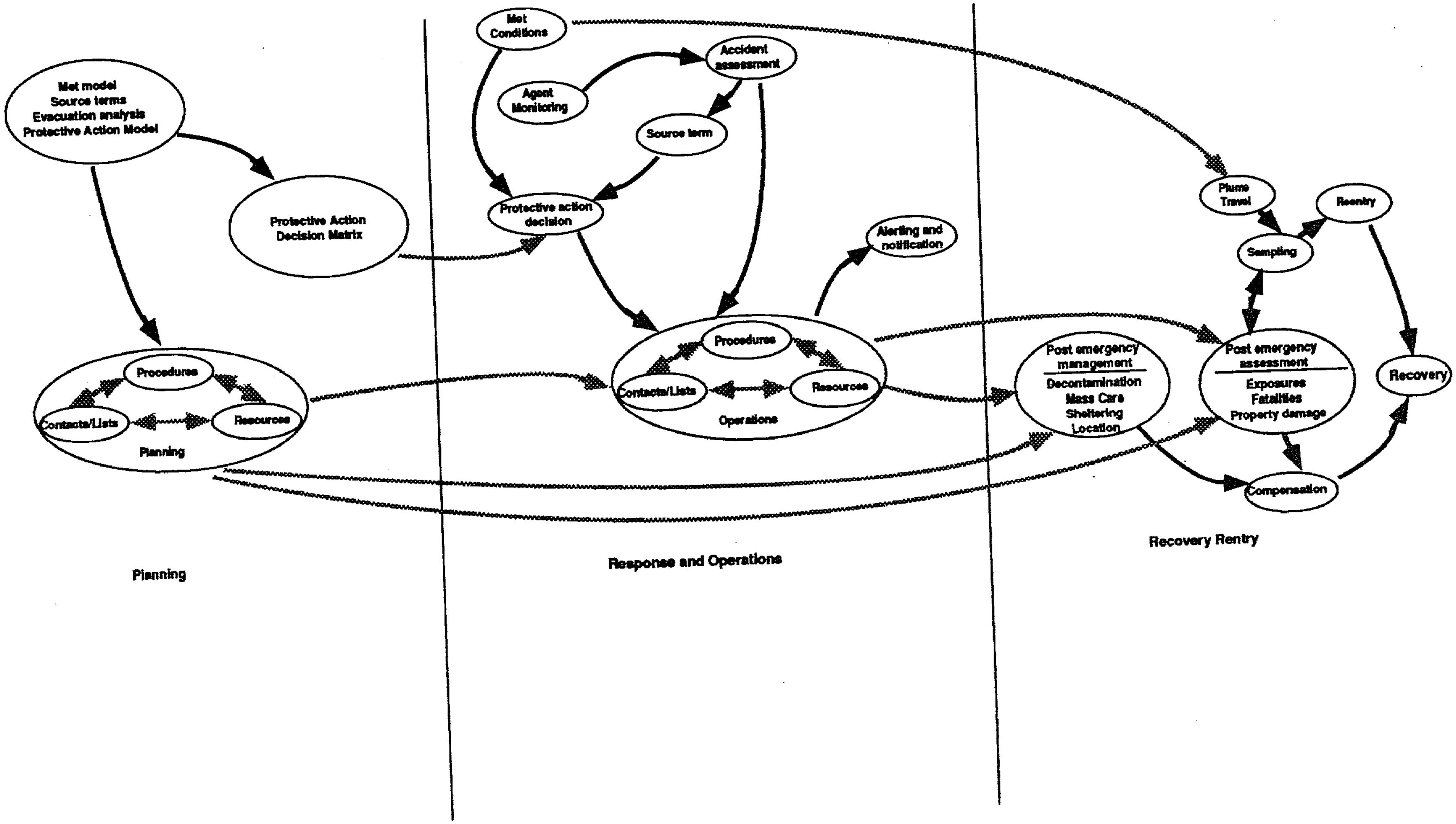

Fig. 3. Emergency Decision Making Processes

institutions in map scale. The three boxes labelled wind direction, zone width, and distance are data entry boxes. In this case, they have been filled with the values of 180° (i.e., the wind is from the south), a zone width of 45° indicating half of the anticipated lateral dispersion of the plume, and a down wind distance of 25 km. By pressing the accident location button and then pointing to a location on the map, the user locates the source of the plume. If the emergency response zone button is activated, a circle with a 25km radius is drawn centered on the source point and radii are drawn from the source reflecting the likely lateral dispersion. All institutions falling within the emergency response zone are then listed in the right middle scroll box (in this case, "building a"). The vicinity map button in the lower right hand corner of the screen returns the user to the general facility map module.

Being able to present prototypes to potential users has several advantages. First, it conveys to them ways in which automation may be useful. Secondly, users, who almost always have some expertise in the field, respond to the prototype by asking questions. For example, they may ask, "Could the phone number and contact persons for "building a" be displayed?" or "Is it possible to get the wind direction directly from the weather station?" Such questions are helpful in identifying additional functions that may be required. Thirdly, and perhaps most importantly, users of the prototype begin to say things like "that's not the way we do business" or "that won't work because . . ." It is these observations that make it possible to further refine the understanding of the requirements and which help us to understand the decision processes of emergency managers. In many instances, users reveal things that they would not have revealed without the stimulus of the prototype. They also reveal how they really handle emergencies as opposed to how they think they handle emergencies.

CONCLUSIONS

This paper has briefly described the process associated with developing functional requirements for an emergency management information system for emergencies characterized by rapid onset, low probability, high consequence events. It is clear that automation has a role in helping to plan for, manage, and recover from such events. However, the role of automation varies among phases.

There is a tendency to think of models as the most important components of emergency management information systems. This perspective is reinforced by the fact that dispersion models, evacuation models, and protective action models are relatively easy to implement and their outputs are easily displayed graphically by automation technology. The uncertainties associated with an actual emergency, the data

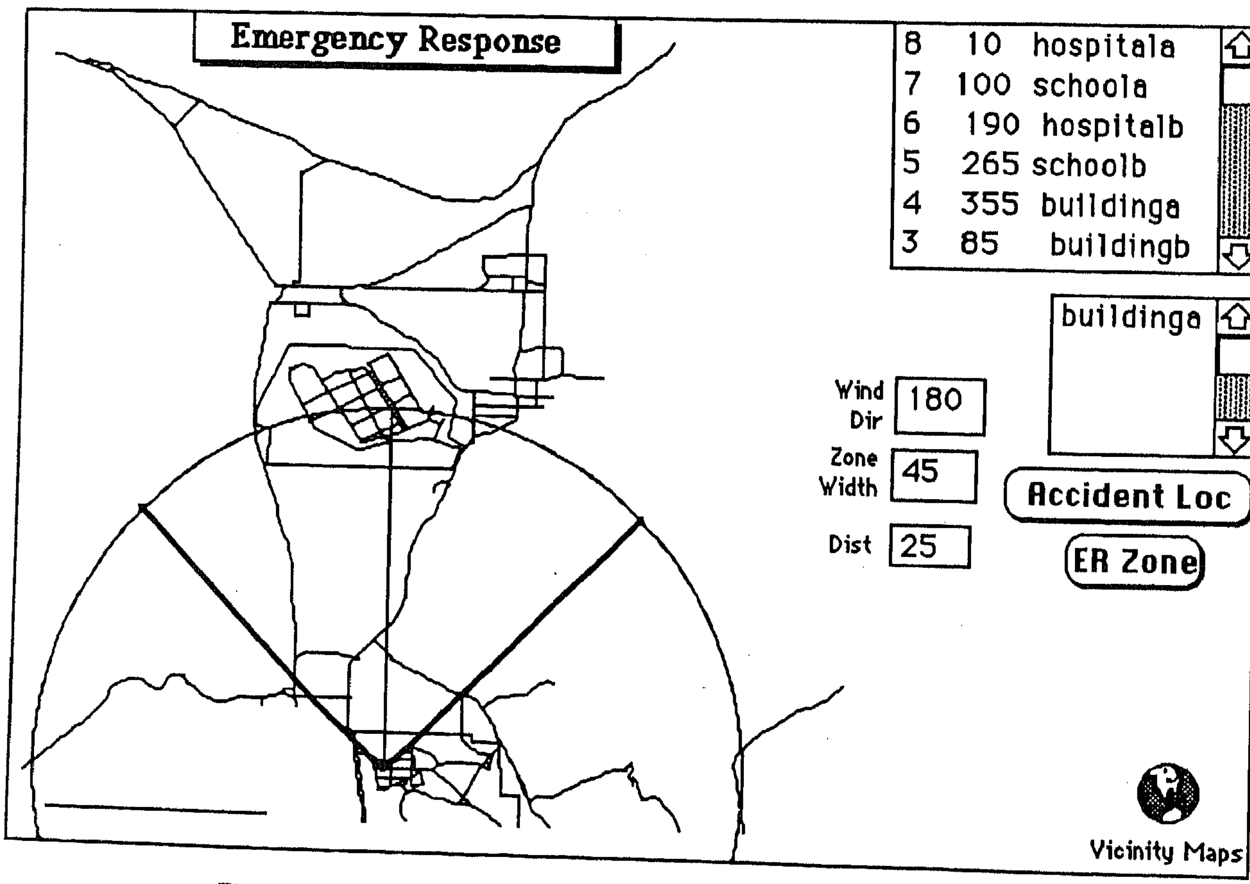

Fig. 4. Example of Emergency Response Stack from the Hypercard Prototype

requirements for the models, the time required to do the calculations, and the rapidity with which decisions are needed, more or less dictate preplanned decisions which can be retrieved from look-up tables. Models are useful in the planning stages for constructing decision matrices, but they are of less utility during the actual emergency and in fact may become obstacles to good decision-making if an attempt is made to use them in time-limited circumstances.

While existing emergency management information systems incorporate models and display model results, they have tended not to provide as much support for manipulating information on organizational resources even though these tasks may be suited to automation. For example, systems have been somewhat limited in their ability to retrieve and display procedures, resources, contacts, lists, and organizational linkages. This limitation is partly due to the difficulties of defining, gathering, and keeping current the information associated with these requirements. For the type of emergency with which this paper is concerned, it is precisely the manipulation of this type of information that may be of most use in an emergency.

Finally, this paper briefly describes the prototyping process which is being used to develop the functional requirements. This process has been very effective in helping to validate requirements and to determine the feasibility of implementing them.

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