TERMINAL DISASTERS

Computer Applications in Emergency Management

Sallie A. Marston, Editor

39

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INTRODUCTION

INTRODUCTION

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The papers presented in this volume offer a sample of the many ways in which computers can be used in emergency management. While each of the papers addresses a somewhat different computer application or framework, a factor common to them all is an emphasis upon the importance of information in emergencies. Central to the effectiveness of any emergency management operation is the capability of obtaining, communicating, and utilizing information. Of additional importance is the capacity to manipulate information to determine hypothetical outcomes under various emergency scenarios. The purpose of this volume is to suggest ways in which computers can help to satisfy these kinds of information needs.

Most of the papers included here emanate from the Natural Hazards Research and Applications Information Center's Annual Hazards Workshop held in Boulder, Colorado in July, 1985. In the previous two or three workshops it had become increasingly clear that more and more work was being done using microcomputers to solve the problems of hazard management, and that there was a concurrent increase in demand by all those involved in emergency management for a comprehensive volume summarizing that work. This book is a first attempt to provide that information.

Advantages and Limitations of Computers

Computers offer many advantages to researchers, decision makers, and others who must efficiently process and act on information. Many people first become familiar with computers through word processing in which the editing, organization, and revision of verbal and quantitative information is made faster and easier by the computer. The advantages of computers—speed, logic, and accuracy—are most evident when we attempt to organize large amounts of information such as data on the population of a large city or an inventory of equipment held by government agencies. In these cases, the familiar spreadsheet (accounting framework) program can be used to update, summarize, and print large amounts of complex information. Many of these spreadsheet programs can analyze data statistically and extrapolate from an existing situation to a predicted or hypothetical future state.

In some cases enough is known about the causes and characteristics of an event that one can program a computer to simulate that event or set of processes. Simulations often require difficult mathematical calculations and the analysis of complex information and interrelationships; here again, the computer provides speed and logic. In many cases, the users of the computer do not need to write the simulation programs themselves. They can purchase, use, and perhaps readily modify generic programs developed by others. Such programs are usually "user friendly," that is, one only needs to know the basics of switching on the computer and reading and running programs in order to use them; once started, a "menu-driven" program prompts the user to enter information in order to provide her/him with the requested results.

Another advantage of using computers is that in writing a program, one must make explicit any assumptions about the set of information to be manipulated or event to be modeled. A decision process simulated by a computer has to be unambiguous and understandable by anyone familiar with the program language. A further advantage is that in simulating an event, one can explore possibilities and conduct experiments that would be unacceptable or impractical in the real world.

Many of these general advantages translate directly into specific benefits in emergency management. In an emergency, speed and accuracy are essential. Computers offer the potential to generate quickly information about people, equipment, and places--saving time, money, and lives. They can also aid in forecasting a developing hazard such as a hurricane, in prescribing patterns of evacuation, and in making critical decisions. Beyond that, computer simulations permit one to anticipate, plan, and train for actual emergencies during periods of relative calm. Hypothetical situations can be examined, alternative decisions compared, and possible mitigation schemes developed without risking much time and money, or "experimenting" with new personnel or new decisions in actual disasters.

A number of papers in this volume discuss problems and disadvantages of computer use for emergency planning. There are several additional cautions that can be added. Purchasing, operating, and training people to use computers can be time consuming and expensive. In addition, it can be difficult to know what system to buy, since costs, technology (hardware), and programs (software) change rapidly. Some agencies find themselves with outdated systems or ones that cannot easily share programs and information with other agencies who have different systems. Personnel may be wary of using a computer or unable to find the time to learn to use it. On the other hand, users sometimes become preoccupied with the technology of computers and forget about its application to real world problems. Beyond that, individuals and agencies should remember that computer programs are no better than the science and programming that constitute them. Before using a simulation model to predict an event such as a flood or an earthquake, or to make decisions, the user needs to know that the model has been developed using good data and theory, that it behaves in a realistic way, and that it can reproduce observed events in a specific environment. Finally, it should be emphasized that some techniques, such as expert systems and artificial intelligence, are in the early stages of development and may not be generally available to the emergency management field at this time.

Most of the above problems can be avoided if computer use in emergency management is informed, coordinated, and clearly linked to user needs. The papers in this volume provide several frameworks, ideas, and guidelines for implementing effective computer use in a wide range of emergency management activities.

Overview of the Book

The papers in Section One center on the use of computers for helping emergency managers to evaluate complex and difficult decisions. The first paper, by Everson, provides an introduction to the role of computers as tools that support emergency decision making. The author provides not only an overview of the subject and a summary of related literature, but also a more detailed look at one system, EPDSS (Emergency Planning Decision Support System). The paper by Belardo and Karwan presents a design procedure for the efficient development of a cost-effective computer-assisted decision support system for emergency medical agencies. The authors advocate prototyping--the building of sample models and systems that can be tested and progressively modified in cooperation with the user. Whereas Belardo and Karwan discuss the development of a decision support system, de Balogh presents an actual system designed to aid emergency evacuation, and in particular analyzes two components of that system. French provides an overview of the current use of decision support systems in earthquake hazard mitigation and examines the possible future evolution of such systems. The final contribution to this section, by Morentz, discusses a working system (EIS--Emergency Information System) and details how small agencies, local governments, and state emergency management organizations are using that system to assist their emergency management operations. He also concludes by predicting future developments in the use of computers to manage emergencies.

The papers in Section Two focus on the use of computers to simulate and model various hazards and emergency situations for both geophysical and social systems. Griffith shows how a simulation model of hurricane storm surge can be used to enhance evacuation planning and management; whereas Haney, after describing the basic features, applications, and products of a generic damage/risk modeling system, discusses the development and use of such a system to model the effects of earthquakes in southern California. In the third paper, Scawthorn discusses computer-based damage simulation and presents a model, using San Francisco as a test case, for estimating earthquake-induced structural damage in urban areas; the paper also discusses changes in risk brought about by changes in land use. In their paper, Schneider, Janarthan, Tung, and Yeh describe the design, testing, and implementation of a population location simulation model that calculates the number of people at a particular place and time within a city. They demonstrate the utility of such a model in predicting the effects of a given disaster and therefore in developing mitigation and evacuation plans. The fifth paper, by Hobeika, describes an actual evacuation model (MASSVAC) and its application to the city of Virginia Beach.

Section Three examines the problems, needs, and future applications involved in using computers to manage hazards. Beriwal's paper outlines the advantages of computer-automated emergency management--if that automation is properly designed and implemented. The paper by Bradford and Brady describes a study conducted by the California Specialized Training Institute to determine the uses, strengths and weaknesses, and possible priorities for future development of computer-assisted emergency management. Comfort proposes a design for an information processing system which permits the user to add and request information as an event progresses, and along similar lines, in the following paper Mick and Wallace discuss the benefits and limitations of expert systems and artificial intelligence (AI) in aiding public decision makers involved in emergency management. As a counterpoint to all these papers, Chartrand's essay focuses on the policy issues involved in promoting computer use in emergency management; he stresses the need for key policy makers to support the use of information technology at all levels of emergency management.

SECTION ONE

DECISION SUPPORT SYSTEMS

EMERGENCY PLANNING DECISION SUPPORT SYSTEMS

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Introduction

Emergency organizations are recognizing the role of computers as tools for information management, a function that is crucial to the control of emergency resources. This is evidenced by two recent conferences (Carroll, 1983; 1985) and the development of at least one commercial "turn-key" microcomputer Management Information System (MIS) for U.S. emergency planners. As Lucy (1984) states, "emergency response is 10% telecommunications, 20% operations, and 70% information. Information, like people and money, is a resource and the only resource that makes possible the coordination of vital services during an emergency."

Belardo et al. (1984) argue that "computer based Decision Support Systems (DSS) and information systems, such as (MIS), can be used to improve public disaster management decisions." Adelman (1984) defines DSS as "any computer software designed to support the decision making process by assisting decision makers in thinking about the various aspects of the decision problem(s) facing them." Callahan (1979) states that DSS denotes "an interactive, computer based system which is designed to aid... professionals in solving ad hoc unstructured problems."

Decision Support Systems are intended to automate clerical functions thereby increasing the time available for decision making; provide a structured framework for computational models, and facilitate a better understanding of decision alternatives (Kosy and Dhar, 1983). A DSS differs from an MIS because it supports decision making rather than transaction processing, record keeping and normal business reporting (Keen and Morton, 1978; Kosy and Dhar, 1983).

The applicability of DSS to emergency planning and response depends on two related assumptions. The first assumption is that the cognitive limitations of decision makers are reflected in the decision making behavior of emergency organizations. The limitations of individuals are well documented in the decision theory literature (Sage et al., 1983). However, emergency organizations must exhibit decision making behavior consistent with these limitations, or non-DSS solutions may be more appropriate (e.g., organization restructuring).

A second assumption is that the elements of DSS must be capable of compensating for cognitive limitations within the domain of emergency planning and response. A domain is loosely defined as an area of interest or endeavor. DSS must be able to capture and express salient domain features, or they will be unable to assist decision makers. This paper examines support for the preceding assumptions and the applicability of DSS concepts to emergency planning and response.

Decision Making by Individuals and Organizations

Individuals

Individuals encounter difficulty making choices in complex (multiple choice) or stressful environments (high information levels or uncertainty) because of limited cognitive abilities. Sage et al. (1983) state that "the inability of humans to deal with a large number of information items... is a potentially significant limitation to judgement and choice in complex situations."

Unaided decision makers, faced with information overload, often construct a simple representation of the actual problem and attempt to deal rationally with the representation (Belardo et al., 1984). For example, a city wide evacuation requires the decision maker to consider many different variables simultaneously (e.g., logistics estimates, traffic flow rates, collector and arterial capacity, alternative network configurations). Attempts to simplify this problem by considering a single neighborhood are too simplistic since neighborhood traffic coalesces on major arterials.

Extensive empirical evidence suggests that decision makers use flawed judgment heuristics and suffer from cognitive biases (Sage et al., 1983). The most common heuristic is to resolve the problem into components and solve each component separately. This heuristic does not guarantee a global solution since component solutions may interact (Sage et al., 1983). Common cognitive biases are "availability"—excessive reliance on easily recalled or recent information—and, "anchoring and adjustment"—the inability to adjust estimates of a situation to new information (Tversky and Kahneman, 1974; Holloway, 1979).

Proponents argue that DSS may compensate for these cognitive limitations. Information overload may be decreased through data reduction or filtering techniques (Jarvis, 1976). Complex problems, such as evacuation, may be explicitly modeled eliminating the tendency to use faulty representations. Moreover, new information may be incorporated, automatically reducing the decision maker's vulnerability to heuristics and cognitive biases.

Organizations

Dynes and Quarantelli (1976) present an extensive review of observed changes in organizational decision making in response to crises. They identify several hundred propositions about organizational response. Organizations do not simply expand their pre-crisis activities and structure in response to crisis. Instead, they extend their structure in order to engage in unfamiliar tasks, interact with emergent groups, modify the roles of existing members, and add new members to the organization. These adaptations are responses to changes in the decision making environment from a stable and predictable non-crisis planning phase to an unstable and unpredictable crisis response phase.

Decision making during crisis is distinguished by "the increase in rate of decision making" and by "number of decisions made" particularly at lower levels of the organization (Dynes and Quarantelli, 1976). The increased speed of decision making implies that items of low priority may be ignored and that decision makers are forced to consider less information before allocating and reallocating resources.

The "extension" of the organization to include new tasks and members is similar to the development of an ad hoc organization. An ad hoc organization is defined as a temporary decision making group set up to manage a specific situation (Shapiro and Cummings, 1976). These groups tend to exhibit decision making pathologies when compared with a permanent organization. Such pathologies include lower decision making productivity, poorer use of available resources, and higher stress and conflict levels among group members (Shapiro and Cummings, 1976).

Organization structure and behavior are observed to undergo profound change in response to a crisis. These changes are manifest in new coordination mechanisms, lower decision efficacy, and frictional group dynamics. These empirical observations suggest that all organizations, have enormous difficulty dealing with crises.

Downward diffusion of authority, an increased rate of decision making, and poor utilization of resources are symptomatic of information overload and support the assumption that individual cognitive limitations significantly influence emergency organization decision making. "Extended" organizations are likely to include inexperienced members. These individuals seem highly susceptible to faulty decision representation and heuristics. The concept of providing explicit decision support with DSS is an attractive goal. This goal achieves special significance in a crisis or disaster where the cost of an inappropriate decision may be high.

Emergency Planning Decision Support Systems (EPDSS)

Existing DSS and Related Systems

The study of Belardo et al. (1984) represents the first systematic application of DSS concepts to emergency planning and response. They developed a four component model consisting of "a databank, data analysis capability, normative models, and technology for display and interactive use of the data and models." The databank (or database) organizes relevant data from the domain that may be manipulated or analyzed using data analysis techniques, or normative models. Data analysis uses statistical techniques to establish trends (time series analysis), differences (analysis of variance) and relationships (regression) among the data.

The technology for display and interactive use of the data and models is termed "user interface." User interfaces mediate user question formulation and system response presentation. They may allow multimodal interaction through various devices such as a light pen, voice recognition and synthesis, keyboard, touch screen, text, and graphics displays (Jarvis 1976).

"Normative models" (Belardo et al., 1984) refer to two distinct classes of models: prescriptive models or normative models (in a strict sense) that search for the "best"—or optimal—solution from a set of alternatives (e.g., linear programming); and descriptive models that examine implications of alternative courses of action (e.g., simulation) (Friedman, 1975; Jarvis, 1976; Kosy and Dhar, 1983). Both classes of models use operations research and management science (OR/MS) techniques (Hillier and Lieberman, 1974). Young (1978) suggests that a DSS requires a collection of OR/MS routines such as minimax allocation algorithms, generalized decision trees, inventory models and PERT/CPM that users may combine in various ways.

Many systems developed for emergency planning or response can be expressed in terms of the Belardo et al. (1984) model. Table 1 summarizes nine different systems, all of which include a database and user interface. ERS, CLEAR, MASSVAC, and REMO use OR/MS prescriptive transportation models to calculate evacuation times and vehicle allocation. BEHAVE and COAST GUARD use descriptive models. RED CROSS, ERS, AND CLEAR provide summary statistics.

	USER INTERFACE	MODELS	DATA ANALYSIS	DATABASE	SOURCE
RED CROSS	TEXT, GRAPHICS	NO	SUMMARY STATISTICS	DAMAGE ASSESSMENTS	BELARDO et. al. (1984)
COAST GUARD	TEXT	HYDRO-LOGICAL	NO	WEATHER, OCEAN CURRENTS	IBID.
REMO	TEXT, GRAPHICS	TRANSPORT, MULTIOBJECTIVE	NO	LOCATION AND TYPE OF EMERGENCY HEALTH VEHICLES CHECKLISTS, LOGS	IBID.
ERS	TEXT, GRAPHICS	ALLOCATION,	SUMMARY STATISTICS	USES OUTPUT OF MAINFRAME RADIOLOGICAL MODELS (PLUME, DOSE)	BELARDO, et. al (1983)
CLEAR	TEXT, GRAPHICS	EVACUATION, NETWORK, TRAFFIC	SUMMARY STATISTICS	FLOW CAPACITY, POPULATION DENSITY	MCLEAN et al. (1983)
BEHAVE	TEXT	FIRE DYNAMICS	NO	FUEL LOADING, METEORLOGICAL	ANDREWS (1983)
MASSVAC	TEXT, GRAPHICS	SEE CLEAR	SEE CLEAR	SEE CLEAR	HOBEIKA AND JAMEI (1985)
EIS	TEXT, GRAPHICS	NO	NO	RESOURCES, LOGS, CHECKLISTS	RESEARCH ALTERNATIVES
RMOC-EIS	TEXT	NO	NO	SEE EIS	AMEY (1985)

Table 1
Existing Support Systems: A Summary of Features

The support systems may be divided into two groups. The first group organizes resource information, simplifying its storage and retrieval (RED CROSS, EIS, RMOC-EIS). These systems are a significant improvement over paper-based directories that are difficult to revise and keep up to date. However, although they may reduce information overload by organizing relevant data, they do not compensate for faulty heuristics or biases. The second group (COAST GUARD, REMO, CLEAR, BEHAVE, MASSVAC) uses sophisticated OR/MS models within the domain subset, but do not compensate for faulty heuristics applied to the remaining domain. Moreover, these systems do not reduce information overload outside this subset.

The Belardo et al. (1984) DSS model tends to rely on OR/MS techniques to correct for cognitive bias and faulty heuristics. Unless the user's domain can be completely described using OR/MS techniques, it is likely that some biases and heuristics will go uncorrected. I do not imply that a DSS based solely on OR/MS is unacceptable, but that OR/MS techniques have limitations in their ability to express domain features. Moreover, a DSS predicated on OR/MS allows the possibility of significant error in problem understanding and specification since the user must select the appropriate technique. The result is the often heard response, "Great solution! Wrong problem!"

Role of Knowledge

The limitations of OR/MS techniques encouraged many researchers to examine the potential role for knowledge in DSS (e.g., Kosy and Dhar, 1983). The design of systems that manipulate knowledge is an active area of study among artificial intelligence researchers in the field of expert systems or knowledge engineering. A DSS that explicitly uses knowledge is termed knowledge-based or expert-DSS (Ben-Basset and Freedy, 1983; Kosy and Dhar, 1983).

Human experts are characterized by expert domain knowledge and problem solving ability. They have mastered publicly available information about a domain and use their individually developed problem solving techniques, problem approaches and rules of thumb (heuristics) to solve problems efficiently. (Hayes-Roth et al., 1983). Human experts are able to make inferences and reach plausible conclusions with incomplete or uncertain data (Michaelsen et al., 1985) unlike traditional computer-based methods.

Expert systems are person-machine systems that derive their knowledge, problem solving expertise, and heuristics from human experts (Hayes-Roth et al., 1983). Knowledge is obtained from interviews and observation of experts solving typical problems. The knowledge acquisition process creates a body of knowledge or knowledge base. Expert systems are able to make decisions on par with human experts in such diverse areas as geological exploration (PROSPECTOR), infectious blood diseases (MYCIN), and computer system configuration (R1) (Hayes-Roth et al., 1983; Michaelsen et al., 1985).

Several types of expert systems may have a role in EPDSS. Interpretative systems, for example, generate a plausible explanation(s) for a given set of observations. Military situation assessment systems are representative of interpretative systems. They attempt "fusion" of intelligence sensor outputs into a comprehensive view of enemy intentions (Ben-Basset and Freedy, 1983). Diagnostic systems infer system malfunctions from system behavior (Hayes-Roth et al., 1983). Medical systems such a MYCIN (blood diseases), PUFF (pulmonary disease), and INTERNIST (internal disease) are examples of diagnostic systems. They use patient symptoms to identify the disease or causative organism and possible treatment. Prediction systems infer the likely consequences of a given situation. A military prediction system such as the Rand Strategy Assessment Centre Project attempts to integrate OR/MS techniques, war game methodology, and expert systems to predict the consequences of U.S. policy and actions on geopolitical events (Davis and Williams, 1982). Finally, planning systems design actions subject to existing constraints and desired goals (Hayes-Roth et al., 1983).

Expert systems are being developed for emergency planning and response. A prototype system for oil and hazardous chemical spill management is discussed by Hayes-Roth et al. (1983). This system assists users in determining the source of a spill and identifying the spilled material. It then suggests appropriate containment and remedial activities.

Andrews and Latham (1984) describe BEHAVE, an expert system for predicting forest and range fire behavior. They state that "BEHAVE is operationally used for a variety of purposes, from real-time prediction of fire perimeter for suppression. . . to planning controlled use of fire. . . ." BEHAVE integrates mathematical prediction models (OR/MS) with expert derived heuristics. These heuristics are used to help the user interpret fire behavior predictions. BEHAVE is intended as an "expert assistant" with the human user making the final decision.

A knowledge-based DSS is intended to provide expert assistance to human decision makers (Ben-Basset and Freedy, 1983). The spill management system is an example of an expert diagnostic assistant. Other diagnostic assistants may help users select or interpret OR/MS or data analysis techniques. BEHAVE is an example of a predictive assistant. Other predictive assistants may analyze evacuation problems integrating OR/MS techniques with heuristics. "Expert assistants" may correct many cognitive biases and faulty heuristics by applying expert knowledge and problem solving skills to social and physical phenomena associated with emergency planning and response. Many of these phenomena are only understood heuristically and do not yield to traditional methods of description and analysis.

The Emergency Planning Decision Support System Component Model

The EPDSS component model is based on Belardo et al., (1984). The model is depicted in Figure 1. The components include: a database, analysis capability, descriptive and prescriptive models, user interface, and an expert assistant. The model explicitly recognizes the need for expert knowledge embodied in the expert assistant. The EPDSS model is sufficiently general to include the Belardo et al. (1984) model as a proper subset.

Ideally, each component should be represented in an EPDSS; however, its sophistication should be tailored to the decision maker's needs. The design of data analysis capability, prescriptive, and descriptive models is discussed extensively elsewhere (Hillier and Lieberman, 1974). The remainder of this paper focuses on user interface and database design issues.

User Interface

An interface comprises both the input and output interactions between the human and computer (Collins and Moon, 1984). The interface may consist of many physical components; however, relatively few modes of interaction are possible. Input modes include keyboard, menu selection, gestures (pointing and drawing), and voice (Taylor et al., 1984; Collins and Moon, 1985). Output modes include alphanumeric display, graphics display, and voice.

All systems are bimodal and many are multimodal (Taylor et al., 1984). Bimodal systems have one input mode (keyboard) and one output mode (alphanumeric display). Most emergency support systems (Table 1) are multi-modal and have two input modes (keyboard and menu selection) and two output modes (alphanumeric and graphic display).

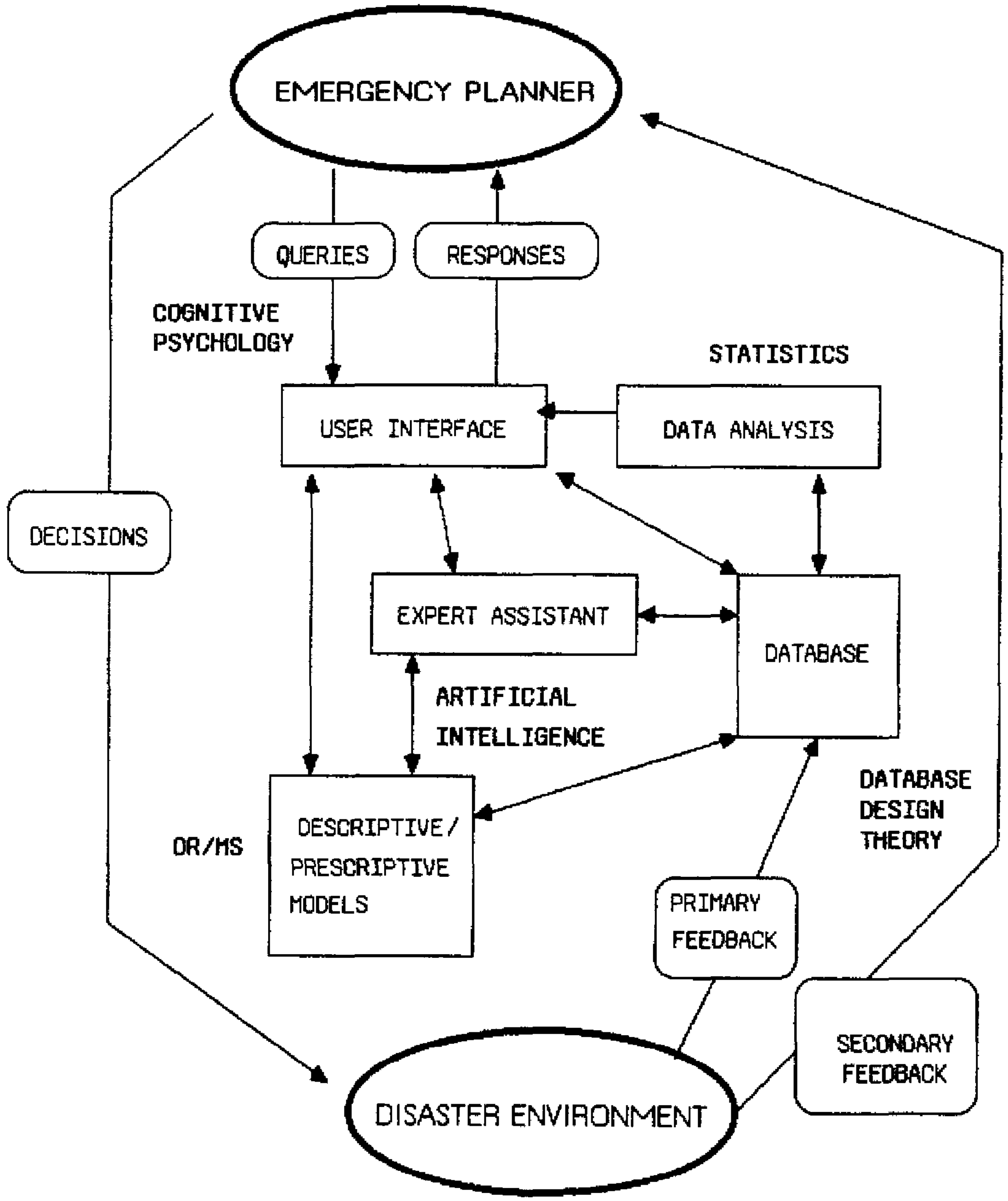


Figure 1
Components of an Emergency Planning Decision Support System (EPDSS) and Relevant Subject Areas

(Adapted from Belardo et al., 1984)

Apple Computer Ltd.'s MacIntosh is a perfect example of a multimodal interface. The MacIntosh allows keyboard, menu, pointing, and drawing as inputs and provides alphanumeric and graphical outputs. Moreover, MacIntosh allows mixed-mode interactions during a single query; for example, a user can asynchronously utilize pointing, keyboard, and menu.

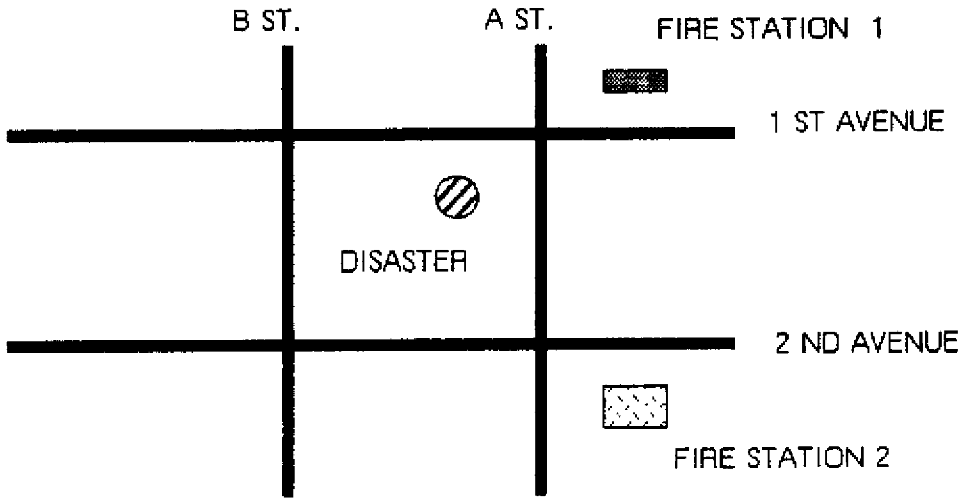
Disasters and key community resources have an important spatial component (Everson, 1985). User queries are likely to include a spatial dimension such as, "Where are the resources?" or "What route should be used?" The EPDSS interface must be predicated on pictorial displays. Pictorial displays are not the same as graphic displays that do not add to information already embodied in a table. However, individual decision makers with strong spatial skills may benefit more from graphs than from tables in problem solving situations (De Sanctis, 1984).

People prefer maps which are pictorial displays of spatial information rather than a description of a place (Taylor et al., 1984). For example, Figure 2 demonstrates how a pictorial display allows a person to recognize immediately which fire station is closest to the disaster site. The table presents the same information clearly. A pictorial display remains more intuitive, more natural. The preference for pictorial displays seems related to the brain's spatial and linguistic modes of thought. Objects are significant to a decision maker because of their spatial relationships to one another. For example, chess masters play endgames by recognizing specific spatial configurations on the chess board. They do not examine all possible moves the way a computer does when playing chess (Everson, 1985). The brain's intrinsic ability to ascribe meaning to particular spatial configurations suggests that EPDSS should support pictorial displays.

Database

A database is the nexus for all other components of the EPDSS (Figure 1), and a component of existing support systems (Table 1). Clearly, its design is critical to overall system performance. A properly designed database improves data redundancy, update consistency, data integrity, data standardization, and data independence.

Databases are expressed at three levels of abstraction (Ullman, 1983). The physical database (or internal schema) describes data storage structures and data access strategies. The conceptual database (or conceptual schema) describes an abstraction of the real world of interest to the emergency



OBJECT	SYMBOL	X_COORD	Y_ COORD
FIRE STATION 1		55	60
FIRE STATION 2		55	30
DISASTER		45	50

Figure 2
Comparison of Pictorial and Tabular Displays of Relationships
Between a Disaster Site and Two Fire Stations

organization (Ullman, 1983). The user database (or external schema) is a subset of the conceptual database. The conceptual database is described using a "data model." This section focuses on the relational data model and use of Entity Relationship (ER) modeling in creating a conceptual database.

Entities are defined as anything that has reality and distinctness of being in fact or thought (Vetter and Maddison, 1981; Ullman, 1983). Entities of interest to an emergency organization are location and description of hazardous materials, heavy earth moving equipment, etc. Any number of entities may be explicitly identified depending on their usefulnes to emergency planning and response.

Entities have properties called attributes, which associate a value from a domain (Ullman 1983). Entities sharing the same attributes form an entity set. Attributes are selected to describe entities of the real world. For example, the entity set, FIRETRUCK, may be described by the attributes: COLOR, WEIGHT, SERIAL_NO., TRUCK_TYPE, etc.

A relational data model uses a set-theoretic concept of a relation. A relation is a subset of the Cartesian product of one or more domains (Date, 1981). A domain is a set of values from which attributes are drawn hence an entity set is a relation (Ullman, 1983). The relation FIRETRUCK is written as FIRETRUCK (COLOR, WEIGHT, SERIAL_NO., TRUCK_TYPE). Relations may be visualized as tables where the columns represent attributes and the rows represent individual entities (Figure 3).

FIRE TRUCK

SERIAL_NO	TRUCK_TYPE	COLOR	WEIGHT
LA 123	625 PUMPER	RED	10 TON

Figure 3
A Tabular Representation of the FIRETRUCK Relation

The relational model is a powerful construct; however, it is difficult for the user to apply. Entity-relationship modeling (ER) (Chen, 1976) allows the user (or analyst) to describe information needs in familiar terms at an appropriate level of resolution (Tuori and Moon, 1984). ER uses the concept of a relationship among entity sets. For example, the relations, FIRETRUCK and

FIRESTATION, are related by the relationship set, STATIONED_AT. The elements of STATIONED_AT are described using attributes of FIRETRUCK and FIRESTATION. STATIONED_AT is written as STATION_AT (SERIAL_NO., STATION__NUMBER).

ER incorporates relevant semantic information, i.e., relationships among entities. Entities and their relationships may be depicted in an ER diagram (Ullman, 1983; Tuori and Moon, 1984). In the diagram, rectangles represent entities, undirected lines represent relationships, and ovals represent attributes (Figure 4). The ER diagram provides a convenient notation for users to describe their world.

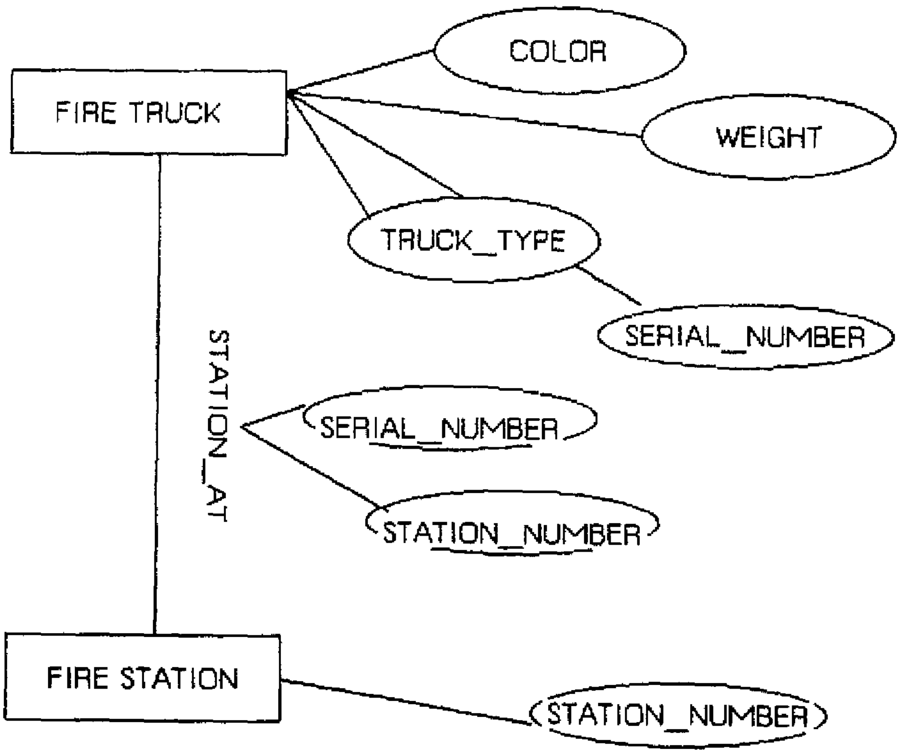


Figure 4
Entity Relationship Diagram for FIRE TRUCK, FIRE STATION and Their Relationship STATIONED_AT

Conclusion

Individual cognitive limitations become manifest in emergency organization decision making. Limitations are realized as faulty decision heuristics in response to information overload. Existing support systems tend to compensate for information overload or faulty heuristics. Only a small number of systems deal with both limitations in other than a few narrow domains (Table 1).

The EPDSS model acknowledges that emergency planning and response includes many phenomena that are imperfectly understood. Attempts by researchers to quantify these phenomena are laudable. However, an EPDSS must integrate knowledge with traditional quantitative support tools (Figure 1).

The EPDSS model represents an ideal--an endpoint in an evolutionary process. Initial support systems should focus on information storage, retrieval, and manipulation. These systems must be predicated on a database and user interface that reflects the user's world. Systems that express spatial dimensions using a relational data model and entity-relationship modeling seem to be an area of promising research (Everson, 1985).

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PROTOTYPING WITH MICROCOMPUTERS: A DESIGN STRATEGY FOR DISASTER MANAGEMENT DECISION SUPPORT SYSTEMS[1]

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Introduction

Despite its success in other management areas, the computer has only recently been regarded as a useful tool for disaster managers. Decreased costs and increased manager sophistication have contributed to the expanded use of computers in emergency management, while that same sophistication and increased public awareness of disasters have created a need for improved support tools for better disaster-related decision making. Another, more subtle reason for greater computer use in this area is the creation of new design procedures that have allowed for the efficient, cost-effective development of disaster management support systems. Those procedures are the focus of this paper.

The next two sections briefly describe the variety of systems design techniques that are available as well as our reasons for selecting prototyping as the preferred approach. The two sections that follow discuss the application of this technique to a particular disaster management environment.

Prototyping

The increasing complexity of computer-based information systems has created a need for improvements in systems development technology. Unfortunately, the evolution of systems technology has lagged behind the evolution of computer technology by five to ten years (Cougar, 1973; Berrisford and Wetherbe, 1979). During the first two eras of computer systems development (Rockart and Treacy, 1980), problems that could be addressed using computers

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[1] A slightly different version of this paper entitled, "The Development of a Disaster Management Support System Through Prototyping," will appear in Information Management, 1986 (forthcoming).

were sufficiently well-structured so that a logical top-down developmental approach could be applied. A number of such approaches [e.g., SOP, TAG, ADS, (Cougar, 1973); PSL/PSA (Teichroew, 1970; Thall, 1971); ISDOS (Teichroew and Sayani, 1971); ISAP (Smith and Knuth, 1976); Data Flow Graphs (DeMarco, 1979); and Structure Charts (Page-Jones, 1980)] were developed to aid systems developers.

Most of the traditional methods referenced above are based on the premise that a computerized information system can and should be fully specified before being designed (Davis, 1982). However, an increasing number of today's computer users have found that "information needs" are not fully understood at the time of initial system design. In many instances, the creator of a system is required to begin designing the system before he or she fully understands it (Fischer and Schneider, 1984). In such situations, where a stable and complete set of specifications is not available, an "incremental" design process may be appropriate.

A number of tools such as heuristic development (Berrisford and Wetherbe, 1979), adaptive design (Keen, 1980), and prototyping (Naumann and Jenkins, 1982; Carey and Mason, 1985) have recently been devised to enhance the probability of users being satisfied with the system that is finally delivered and/or implemented. Prototyping, the most widely discussed method, involves the building of partial models of the system that can be evaluated by users. Once evaluated, these models or prototypes can be changed until a preferred version of the system has been obtained. One of the key features of this procedure is that each test of a prototype provides a forum for user involvement in the design process. Perhaps equally important, particularly when developing applications in new areas, is that information requirements can be reexamined each time a prototype is evaluated. Consequently, a system designed using prototyping typically exhibits very few final "surprises" to the user.

New Technology, Microcomputers, and Disaster Management

Prototyping has become a useful technique for systems development primarily due to a number of recent changes in computer technology. Software tools that permit the rapid development of prototypes are proliferating (Carey and Mason, 1985), and, perhaps more importantly for disaster managers, the portability and low cost of microprocessor technology have made it possible for organizations to experiment with computer systems and assess their value in supporting disaster management decisions.

The remainder of this paper describes the development of one particular system that was developed over a two year period for a regional emergency medical organization in upstate New York. This particular case demonstrates well the advantages of the prototyping design approach and the benefits of using the microcomputer as a disaster management tool.

Multiple Casualty Response: A Case Study

In most medical emergency situations (e.g., heart attack, auto accident) individual ambulance agencies and/or fire departments can respond quickly and effectively. However, in the event of a large fire, an explosion, a plane crash, or a train derailment, the capabilities of any one agency are typically inadequate. In such situations, the activities of various provider agencies need to be coordinated.

In responding to this need in the Albany, New York area, the Regional Emergency Medical Organization (REMO) is developing procedures to address problems brought about by multiple casualty situations. The region serviced by REMO consists of six counties (Albany, Columbia, Greene, Rensselaer, Saratoga, and Schenectady) covering 3,500 square miles and containing over 860,000 people. Service is provided by 135 emergency medical service (EMS) agencies. The equipment located at each agency site ranges in number and type as well as in communications capabilities. Some sites have only one Basic Life Support ambulance available while other sites may have a combination of Basic Life and Advanced Life Support ambulances with voice and telemetry transmission capabilities. The majority of the more than 78,000 calls for emergency medical assistance that the EMS providers receive each year can be adequately handled by individual agencies or by several agencies working together. It is during a multiple casualty emergency situation, however, that a system for deploying resources and providing backup ambulances to those agencies stripped of their resources is needed.

To aid REMO in such emergencies, a Multiple Casualty Computer Aided Dispatch System (MCCADS) was developed over a two year period using a microcomputer-based prototyping strategy for information assessment. The general iterative approach that was used is shown in Figure 1 below and subsequently described in detail.

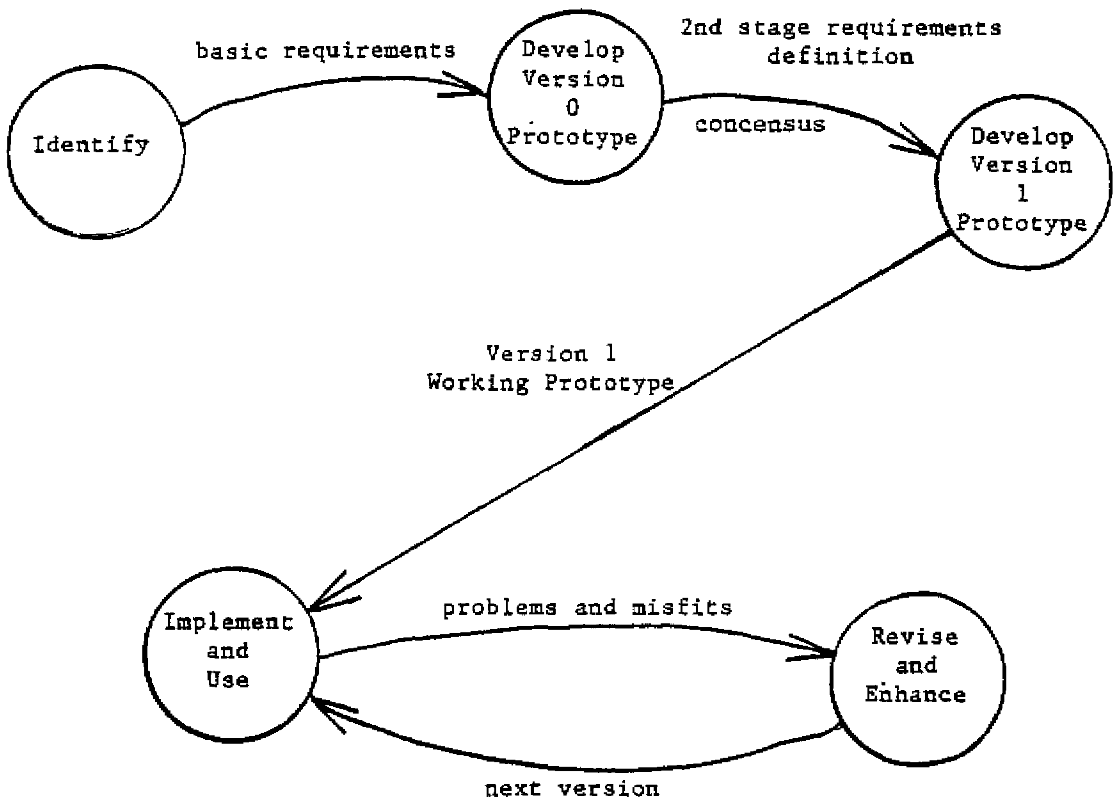

Figure 1
MCCADS Prototyping Strategy
(Adapted from Naumann and Jenkins, 1982)

The First Prototype: Definition Phase

In our initial attempts to develop a system, we held discussions with REMO officials and representatives of the local (Albany) disaster management community to ascertain the procedures used to make decisions concerning the deployment of resources. We then designed a prototype system to determine if we understood the problem and whether the system components contained in the prototype adequately fulfilled the managers needs. This "Version 0" prototype was then evaluated in a field setting by ten individuals of the REMO control center and training facility in Colonie, New York.

The results of the field experiment (discussed in greater detail in Belardo, Karwan, and Wallace, 1982) provided several specific insights into the decision process employed by REMO dispatchers. Tests administered to assess opinions about the various components and features of a DSS for multiple casualty response (both before and after the experiment) showed that data retrieval was considered to be the single most important feature. This was an expected result. However, despite the fact that emergency dispatchers typically employ standard road maps as tools, the participants indicated that enhanced graphics were not particularly important in their decision processes. In the experiment, we observed that their decisions did not involve interacting with supplemental computer generated graphics displays, but rather almost exclusively with street maps that were also supplied. The primary reason for this preference seemed to be the relative lack of sophisticated graphics capabilities available to the participants; therefore, we suspected that interactive graphics capabilities developed subsequent to the field test would probably be better received.

One initial component of the Version 0 prototype was a dual objective algorithm that evaluated both total transportation time as well as the maximum time from dispatch to arrival on-site. The field examination of the prototype showed that those with this model-based component did significantly better in assigning resources than those using traditional manual procedures. Not only were their assignments feasible (i.e., all ambulances assigned, no ambulances used twice), but later, when all the participants were asked to carefully deliberate and select what they considered to be the most appropriate assignment of resources for each of three scenarios presented, they overwhelmingly chose solutions presented by the computer-based dual objective algorithm.

Despite this "success" with an algorithmic approach, the tests also revealed that the straightforward use of such a model did not allow for adequate solutions to the problem of deploying resources in response to multiple casualty events (a problem that will be discussed in more detail in the following subsection.) On the other hand, the use of the normative technique did help the users to focus their attention more directly on the design of the system. Once the dispatchers had seen that they could more adequately respond to emergency situations with the benefit of a computer-based system, their interest increased, and they began to participate in the definition stage to a greater extent than they had before. It was only after the field test that they began to describe the decision rules that they employed and the heuristics that they incorporated in their decision processes. As an example, each dispatcher knew that each agency and/or ambulance was capable of different response rates. These rates had never actually been estimated or recorded; however, in building a system to help them choose ambulances to respond to a multiple casualty incident, it became readily apparent that these "handicaps" would have to be made more explicit.

The Second Iteration: A Working Prototype

The Regional Emergency Alerting Center (REMAC) is located at REMO headquarters in Colonie. This center is staffed by professional dispatchers provided by the town of Colonie Police Department and serves as the central Advanced Life Support frequency monitoring and coordinating center for the entire REMO area. The center was the obvious location to choose for further tests of a centralized, computer-based dispatch system.

With the aid of REMAC personnel, a second prototype (Version 1) was developed over a several month period. This system, entitled MCCADS, (Multiple Casualty Computer Aided Dispatch System) is simple to use, and menu driven. It allows dispatchers to make complicated decisions about areas of the region for which they do not routinely dispatch vehicles.

In developing this prototype, several assumptions and decisions were made. The Universal Transverse Mercator (UTM) grid system was chosen as a reference because of the availability of maps for the entire state of New York (which are all on the same scale, 1:2400) and because each map is large enough so that agency base coordinates can be plotted reasonably accurately.

Further, it was decided that during a medical emergency, the agencies contacted initially should dispatch their units directly to the incident site and that the decision concerning the total number of required ambulances would be made by the commander on the scene (based, for example, on the number of patients and their condition). It was decided that rather than using a pre-determined plan to accommodate say 10, 20, 30 or more patients, MCCADS would automatically locate 1 1/2 times the number of ambulances requested by the dispatcher. These ambulances would be those of the agencies closest to the incident (either by town or village designation or UTM coordinates).

In actual operation, a list of the agencies, the number of ambulances available, and other pertinent information is provided by the microcomputer to the dispatcher who communicates with the various agencies. Once an ambulance is dispatched, the system removes it from the available list until it returns to its base. Those areas which are left without coverage will then be covered by back-up units (suggested by MCCADS) which move progressively closer to the incident in case additional units are needed on the scene. This relocation is done by actually sending the back-up agency's ambulance(s) directly to the base of the agency it is now covering.

The concept of a "handicap" was also built into the computer's calculation of distance of ambulances from an incident. The computer ranks agency bases from nearest to farthest for a particular incident/coordinate location incorporating the handicap which represents the average time from receipt of a call until time en route (i.e., ramp time) plus average transport time. It was developed by using a formula for the number of meters travelled in each minute with the average speed a conservative 45 kilometers per hour.

Data Collection

In addition to the data obtained through the field experiments, data necessary for the development of MCCADS was obtained from various providers. A survey form was designed and sent to all 135 emergency medical service agencies throughout REMO's region. The following information was obtained:

1) Agency name

2) Agency Code Number (four digit number assigned by REMO)

3) Street location on a map of each base station. This information was converted to the UTM coordinates on the REMO large maps.

4) Average time off the ramp (used to develop handicap)

5) Number of bases, number of vehicles, and type (transport/nontransport) of vehicle at each base

6) Agency emergency phone number. Although there are a few central county-wide dispatch centers, there still exists a few "mom and pop" dispatchers and answering services in the region.

7) Agencies' "own choice" of five backup ambulances to cover their base if their own vehicles are unavailable. This, of course, takes into consideration both previous mutual aid agreements and parochialism which has developed over time.

The next group of data obtained was the centroid locations of the municipalities in the region as a beginning of the location file. The Local Accident Surveillance Project Group of the New York State Department of Transportation provided this information and thus helped save many hours of coordinate plotting on the over 80 maps of the region.

The software for MCCADS was developed on an Apple IIe microcomputer with two 5 1/4 inch floppy disks. One disk contains the permanent agency file (the number of agencies is currently 250), the temporary agency file which is copied from the permanent file and manipulated during the execution of the emergency program, and the location file (the current number is 2,000).

Current Procedure for Using MCCADS

A schematic of the MCCADS system is shown in Figure 2. The dispatcher simply inserts the two disks, turns on the computer, and is given a menu which includes editing functions, file building functions, copying functions, and a "run" emergency program. When the emergency program is selected, the computer automatically copies the permanent agency file into the temporary agency file, and the dispatcher is asked the incident location. Any one of the locations in the file may be typed in by name, or the word "coordinates" can be typed and the dispatcher will be prompted for the actual UTM coordinates, which he can obtain from available maps. When the number of ambulances requested is then typed in, an ordered list of agencies with their number of ambulances, first responding vehicles, and phone number is provided on both the screen and printer. In the next phase, the screen goes directly down the list giving the

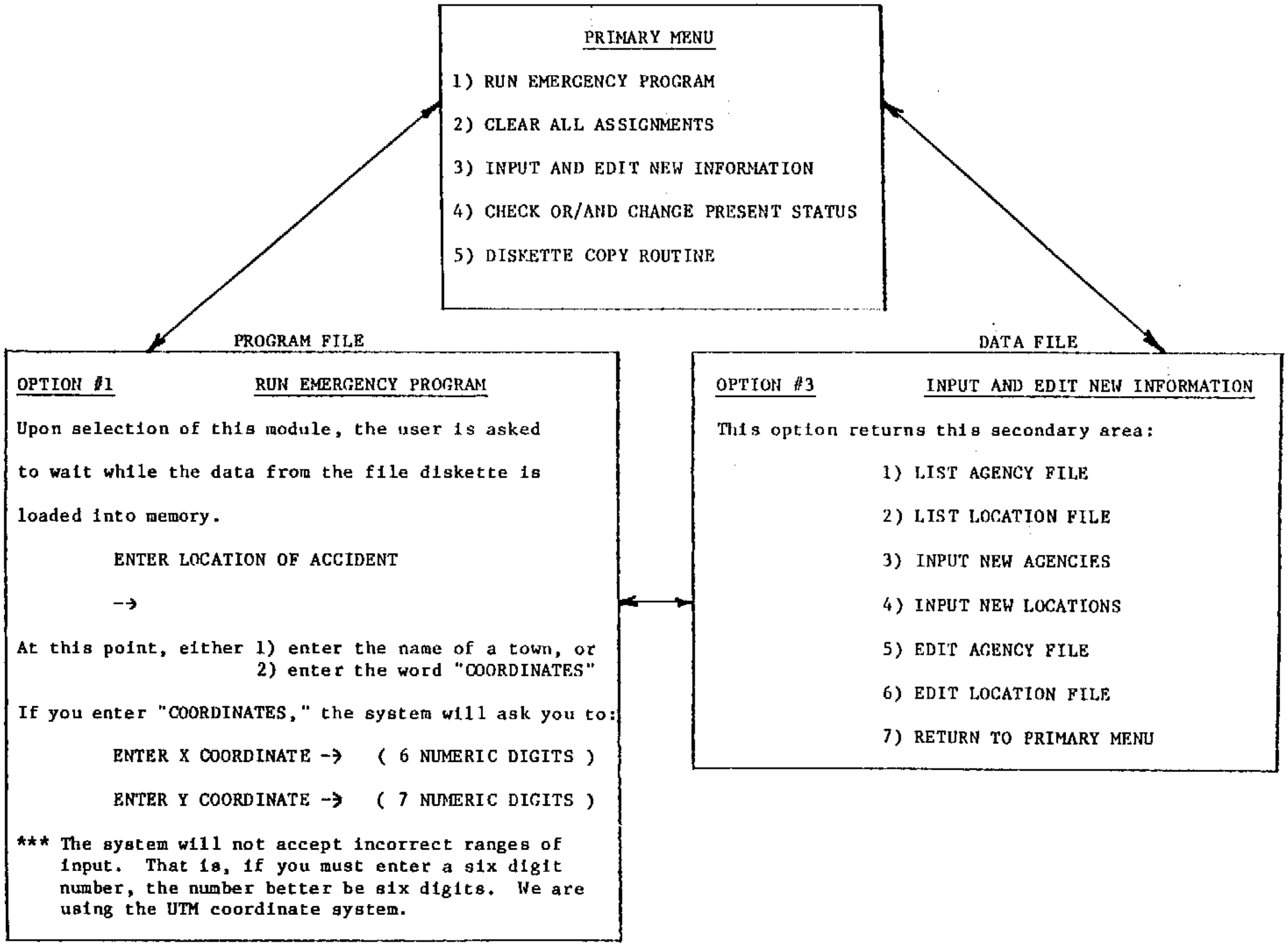

Figure 2
The Multiple Casualty Computer Aided Dispatch System

dispatcher the opportunity to assign each agency as his phone or radio message to them determines availability to respond. After the required number of ambulances have been sent to the scene, or after a control command is depressed to exit this phase, the next phase is begun. At this time, the computer goes down the list of ambulances assigned, giving the dispatcher the prearranged plan that determines who is to be used to cover the vacant districts. Every new list takes into consideration units which have already been assigned or put off service, so that those vehicles will not be listed as available until the dispatcher puts them back in service or the incident is over. The emergency program can be run again using the same or any other location should additional ambulances be necessary. When the incident is over, the dispatcher "clears all assignments" by simply erasing the temporary file.

Review and Test of the Second Prototype

The second prototype was tested at REMAC using a number of fairly simple scenarios. The most complex test involved a (fictitious) situation in which a university fieldhouse in the area partially collapsed. In this scenario, the local fire department that was initially contacted set up a command post near the fieldhouse and requested 20 ambulances from REMAC. During the test, the REMAC dispatchers employed MCCADS to generate a list of ambulances and actually telephoned each of ten agencies suggested by the microcomputer system. (Each agency contacted was informed at the outset of the conversation that "THIS IS ONLY A TEST. NO UNITS SHOULD BE DISPATCHED AT THIS TIME.") In this particular situation, a total list of 25 ambulances was required in order to dispatch 20 of them since three of the 25 were already on call. There was no answer at one of the agencies that had only one ambulance, and one ambulance in the data set was being dispatched by two different agencies (!)

The four REMO employees who routinely worked as dispatchers were involved in this particular test, and their evaluation and comments were helpful in assessing the need for further improvements in MCCADS. In particular, on a scale of one to ten, the four dispatchers rated the prototype system on four attributes as follows:

Attribute	Average Rating
Speed	7
Accuracy	7
Usefulness	8
Ease of Use	8

These numeric assessments are clearly not overwhelming endorsements of the system. However, many of the dispatchers' detailed comments were enlightening in explaining the problems remaining with the second prototype. Specifically it was felt that:

1) The system should have the ability to review input data at any time (coordinates and location of incident, whether or not an ambulance has already been dispatched, etc.)

2) Greater flexibility is required in assigning backup ambulances to uncovered areas. In this regard, the system needs to be dynamic and should consider all current assignments before recommending backups. Furthermore, no area should be totally stripped of ambulances when backups are arranged.

3) The data on handicaps are not totally believable. Some agencies appear to have reported extremely optimistic ramp times, and these figures should be reviewed by REMO experts.

4) The required phone calling would almost be prohibitive during busy hours of the day. (Actually much of this communication would be done by radio, but interference due to the time of the day and other radio traffic generated by an emergency would still cause problems.) An automatic dialing system would be helpful for calls made by phone.

5) Since the second prototype is primarily a stand-alone microcomputer system, it is difficult for two or more dispatchers to work together. A small network of terminals would allow all involved dispatchers to coordinate calls to the agencies.

6) The system should prompt dispatchers to call other appropriate emergency agencies, e.g., it should direct dispatchers to notify hospitals and arrange for local aviation support.

As will be discussed in the next section, most of these difficulties can be solved in a straightforward manner in the development of the third prototype. Items 4 and 5, however, deal with issues of emerging technology and will most likely require further technical evaluation.

The Next Step

The second prototype is currently available for use by dispatchers at REMAC. A third prototype that incorporates most of the straightforward suggestions described above is being designed to replace it. This system will include a less confusing display of the status of the current situation, an improved ability to provide backup ambulances for "uncovered" agencies (using more expert-like decision rules), and will provide phone numbers (and possible recommendations) for contacting other related emergency personnel and facilities.

It is also hoped that REMO officials will examine in detail the handicap times collected from the provider agencies. Dispatchers have indicated that they would be much more trustful of MCCADS if "accurate" numbers were incorporated in estimates of response time. A procedure for arriving at these figures needs to be agreed upon.

Discussion

Many observers advocate that all systems development projects should borrow as much as possible from prototyping and heuristic development. (See, for example, the discussion in Naumann and Jenkins, 1982, or McNurlin, 1981.) Our reasons for using a prototyping design strategy in the environment described here were compelling. Since computers have been used so little in disaster management, it was important that we demonstrate early in our interactions with REMO how these tools could be employed to improve the decision process. Prototyping also proved invaluable since the multiple casualty problem with which we were dealing is poorly understood, and appropriate (dispatching) decision rules are still being formulated.

Although some analysts suggest that "rapid prototyping" should be the universally preferred development strategy since user feedback is maximized, our project has not permitted such a strategy. Our development of MCCADS was planned and deliberate because:

1) Such a system is not a high priority item due to the limited amount of time that it is used in actual operations,

2) There is no room for error, since the system will be used as an aid in life and death situations, and

3) Cost justification is extremely difficult, and cost quickly becomes a prohibitive factor. Furthermore, in this and many other environments (Keen, 1985), the required data is not readily available, and the data collection process must go hand in hand with the development of the appropriate DSS.

In measuring the success of prototyping it is important that the procedure be an effective or "superior" one. According to Young (1984), effective prototyping is characterized by design improvements at each stage and by quick recognition of deficiencies in definition. In the case of MCCADS, design improvements have been dramatic at each iteration of the process, and straightforward unobtrusive tests (as we have described) have allowed us to efficiently observe design problems that have remained at each stage.

In summarizing our work, it now appears that there will be at least four stages in the prototyping of MCCADS:

Stage 1

The original problem was brought to our attention by New York State officials in the Office of Emergency Preparedness. As described in the previous section, the Version 0 prototype was designed primarily to test the feasibility of employing a microcomputer-based system to aid dispatchers. The prototype was model-based and a crude representation of what was really needed. As observed in numerous other settings however, the original, fairly simple system generated great interest among all potential REMO users and managers.

Stage 2

As discussed above, this working version of MCCADS (the Version 1 prototype) incorporated most of the real requirements of the users. Because of the dispatchers' cooperation following stage 1, and because we employed a relatively straightforward microcomputer-based system, design at this stage was manageable. Tests of this prototype involving simulation scenarios revealed that the second version was an excellent model for a "final" system. Currently it is being used by REMO.

Stage 3

This prototype has been designed and will be tested in the near future. It is an enhanced version that provides more effective information and greater detail than the stage 2 prototype. It is intended to be an "expert system" (Hayes-Roth et al., 1983; also see the article by Mick and Wallace in this volume) that will incorporate the decision rules employed by dispatchers.

Stage 4

For a number of reasons, this prototype has proven easy to envision but difficult to deliver. It is really one of the "ideal" system (Lucas, 1976) that designers often specify in the early stages of typical systems development. Thus, this ideal dispatching system would always have current information on the location of all ambulances and personnel, as well as an (almost) instantaneous ability to notify appropriate agencies. With today's technology, such a system is certainly a technologically feasible one. Microcomputer telecommunications networks have become a reality (Brennan and Malloy, 1983) and are ideally suited for this type of application. Unfortunately, economic infeasibility will likely prevent an agency such as REMO from implementing such a system in the near future. At this time, it is more likely that a technologically improved system will consist of two or three microcomputers in a network that has automatic telephone dialing capabilities. Such a system would allow several dispatchers to work simultaneously in locating, contacting, and allocating a large number of resources.

The major practical problems that remain are typical of disaster management environments (Belardo, Karwan and Wallace, 1982, 1984). Since actual events seldom occur, it is difficult to justify investment decisions in cost-benefit terms that look primarily at actual system use. Since most of the time spent by managers and dispatchers at an organization such as REMO is devoted to training (and not to actual emergency response), it is important that decision support tools such as MCCADS can also serve as training devices. In this regard, MCCADS has received favorable reviews; it is being used to train new dispatchers as well as to prompt experienced personnel to think about improvements in decision rules that were developed exclusively using past experience.

Another practical problem that confronts all emergency management systems is the difficulty of keeping information accurate and relevant. REMO is no exception. It is extremely difficult to justify the constant updating of data, especially to the point where the precise location of resources is always known. This would require both considerable resources and considerable co-operation from all involved agencies. It currently appears to be a low priority item at REMO and other, similar agencies that have only recently organized and are still formulating procedures.

Concluding Remarks

This paper has described the development of a microcomputer-based response system for managing disaster situations. The prototyping strategy described in much recent MIS/DSS systems design literature was found to be an appropriate one, yielding what appear to be impressive improvements at each succeeding stage. It is our belief that the prototyping approach lends itself nicely to the development of emergency medical response systems, and, in fact, that its use will speed up the development of decision support systems in environments that deal with other rare, potentially catastrophic, events.

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DECISION SUPPORT FOR EVACUATION OPERATIONS USING MICROCOMPUTERS

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Introduction

Background

The large scale destruction left in the wake of Hurricane Elena in the southeastern part of the United States in August, 1985 was a reminder of the awesome power of nature. Because the hurricane forced the evacuation of over one million people, it underscored the necessity for having sound evacuation plans and systems in place for emergency managers. Part of the solution for establishing such systems is the application of computer technologies (such as information management and simulation modeling) to improve both preparedness and actual evacuation management.

This article describes one such technology employing powerful microcomputers and software within the framework of a new class of information system--Decision Support Systems (DSS). It is based on the work of the Decision Support Systems Laboratory (DSSL) of the University of Southern California which has developed automated decision aids for persons responsible for managing the evacuation of smaller localities (Linaweaver et al., 1985).

The article is divided into three major sections. The first part defines the concept of decision support systems. The second describes the general functional requirements and proposed general system design for an evacuation decision support system called Evacuation Management System (EMS) being developed by DSSL. The third part is a detailed discussion of two EMS demonstration modules under current development at DSSL, one dealing with the management of an evacuation data base and the other with actual evacuation operations.

What is a Decision Support System

Since the DSS framework underlies this entire article and it is a concept that has received widespread recognition in the last five years, it is helpful to define it in some abbreviated detail. A Decision Support System (DSS) is a collection of computational, analytical, and decision-theoretical models together with a data base which reside in an interactive computer environment. Its purpose is to improve the effectiveness of what have been termed "knowledge workers" (Sprague and Carlson, 1982). A DSS consists of three major components: the data base, the model base, and the software system which contains the data base management system, the model base management system, and the dialog management system.

The data base contains information on the particular problem environment. The associated data base management system accepts user queries and retrieves the requested data. The model base contains the reservoir of mathematical and decision oriented models (some with simulation functions) which operate on selected subsets of the data base. Communication between the data base management system and the model base is performed by the model base management system. Thus, the DSS is "integrated" in the sense that the models can directly use the data stored in the data base. The user simply has to select a model and specify the desired data to be used. The model base management system generates the proper data queries and submits them to the data base management system. The dialog management system controls the interface between users and the system functions. It contains input programs which control menu selections (by such means as light pen, mouse, voice, finger pointing, etc.) and output programs that control graphic display, plotting, etc. (Wallace, Belardo, and Karwan, 1983).

EMS Functional and System Description

Introduction

There are three major levels of detail that can be employed in describing EMS:

1) **General Functional and Technical Description** provides a broad overview of the functions of the proposed system and the technical framework or architecture which is being proposed for development.

2) **Detailed Functional and Technical Description** provides greater detail on the characteristics of the system's functions and specific technical components.

3) **Operationalized Functional and Technical Description** includes precise definitions (specifications) of functional or decision processes. It defines data, mathematical modeling (including algorithms to be used, input and output formats), as well as technical hardware and software specifications, and testing and evaluation (performance) criteria.

This article provides the first two levels of detail but not the third (which would require documenting such things as record layout, file design, model parameters and equations) since EMS development is presently funded internally by the University of Southern California. Level 3 illustration of EMS is provided only during demonstrations or presentations by DSSL staff.

Outside funding sponsorship for full-scale EMS development is being actively sought by DSSL. Once that is obtained, EMS may become public domain software.

General EMS Functional Goals

The broad, long-term EMS design which is planned for the future is based on a general framework of information required by emergency managers to meet one or more functions listed below:

- Process evacuation-related data thus providing a data base of key files including population, evacuation centers, evacuation routes, emergency agencies, communication systems, and transportation resources—including input, update, ad hoc inquiry, indexing, sorting, and reporting of data;
- Identify evacuation requirements and prepare a response plan for relocation of affected populations;
- Record evacuation data and conduct evacuation analysis;
- Analyze potential alternative evacuation scenarios and their time and resources requirements;
- Estimate actual evacuation response requirements and manage response resources;
- Support the operation of mobile units in the field during evacuation;
- Display and print data on resources required for evacuation on a map of a geographic area such as a city or county;
- Communicate with the computers of key organizations such as the local fire or police departments, medical systems, regional and/or national emergency operations centers;
- Interface with other automated components of an Integrated Emergency Management System (IEMS) which include earthquake, flood, toxic spill, nuclear, and other disaster components since an evacuation may be a secondary effect of these major disasters;
- Support all phases of evacuation including preparedness, mitigation, response and recovery.

- Be flexible and affordable enough to be customized to meet the requirements of the following organizations:

    - small-to-medium size cities and counties and their emergency response agencies,
    - specialized institutions (e.g., hospitals, schools, prisons);
    - industrial complexes,
    - military bases,
    - emergency medical centers,
    - state and federal agencies with direct responsibilities in the evacuation area.

A proposed EMS system architecture based on a modular approach to meet these functions is shown in Figure 1. It relies on a powerful microcomputer such as the IBM PC-XT or PC-AT with commercially available software such as LOTUS 1-2-3 or SYMPHONY. A variety of software and hardware enhancements could be added.

Functional EMS Modules

The general functional requirements of this system have been partitioned into eight EMS functional modules, five of which have been developed. While only modules 1 and 2 will be discussed in detail, it is expected that all of the following modules would have some simulation capability and would be model-based.

- **Module 2—Evacuation Response Organization and Resources**—aids evacuation response managers by suggesting a plan for a specific evacuation given the type, location, and scope of the impending or actual disaster. This process is discussed in detail later in this article.

- **Module 3—Incident Cost Estimation And Forecasting**—in combination with module 2 uses the per hour cost of all response resources for a specific evacuation, as well as other cost categories, to estimate the total cost of an evacuation. This estimate can be used later to recover costs from federal or state agencies. An aggregate cost model permits "what if" analysis by varying cost parameters.

- **Module 7—Natural Language Retrieval**—incorporates specialized software making it easier to retrieve data from EMS files. Current examples of such software commercially available for microcomputers are CLOUT and SAVVY.

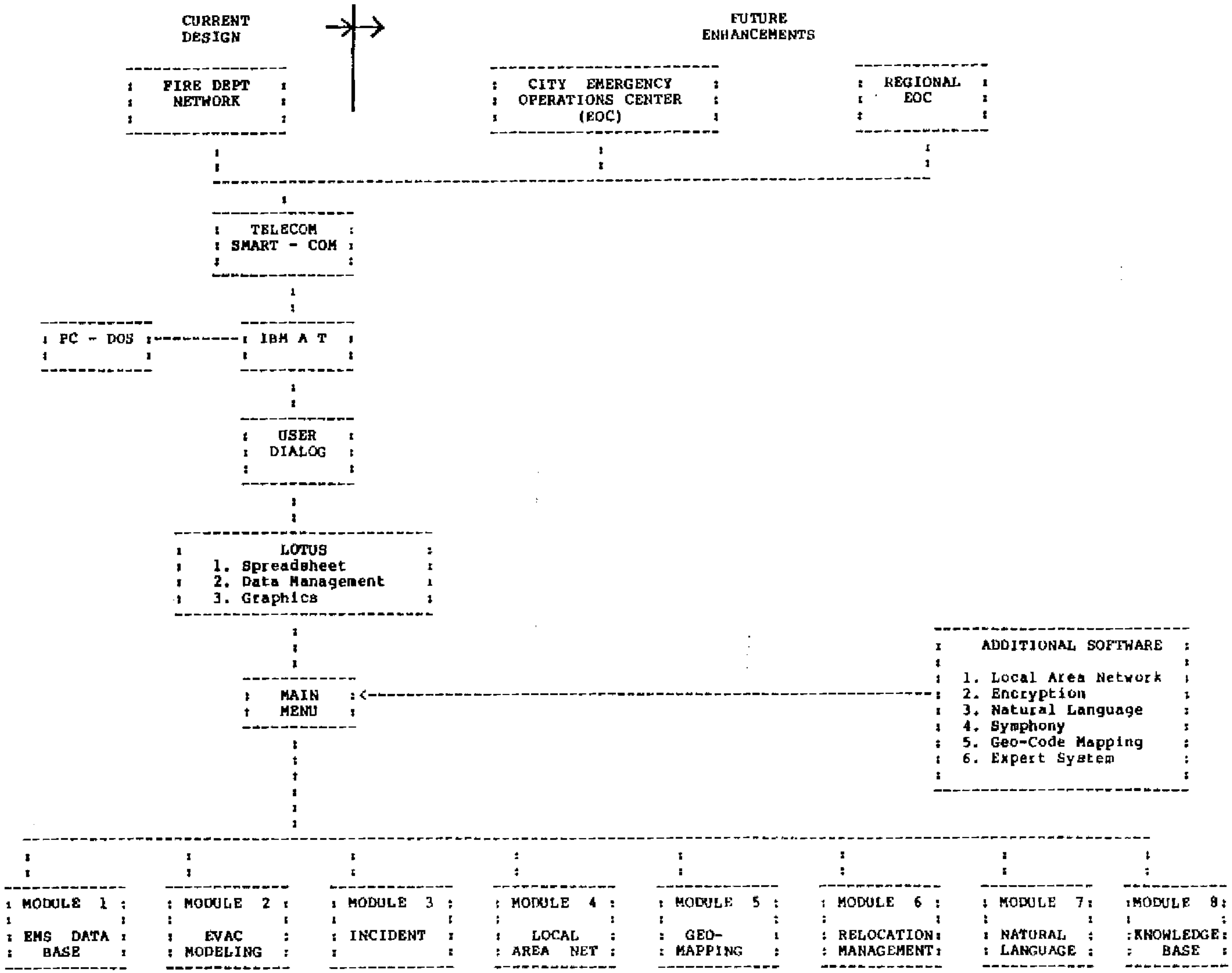

Figure 1
EMS General System Design

- **Module 8—EMS Knowledge Base**—involves a new class of information system, the expert system. This system contains procedures, rules, and knowledge which algorithmically represent expert human decision making. Expert system software and the knowledge base permit simulation through the variation of rules. The development of this kind of system is a long-term process which will require the accumulation and refinement of large amounts of expert knowledge (Hayes-Roth, 1984).

EMS Data Management Module

An initial basic requirement for EMS is that users be able to carry out basic data management functions. This requirement is satisfied in module 1 which would have the following menu-driven capabilities (see also Figure 2):

- A **Help Feature** to assist the user while operating EMS,
- A **Tutorial** to train the user to operate EMS under a variety of scenarios,
- An **Audit Function** to evaluate the entered data against certain error checking criteria and identify exceptions,
- A **Data Manipulation** function including:
  - **Input**
  - **View**
  - **Update**
  - **Print**
  - **Graph**
  - **Dif** (Data interchange function) revises data and model output files into different computer formats such as ASCII or BASIC for processing by other software,
- A **File Manipulation** capability that can:
  - **Change**
  - **Merge** with other files (spreadsheets)
  - **Delete**,
- The ability to **Exit** to communication software (upload & download), command language of software (e.g., LOTUS 1-2-3), or the PC-DOS operating system.

Modules for Organizing Evacuation Response

The following section describes EMS, the demonstration DSS. It focuses on preparedness (through training support) and actual response to an evacuation of a limited size.

The purpose of EMS is to aid managers in configuring a "best" response to evacuation problems. It consists of 1) a data base of population distribution, evacuation and relocation centers, communications agencies, major evacuation routes, transportation resources, and emergency agencies; 2) a model base which includes major evacuation routes and route capacities and an algorithm for calculating evacuation times given demand and capacity level for evacuation;

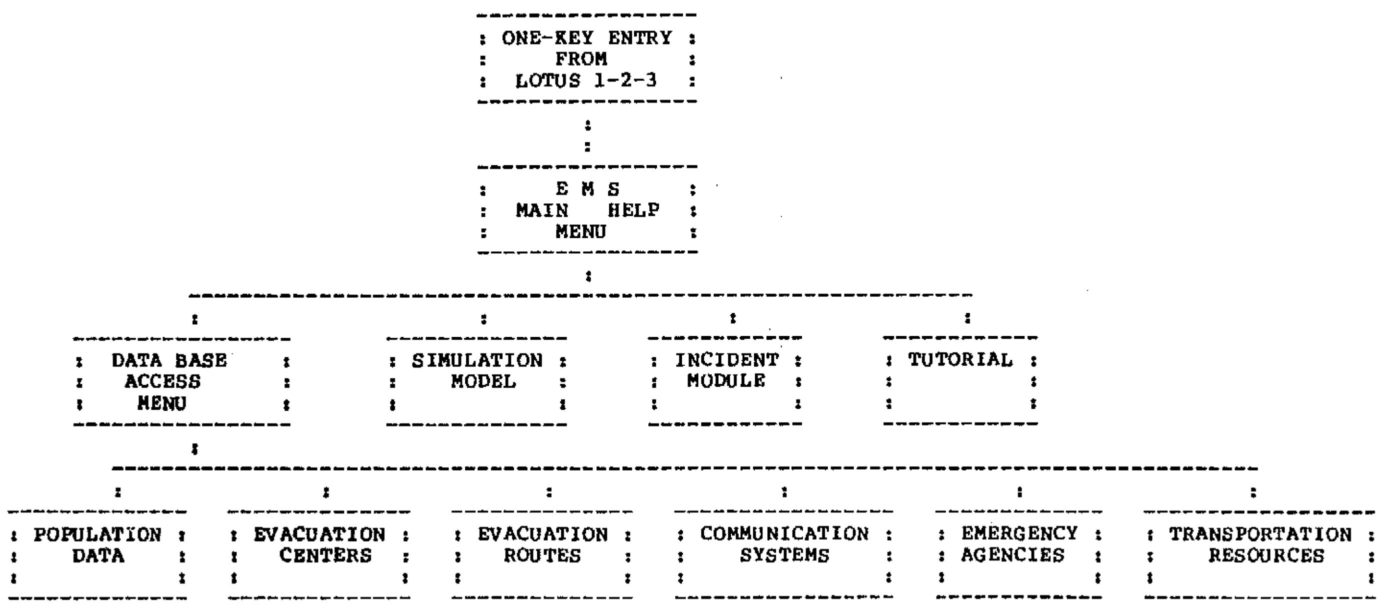

Figure 2
EMS Data Flow Diagram (Current System)

and 3) a menu-driven system for dealing with an actual evacuation.

Such a DSS is valuable for preparedness training and for actual response to an evacuation. EMS is based on a demonstration model that used the city of Rialto (in Southern California) for test bed data.

Evacuation Response Functions

The current prototypical EMS system incorporates a number of interesting features as well as some of the functions that are planned for other modules. These functions:

- Determine the plan of evacuation and include the use of in-house as well as contract resources,
- Assist in providing immediate information about what can be done to meet evacuation requirements,
- Notify appropriate agencies about the evacuation, its magnitude, immediacy, and other consequences and requirements,
- Identify possible relocation sites given the specific characteristics of the evacuation,
- Aid in determining evacuation responsibilities, and
- Estimate immediate evacuation response costs for later budgetary planning and cost recovery.

Specific DSS Design Features

The three DSS components--data base, models, and user dialog--for this EMS model are discussed below. However, since it is a demonstration model, the evacuation model referred to is rudimentary and not fully developed.

Data Base. The following data bases are part of the module:

- **Population**--includes the location, type number, and designated evacuation routes for several population areas of Rialto;
- **Evacuation Centers**--contains the location, capacity, evacuation route, and ultimate evacuee destination for the centers available during a disaster;
- **Communication Systems**--lists the various systems that are activated during an emergency, their responsibilities, and contacts;
- **Transportation**--lists resources and facilities, including their description, capacity, and any special features. This information is made available through EMS to the City Emergency Operations Center. The data base used in the EMS demonstration model includes data from the City of Rialto Emergency Plan, the Rialto telephone book, and other sources.

There is also an incident file (module 3) that is a special data base which stores data on past and current incidents involving evacuations and provides an historical record that can be used later for analysis. This information is useful in improving future response.

Models. At present EMS incorporates one model which is designed to determine the maximum time required to evacuate a certain geographic area. This permits both simulation and use in an actual response situation. "What if" analysis is possible by varying the number of people to be evacuated and the speed and capacity of evacuation routes. This component is based on an internal program (a "macro") to EMS and constitutes the modeling portion of this DSS.

User Control (Dialog). EMS is geared to be used by nonspecialist personnel with a minimum of training. This is especially important during the response phase of an evacuation. Therefore, it has been designed to be menu driven. It prompts the user to select one of the following functions:

*DATA BASE ACCESS
*EVACUATION SIMULATION
*INCIDENT FILE ACCESS
*TUTORIAL

Prototype Computer Hardware and Software

EMS has been developed on the Digital Equipment Corporation (DEC) Rainbow 100+ personal computer, a dual processor (8 and 16 bit) with 256k byte main memory, 2 floppy disk drives with about 400k byte storage capacity, color monitor, SA100 dot matrix printer, and Hewlett Packard plotter. It employs the MS-DOS operating system and the LOTUS 1-2-3 software which combines spreadsheet, data management, and business graphics capabilities.

In summary, EMS allows for easy access to extensive data about evacuation requirements and resources permitting better and faster choices by those having direct responsibilities for managing the evacuation problem.

Technological Advances and the Future Development of EMS

The continuing trend of more powerful computer hardware becoming available at lower cost will clearly make more and more possible the acquisition of computers by emergency management organizations. The proliferation of computers and powerful multifunction software (that eases data base development, modeling, spreadsheet use, graphic display, and telecommunication) is making DSS technology more accessible. The introduction of small computers (e.g., the IBM PC3270 or the IBM PC-XT370) that can effectively and easily link with larger computers to extract and exchange data will open up even more opportunities. (Wallace and de Balogh, 1985)

In the next ten years the advent of "thinking" computers (fifth generation machines under development in Japan and the U.S.) will further enhance the the contribution of decision support systems to evacuation management. These new machines will employ software based on Artificial Intelligence (AI), giving them the capability to reason, make judgements, and even learn (Hayes-Roth, 1984). They will have at their disposal a vast knowledge base on major types of evacuation as well as explicit rules to guide situation assessment, modeling, command and control, and evaluation of alternatives at various stages of a disaster (de Balogh, 1985). This knowledge will be gained from experts whose insights into structure and heuristics (rules of thumb such as "If-Then-Else" inferences) will be incorporated into the machine's knowledge base via "knowledge engineering" techniques. The goal of this approach is to encode facts and reasoning used by experts and make that information easily available to planners, elected officials, and emergency managers.

In conclusion, one of America's leading futurists on computers, James Martin, has stated that it is certain that the dramatic growth of information technology will lead to a much larger role for Decision Support Systems in organizations (Martin, 1982). In the field of disaster management, planners and decision makers with the responsibility for evacuation will have no choice but to learn to understand DSS and to build and to use DSS for the benefit of their communities.

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THE EVOLUTION OF DECISION SUPPORT SYSTEMS FOR EARTHQUAKE HAZARD MITIGATION

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Introduction

This paper will focus on the kinds of decision support systems that are currently available for use in earthquake hazard mitigation and attempt to predict the evolution of such systems over the next five to ten tears. In sodoing, it discusses the state of the art in earthquake hazard simulation and in computer usage by various urban development professionals. In the next ten years these trends are likely to result in the building of expert systems that can aid those professionals in the design and analysis of urban development projects. These trends and the likely evolution from today's simulation models to tomorrow's expert systems are highlighted.

The Context for Earthquake Hazard Mitigation

Earthquake hazard mitigation requires the transfer of information from the scientific community to political decision makers. This transfer is not, however, made directly. It is accomplished by a number of intermediate transfer agents. Figure 1 shows a number of important professional groups that are involved in the transfer of earthquake hazard mitigation and expertise. These professional groups involved in urban development (planners, architects, civil and structural engineers, consulting geologists) are the most likely users of computerized decision support systems. Even today, a large amount of technical information is used in the design and review aspects of the urban development process.

One key to utilizing the increased understanding of earthquakes and their mitigation, produced by recent research, lies in improving the hazard information and analytic models routinely used by these groups in areas with significant seismic risk. Expert systems can help urban developers to incorporate the latest earthquake hazard mitigation techniques and information into their practice. Earthquake hazard mitigation then becomes as much a question of professional practice as of public policy.

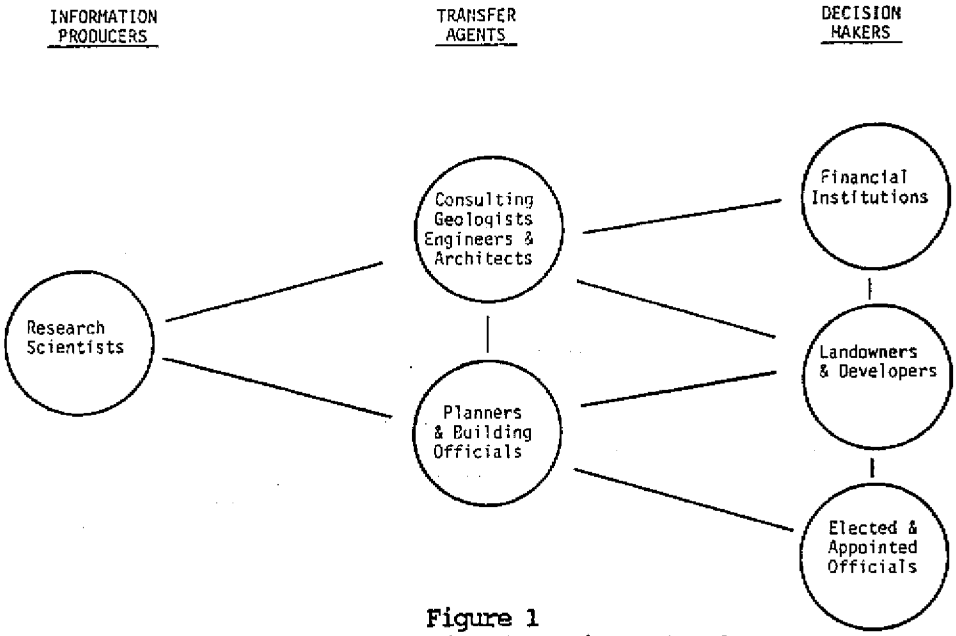

Figure 1
Earthquake Hazard Information Network

Where Are We Today?

In Modeling the Earthquake Hazard

The state of the art decision support system for earthquake hazard mitigation is embodied in simulation models. These models have evolved over the past five to ten years and generally run on minicomputers and use empirically estimated equations to describe the hazard and its potential damage. Simulation models are not standardized. Many are proprietary, and many were developed for specific case studies. They are generally not used interactively in the design and decision making process. There are numerous technical differences between models. Some consider only one or more scenario earthquakes, whereas others use a probabilistic approach which averages damages over a whole range of possible earthquakes. In addition, the models they use to classify structural building types vary. Despite these differences, the general form of the earthquake simulation model is well developed, even though incremental technical adjustments are still being made.

Simulation generally begins with an evaluation of the probability of earthquakes of various sizes affecting an area of interest. If likely sources can be identified, the attenuation of energy from the source to the area of interest must be estimated. The probability of various ground motion intensities (or acceleration or other parameters affecting the structural integrity of urban development) is then estimated for various locations. This process provides a judgement of the physical parameters of the hazard. Various factors such as the relatively short duration and small number of actual observations of these rare events and technical questions about attenuation relationships combine to make such estimates considerably uncertain.

These physical parameters must be translated into estimates of likely damage, injury, and loss of life. Again, empirically derived relationships combined with information about the inventory of structures in the area are used to estimate the damage likely from earthquakes of various sizes and locations.

These estimates may take the form of damage ratios which indicate the percentage of replacement value of various types of structures likely to be lost. More sophisticated models include the additional damage attributable to secondary hazard factors such as landslides, liquefaction, or intensification by certain types of surficial deposits. It is also possible to simulate the effects of other earthquake induced hazards such as fire, tsunami, or dam failure. Again, there is considerable uncertainty throughout the process.

The companion paper in this volume by Haney provides an excellent description of the use of simulation models to estimate the damage resulting from an earthquake in a major urban area. A similar discussion is provided in the Journal of the American Planning Association by this author (French and Isaacson, 1984). Simulation models have also been widely used in various research projects (e.g., H.J. Degenkolb Associates, 1984; Rice Center, 1984). Simulations have also been used to provide the base data for earthquake preparedness projects in several urban areas with particularly severe seismic risk (e.g., Southern California Earthquake Preparedness Project). Another interesting application of simulation techniques for estimating damage to urban infrastructure is contained in the planning scenario documents prepared by the California Division of Mines and Geology (Davis et al., 1982 and 1982a). While specific estimation techniques may differ, these policy oriented simulation models generally follow the steps outlined in Figure 2.

To be useful in a policy context, simulation models must produce several types of output:

1) Quantitative estimates of ground motion at various locations,
2) Maps of ground motion and areas subject to secondary hazards,
3) Numbers of structures and the extent of damage likely for various types of development (including urban infrastructure as well as buildings), and
4) Maps of likely damage patterns.

To date, the models have generally been used to produce background data to aid decision makers. They have not been used interactively in the day to day design and analysis of most urban development projects. They have shown that damage varies spatially but is often concentrated in areas where an older building stock or secondary hazards intensify the losses.

In the Planning and Design Fields

At the same time that these earthquake hazard simulation models have been developed, some interesting changes have been occurring in the urban development professions—architecture, engineering, and planning. There has been a widespread adoption of microcomputers in the daily practice of firms and agencies in these professions. The IBM-PC and its clones are ubiquitous. There are three types of software that are in widespread usage in routine project design and analysis:

1) Spreadsheets, particularly special purpose spreadsheet templates,
2) Database management programs, and
3) Programs designed for a specific task (e.g., finite element analysis or air pollution modeling).

These systems are in widespread use by the professions today and will be standard support tools in each of the urban development professions in the near future.

For example, city and regional planners now use spreadsheet templates for population projection, fiscal impact assessment, economic base analysis and real estate development feasibility. For a more detailed discussion of the use of spreadsheets in planning see Ottensman (1985) and Landis (1985). Spreadsheets are being rapidly adopted by the planning profession, because they allow the user to test the consequences of alternative actions. Planners also use database management systems to store and analyze information on individual land parcels and the physical and economic factors associated with them.

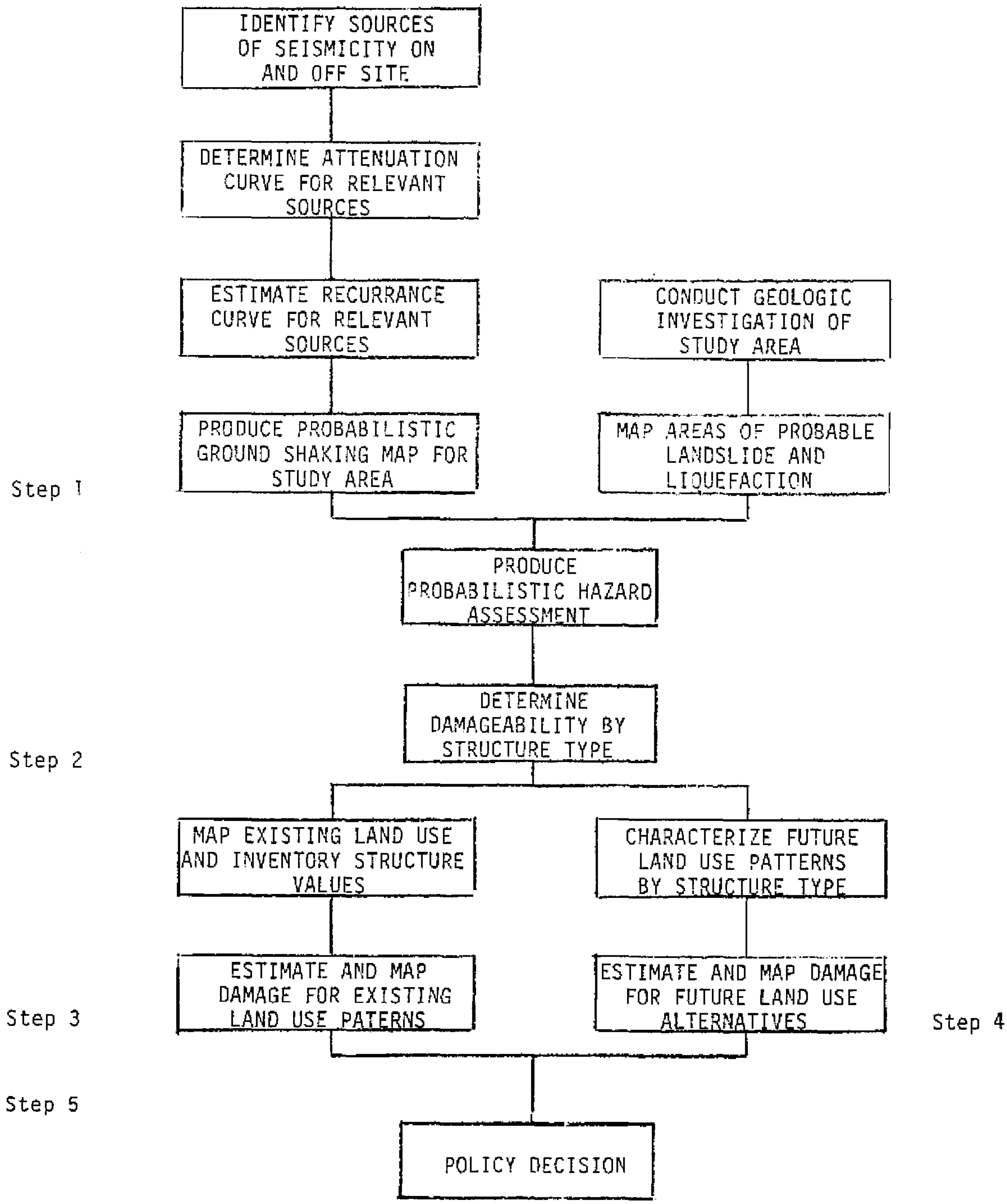

Figure 2
Steps in the Earthquake Risk Analysis Process

Engineers and architects routinely use spreadsheets for cost estimation and similar purposes, but also use a considerable number of vertical market packages for specific tasks such as finite element analysis, air and water pollution analysis and project scheduling. Thus, we see that the urban development professions are now widely using microcomputers and various types of software in practice.

Where Are We Heading?

In The Next Five Years

In the next five years we are likely to see a coming together of the two trends discussed in the last section. This would result in the incorporation of some of the expertise and information embodied in the simulation models into the types of computers and software currently being used by the urban development professions. Figure 3 shows typical tabular output from an earthquake damage assessment simulation. It is not hard to imagine a planner using such a matrix in a risk analysis spreadsheet template. Such a tool might be very useful to investigate how damages are likely to vary given changes in the types and number of structures in various locations. Beyond this, planners and decision makers might be interested in knowing how different structural mitigation measures might affect the damage ratios shown by the simulation. The costs and benefits of these various mitigation measures could then be weighed. Such cost-benefit analysis of mitigation alternatives has in fact been identified as an important part of the decision making process by Wolfe et al., (1984) and by others.

It is also not hard to imagine databases which contain the likely physical parameters of an earthquake for various parts of a wide geographic area (e.g., the San Francisco Bay Area or the State of California). Such systems (on-line or otherwise available to structural engineers and architects) could supply the data used in the design of structures and thereby become quite useful to firms that practice in seismically active areas.

It seems that we will see some earthquake hazard mitigation analysis systems integrated with the types of software and small computers widely available in the urban development professions. This integration should take place over the next five years and is a necessary condition for the maturing of earthquake risk analysis from research and case study analyses to routine use in everyday practice.

Location	Total Value (in thousands of dollars)	Damage Ratio	Damage Value (in thousands of dollars)
Paso Robles (1)	131,255	.09	12,287
Wood Frame	90,935	.06	5,456
Masonry	35,100	.16	5,616
Steel Frame	2,660	.12	319
Mobile Homes	2,560	.35	896
East Paso Robles (2)	54,920	.08	4,535
Wood Frame	47,970	.06	2,878
Masonry	1,170	.17	478
Steel Frame	900	.12	108
Mobile Homes	3,060	.35	1,071
Templeton (3)	30,725	.13	3,995
Wood Frame	22,815	.07	1,597
Masonry	1,170	.17	199
Steel Frame	440	.13	57
Mobile Homes	6,300	.34	2,142
Airport/Jardine Road (4)	7,035	.09	611
Wood Frame	5,100	.06	306
Masonry	1,495	.16	239
Steel Frame	380	.12	46
Mobile Homes	60	.34	20
Linee (5)	6,315	.08	482
Wood Frame	6,000	.07	420
Masonry	195	.16	31
Steel Frame	40	.13	5
Mobile Homes	80	.33	26
Rural	75,000	.06	4,500
Wood Frame	75,000	.06	4,500
Totals for Study Area	305,250	.09	26,410

Figure 3
Typical Damage Estimate Matrix

In the Next Ten Years

Within the next ten years we are likely to see the development of expert systems for earthquake hazard mitigation. These complex programs, which are an outgrowth of the artificial intelligence field, simulate the way human experts solve complicated problems with specialized knowledge. They can lead a user through the various steps in the earthquake risk analysis process by asking questions, explaining the reasoning behind various steps in the analysis, and by providing useable data or data sources for the user. Such systems can be used both for training purposes and interactively in the design and analysis of specific development projects. These systems are currently being applied in a number of specialized applications such as medical diagnosis and oil and gas exploration. For a discussion of the expert systems technology, see Webster and Miner (1982) or Dudek (1985).

An expert system for earthquake hazard mitigation should provide the user with the appropriate analytic tools to use at various points in the risk analysis process. It should help the user select analytic tools that are compatible with the type and amount of data at hand. It should also provide data needed at various points in the analysis or help the user select between alternative sources of secondary data or guide the user through procedures for collecting primary data (e.g., a building inventory) when necessary. Such a system would support a wide range of decisions made every day which affect the level of mitigation in new development.

Expert systems can also be seen as a means for increasing the flow of information from the research community to practitioners. By making the information and techniques developed in the multitude of earthquake research projects available to various urban development professionals, creators of expert systems can greatly advance the practice of earthquake hazard mitigation. The level of knowledge regarding earthquake mitigation is sufficiently developed that it could now be more widely applied; unfortunately, it is currently being used by only a relatively small group. Expert systems are a effective mechanism for bringing this expertise into widespread use by practitioners.

Admittedly, expert systems are not currently practicable, but the impetus of more powerful hardware and the increasing complexity of software seems to be leading in this direction. Several recent research projects have developed "how-to" manuals which outline the steps in earthquake risk analyses

(Heikkala, Greene, Bolton and May, 1985; Jaffe, Butler and Thurow, 1981). These manuals can be thought of as providing the basic outlines of an expert system for earthquake hazard mitigation.

One of the definitive features of a true expert system is its ability to learn. Therefore, the initial systems can be expected to improve as they are applied to more and more situations and as more observations of actual earthquakes provide better data on which to calibrate various models. Whether or not expert systems will play a key role in mitigating the earthquake hazard remains to be seen, but the urban development professions seem ripe for the adoption and use of such systems in the next decade.

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EMERGENCY MANAGEMENT
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This author has a clear bias that all readers should recognize. It is, in fact, an advocacy position, and was first expressed in 1981 in hearings before the U.S. House of Representatives, Committee on Science and Technology, Subcommittee on Investigations and Oversight:

> I believe that unless a consistent policy and program for using information technology in emergency management is developed, three years from now emergency programs in the local communities in this country will not be as well managed as the local barber shop or butcher shop. Inexpensive computers will have made such an impact on small business that even the smallest will have more knowledge and analytical power at their fingertips than the office charged with protecting the entire jurisdiction from catastrophe and leading the community's survival from a nuclear attack.

It has been over four years since that statement, and the words have proven to be accurate. Butcher shops and barber shops--as well as second grade classrooms--have moved into the computer age. Today, however, the community of emergency management professionals is just beginning to peek over the horizon to see the future--and the present--of computer applications in emergency management.

Emergency management is an exceptionally fertile field for the application of computer technology. However, this application will not take place overnight. To reap the fullest rewards of technology, implementation of computer systems in state and local emergency management offices will have to be thoughtful and sequential, yet still aggressive. This paper describes how small jurisdiction governments and state emergency offices are presently using computers. These case studies are drawn from personal experience in the design, development, and installation of a proprietary computer software package--the Emergency Information System (EIS)--developed by Research Alternatives, Inc.

Based on this experience, the paper also offers an analysis and forecast of five stages through which computer applications in emergency management are now passing and will pass in the next five to seven years.

Small Jurisdiction Computer Applications

The scene could be Hattiesburg, Mississippi, or Barrow, Alaska, or Hobbs, New Mexico, or Starke County, North Dakota, or any other small jurisdiction with an emergency organization. While the hazards confronting an area may differ, emergency management needs are all similar. We have learned a lot from locations like these that utilize single computers; some of that information can be summarized by examining a single site—Waseca County, Minnesota.

Waseca County is located in the south-central part of Minnesota. It is a rural community in which agriculture is the principal occupation. The population of Waseca, the county seat, is about 9,000. The population of the entire county is approximately 20,000. Among the hazards for which the county government must prepare are tornadoes, snowstorms, floods, transportation accidents, thunderstorms, and hazardous materials problems.

The unit of government charged with emergency preparedness is the Waseca County Civil Defense Organization. The office operates out of the county security building, where the Emergency Operations Center (EOC) is housed. The emergency program in Waseca is a good one, and the Emergency Operations Center is better than most others around the country. The EOC is linked to the rest of the county by numerous radio systems; it has a closed circuit television system that can display news broadcasts to all the staff in the EOC and can also be used to keep everyone up-to-date on the most recent events in an emergency by focusing one of the closed circuit cameras on the disaster status board.

This last capability—updating information—is the function that involves the Emergency Information System. One of the Information System's important capabilities is to keep a current Event Log and Resource Deployment Status Report.

The Resource Deployment Status Report is an interactive program operating, as do all the programs, on an IBM-PC microcomputer. Resource deployment is a vital task of the Emergency Operations Center. At the EOC, representatives of all the local government's emergency services (police, fire, public works, civil defense, emergency medical), as well as the emergency program manager, coordinate the emergency (see also Belardo and Karwan, in this volume). The Resource Deployment Status Report is an important tool that facilitates this coordination.

The Status Report should not be confused with computer-aided dispatching that is used by fire departments across the country. Its purpose is one management level above dispatch, for contained in the computer is the deployment of resources for all government emergency services plus resources available from private business, industry, and voluntary organizations. The output from the computer, therefore, is designed to answer the following management questions:

- What resources (from all sources) are currently involved in the emergency operations?
- Where are those resources?
- Are there gaps in resource allocation, i.e., unmet needs? Or are there overlaps in resource allocation?
- What and where are the currently available resources to fill present or anticipated gaps?

In addition to answering these four questions, the Resource Deployment Status Report provides data to answer two additional questions that are of crucial importance to the policy-making level of government to which the emergency program manager is responsible:

- Are outside resources required?
- Are extraordinary powers required to acquire such resources?

The Resource Deployment Status Report allows the staff in Waseca to perform several data manipulations.

1) When a disaster begins, the emergency services (police, fire, etc.) designate staging areas or incident sites from which they will manage the emergency conditions. The first step in using the Resource Deployment Status Report is to designate such a site by name and map reference point. The site is automatically assigned a number.

2) Several hundred categories of resources might be available in a community. The Emergency Information System begins by presenting a comprehensive listing of these categories. As the emergency staff in Waseca develop their resource inventory, unnecessary categories are deleted and new categories are added as needed.

3) When a resource is needed, calling up one of these categories results

in the display of data summarizing all of the resources in that category. For example, if there were a need for sandbags to construct dikes to control a flood, the user could query the system for all sandbags. Appearing on the screen might be the information that sandbags are owned by the emergency management office, by a neighboring county, by a supplier in Minneapolis, and by the public works department. Contained in the citation of all these sources would be:

- quantity available
- location
- organization
- complete description of resource
- phone number for contact
- notes or further details
- source of resource
- primary contact home phone and address
- alternate contact and phone
- cost of using resource
- authority to obtain resource

4) In addition to the above data, the system displays current deployments, if any, for each resource. Information regarding deployment includes the quantity deployed, the site deployed to, the organization deploying, and any notes entered by the user at the time of deployment.

5) Not only can a composite list of all resources in a single category be displayed; individual resources can also be displayed and directly deployed.

6) Moreover, a key coordination function is performed by the Resource Deployment Status Report: it can display all "working" sites and then all resources deployed to any of those sites. The emergency program manager can then quickly spot the inappropriate deployment of, for example, public works department debris clearance crews to the same location at the same time as an emergency medical service triage team.

7) Finally, as emergency equipment is recalled from individual staging areas or emergency sites, the Status Report recalls them also. In the later stages of the disaster, as portions of the emergency operations are concluded, individual staging areas may be closed down. By simply deactivating a site, all resources then deployed to that site are returned to their home location. Any resources that have been consumed (sandbags, for example) are noted, and the computer automatically prints out a reorder form.

When one stops to consider that a small community is likely to have a resource inventory that consists of 700 to 1500 separately identifiable resources, the value of a computerized Deployment Status Report in even small emergencies is great.

The managing of resource deployment is complemented on the Emergency Information System by an automated Event Log that keeps track of all the events occurring in an emergency and the status of each. The Event Log is linked to the Resource Deployment Status Report by the use of the same site identification file. Thus, the user can ask for a display of all resources deployed to a particular incident or staging area and, subsequently, request an update from the Event Log on activities that have taken place related to that incident. These Event Log updates take the form of narrative descriptions of the status of the incident. For example, each time a report on the progressive containment of a fire reaches the operations center, that incident's status would be entered. The emergency manager, then, can quickly obtain a comparison of resources committed to the scene and the status of operations to provide policy-level decision makers with a forecast of future resource needs.

In addition to these uses of the Emergency Information System, a wide variety of programs complete the system and enable the local emergency office to fully utilize the computer's capabilities in shelter management, routine training, planning, budgeting, and administrative work in emergency preparedness. Thus, the computer benefits the emergency office throughout the year, not just during the crisis of an actual emergency.

State-Level Use of Computers

The Emergency Information System is now operating in several states. Delaware has installed the system at its state Emergency Operating Center, at the EOC's of its three counties and Wilmington. It has also purchased the EIS for the Red Cross. New Mexico, Minnesota, Maine, and New York all use the EIS in their state offices. New Jersey operates the system specifically for managing response to incidents at a nuclear power plant. Use by the Commonwealth of Pennsylvania is examined in detail below. That state is developing large-scale networks of computers for use in emergency management. These systems utilize an Emergency Information System that includes the graphic maps of all 67 counties and specialized maps of high vulnerability flood plains, hazardous materials sites, and nuclear power plants.

The Pennsylvania Emergency Management Agency is using the Emergency Information System Mapping Version to perform more than two dozen functions that aid the state and local emergency services organizations in analyzing hazards, planning for emergencies, and responding to those emergencies. Among the program's specialized emergency response subroutines are an Event Log, Resource Deployment Monitoring, Mass Care and Shelter Status, and Special Population Needs.

The Pennsylvania Emergency Management Agency is the Commonwealth of Pennsylvania's coordinating unit for all emergency preparedness and response. The agency and its emergency operating center are located in Harrisburg, Pennsylvania, the state capital, with operational units in three regions across the state. These regional offices serve as direct liaisons to the 67 counties in Pennsylvania that actually conduct emergency response operations.

The Emergency Information System in Pennsylvania consists of a network of eight IBM PC-ATs linked to a large capacity System 36 and more than a dozen other IBM PC-XTs. All these computers operate together as a multi-user Emergency Information System. The network of ATs is located in the Emergency Operating Center. The System 36 is linked to the Emergency Operating Center network while serving several administrative offices for routine word and data processing. The System 36 has virtual disks accessible by all of the ATs. Thus, it actually serves as a back-up to the PC-centered network in the EOC.

The remaining PC-XTs are located in "response cells" in adjacent rooms, where they are utilized by other state agencies. For example, the Department of Health can send a representative to the Emergency Management Agency's facility, where he/she can use the machines to establish contacts between the Department of Health databases resident elsewhere in Harrisburg or across the state. The Department of Health's representative at the Emergency Management Agency can access the agency's databases, analyze that information, and then produce results in a format that is usable by the Emergency Management Agency. These new data displays can then be sent to the Emergency Operating Center network through the System 36.

In the Emergency Operating Center, where the network of ATs resides, there are two large screen displays that permit the governor to view, at the press of a button, the most important information being analyzed by any of the eight ATs on the network. The governor's emergency briefing room adjoins the Emergency Operating Center with a fifteen-foot glass wall. Thus, the governor can observe and immediately communicate with the operations center, but is physically removed in a quiet location designed specifically for the making of executive level policy decisions.

An additional communications system consists of a closed circuit television network. The closed circuit system permits the display of information on any of the operating center's network computers throughout the Emergency Management Agency as well as in the governor's office located in the state capital. One of the system's cameras can also be used to show the activities of the Emergency Operating Center or to give to the governor or other state agency officials a direct briefing about an emergency without the executives having to leave their offices.

At the center of this extensive hardware system is the Emergency Information System Mapping Version software.

Emergency management is, perhaps, the most spatially oriented of all management sciences. A critically important computer tool for emergency management agencies, therefore, is the graphic display of maps of the jurisdiction and the ability to relate several different databases to those maps. Being able to geographically display the real-time relationship between hazards, the disastrous events that are created by those hazards, the population that is at risk from those disastrous events, and the resources that are available to combat the event is an extremely valuable decision support capability.

The Emergency Information System does this quickly and efficiently. The system comes with a base map of the jurisdiction and additional, separately digitized, and therefore far more detailed, "zoom" maps. All these maps are used in the display of information from the databases. With the press of a few keys all of the ongoing emergency events can be shown on the screen. By moving the cursor to any of those events and pressing a single key, a complete chronological description of the incidents and responses that make up that emergency event is displayed on the screen.

If one of those events is a fire, for example, the press of a few more keys will display whether that fire is occurring at the same location or close to the location of another hazardous site. For example, the computer will quickly show if the fire is in a building that is next door to a hardware store containing paint, turpentine, propane gas, or other hazardous materials. The computer will alert the user and, perhaps, avoid a mishap involving unprepared response personnel.

With the press of other keys, one can ascertain on the same screen whether there are individuals or institutions near that emergency scene that have some type of special emergency requirement. For example, during a utility failure the emergency manager must know whether emergency generators need to be supplied to hospitals, doctors' offices, or to an individual on a kidney dialysis machine. Immediately, the Emergency Information System shows the location of any special populations needing emergency assistance in the vicinity of the disaster. The special populations may include schools, nursing homes, prisons, or elderly residents of apartment houses who might need special help or early warning of an evacuation in the face of an oncoming flood. Industries that need a lengthy period of time to close down their operations in the event of a severe storm or hurricane might also be included as special populations. The Emergency Information System takes into account all of these special needs and quickly identifies for the emergency manager the specific needs of a given geographical location. He/she can then examine displays that detail the special emergency needs of those located near the emergency. Thus, in the course of an emergency, the computer will have displayed specific emergency events, their chronology, any other secondary disasters that might take place, and any special emergency needs created by organizations or individuals.

The emergency manager usually has the additional task of monitoring the response needs of fire, police, emergency medical, public works, or specialized private sector personnel. This can be done with a graphic mapping deployment monitoring program. For example, when the word "crane" is typed below the map, all cranes located within the jurisdiction appear on the map as a new symbol. The press of a single key replaces the displayed map with brief details about each crane. These details enable the emergency manager to select the appropriate crane for the task at hand. The manager can then also obtain full details about the selected crane, including the contact person, his/her telephone and address, costs, and the authority under which the government can obtain that crane. This information can then be passed to the resource manager who dispatches the crane. That person reports back to the emergency manager who then logs in the dispatch of that equipment to the emergency site. This information is then placed on the permanent record of that resource so that the next time the resource is called up, all displays will indicate that the crane has already been dispatched to a specific location. In addition, that same information is entered on the event log so that the chronological listing of incidents that occur during a specific disaster is automatically updated to include the dispatch, or eventually the recall, of a specialized emergency resource.

A final part of the currently existing databases that can be used with the maps is an inventory of mass care and shelter facilities. In the event that people have to be removed from an emergency scene and temporarily cared for, the Emergency Information System provides details about the nearest available care and sheltering facilities, including the type of supplies and equipment at the facility, and the current occupancy of the facility as compared to its maximum capacity. As with the other databases, the shelters are shown on the maps in geographical relationship to resources, events, or hazards. Moving the cursor to any of the symbols that appear on the map will result in the display of a summary text about all available mass care centers or specific details about any single mass care center.

The large, multi-user system being installed at the state of Pennsylvania's Emergency Management Agency will include maps of all 67 counties plus specialized maps of the five nuclear power plants and high hazard flood-prone areas of the major river valleys in Pennsylvania. Each county and the special hazard areas will be represented by a base map and several more detailed "zoom" maps. The more than 700 maps will be stored on the System 36 from which they can be obtained by the local area network for display on the ATs. From the ATs the maps can be redisplayed on the large screen projection television or broadcast over the closed circuit television system throughout the agency and into the governor's office.

The Pennsylvania Emergency Management Agency has made a far-sighted commitment to the automation of emergency planning and response. During the summer of 1985 the hardware, and the database version of the Emergency Information System were installed. Throughout the fall of 1985, the maps of the counties and special hazard areas were completed, and by the spring of 1986 the system will be fully on-line and tested in a series of simulations and exercises. By that time, the Emergency Information System will be deployed to the three regional offices of the Emergency Management Agency that will be linked, as part of a remote communication network for the instant transfer of information, to the central coordinating center.

Already, counties in Pennsylvania are making independent purchases of the Emergency Information System so that they can be linked to the regional offices and through the regional offices to the headquarters in Harrisburg. As a result, Pennsylvania stands on the brink of having the fastest, most innovative and comprehensive network for the collection, analysis, and communication of emergency information anywhere.

Five Stages of the Present and Future

Based on research and work in developing the Emergency Information System and experience in installing the software in both large and small jurisdictions, I suggest that in the next several years computer applications in the emergency management field will pass through five distinct stages of development. Here, "emergency management" means management at the level of state and local emergency offices, and "computer applications" means the relatively widespread use of computer hardware and software for the purposes described below. There is no question that these computing capabilities are available for different applications today. The provision of affordable and appropriate emergency applications to the thousands of jurisdictions across the country is a different matter, however.

Database Applications

Emergency managers have always had databases. Plans, resource manuals, shelter lists are all databases. However, in the past these have been kept in notebooks or filing cabinets. They were generally inaccessible or forgotten during the stress of an emergency when quick response was necessary. To automate such databases is a relatively straightforward process, and a database version of the Emergency Information System, working on inexpensive computers, has been available for more than four years. The study above of the local computer system illustrates the feasibility and success of this first stage of computer usage.

Databases, however, are independent of one another. One can relate them in some ways, but the ability to manipulate facts across databases is not well developed. (When one want facts on special populations, one cannot be using an event log.) Generally, the computer does not do any cross-database processing—a failing that takes us to the second stage of computer applications. In this stage the single most important way that databases should be related in order to help emergency management decision making is implemented. They are related spatially.

Geo-Mapping Applications

This second stage in computer applications in emergency management, like databases, is a currently existing stage. It involves the use of a computer graphic map to display the spatial relationship of the databases of resources, events, hazards, etc. The study of the state emergency office in Pennsylvania illustrates well the use of such technology. The development of such a system is an important breakthrough in computer applications in emergency management because it closely mirrors the current practices and procedures of emergency managers. The geographic relationship among resources, damage, evacuees, response forces, and other locationally variable components of emergency planning and response is crucial. Now, the mapping capabilities of the computer can make such relationships quickly retrievable and readily apparent. The second stage of computer applications--mapping--is now available and affordable to a growing number of jurisdictions.

Prescriptive Applications

In the third stage of computer applications in emergency management, the computer will actually help prescribe what should happen in an emergency response. (It is also possible to utilize such a system to describe what could happen in emergency planning or in hazard mitigation; that will be discussed below.)

Prescriptive plans exist right now--on paper. Emergency managers have plans that tell them: when X happens, call these 16 people, go out and set up a command post, and roll this hazardous materials unit. However, because these plans are not readily accessible or adaptable, in an emergency they usually just sit or are potentially counter-productive because they lack the flexibility to handle situations even slightly different from the plan.

The computer's capacity for prescriptive applications is due to its ability to indicate, based on a) time, b) geography, c) resources, and d) the nature of the hazard itself, how the manager should respond.

For example, by simply tracking time, the computer can identify how many personnel are on the scene two hours after an event is logged in. A prescriptive system could then automatically dial the Department of Sanitation and say, "Dispatch sufficient portable toilets for 16 firemen who are fighting this fire." Automatically, this prescriptive plan tells the Sanitation Department where to go, how to go, what time to go, what quantity to take. No one needs to think about those logistics.

A prescriptive computer application will take a general plan and make it geographically and temporally specific. Thus, the computer can do everything from sorting facts to acting on rules established in the plan. The result will be fewer mistakes and greater anticipation of future needs in emergency response.

Predictive Applications

The fourth stage of computer applications will be predictive. One will be able to assess what kind of emergency response is needed based on time, hazards, resources, needs, and plans; and, moreover, the computer will continually prompt the user to examine the effect, up to the current moment, of the emergency on the organization's capacity to respond, as well as the replanning necessary to deal with the situation.

Eventually, such a system will be able to do emergency response needs predictions in real time. Every time a manager reaches level A of an emergency, before him/her will be arrayed all of the Bs. When the manager gets to B, he/she will already have begun looking for action D, or for a series of possible Ds. Action D might be an evacuation that requires 12 hours. If one can only find out about D when he or she has gotten to C, one may not have 12 hours left to evacuate. But at B, a manager has the time to sit and say, "Let's start to think about that 12-hour evacuation."

As a further example, the predictive system will allow a person to ask, "An earthquake reported to be of 7.2 magnitude just occurred at this location. What are the medical requirements created by this event?"

The predictive system would respond by reporting that the earthquake has taken out 40% of the medical facilities within a 100-mile area. Those medical facilities would have been able to satisfy the needs of 3000 people in hospitals and another 1750 outpatients. The computer would then describe how far one must go outside the damaged area to find emergency medical facilities to make up for the destroyed facilities. It would report where the manager would have to go, whom he or she would have to contact, and when contact would have to be made. The computer would be projecting a need five hours in the future while the manager is in the first 15 seconds of hearing about the earthquake.

Such a system is still in the future, because it requires models of natural events, effects on structures, damage estimates, and response plans that do not yet exist. However, a database in a specific geographic area sufficient to permit such a predictive system will soon be feasible. Two years from now one should be able to sit down in front of a computer-generated map, mark the epicenter of a 7.2 earthquake, move the cursor to any hospital on the map, and get a prediction of the damage to that facility. Ultimately, when asked how to replace that loss, the computer will respond by showing all the hospitals that are undamaged, and indicating the likely available capacity of a given hospital. That information will then be used to develop a transportation plan for taking victims to the nearest facilities. When predictive models such as these are in place, the fourth stage of computer applications in emergency management will have arrived.

Expert Systems

The last stage of computer applications will be expert systems (see the paper by Mick and Wallace in this volume, for example). The principles of artificial intelligence will be used not only to fill in a database of facts about an actual event, but also to simulate the thoughts, beliefs, and emotions of an individual so that that information can be synthesized into a database to help make decisions.

Some expert systems already exist in the medical field. The user simply states his or her symptoms and describes any drugs or other medications he or she is taking, and the computer then uses a database of medical knowledge to arrive at a diagnosis for a physician's review.

An expert system in emergency management would allow an emergency manager to sit down and say to his computer, "We just had a railroad tank car accident. There's a fire going on, and there are other tank cars at the scene. I'm afraid they are going explode, and I think we ought to evacuate." The computer would assess the facts (the railroad accident), the fears (of the manager), and the possible need (an evacuation), and then compare that information with a large database of the reactions of emergency personnel in similar situations. Those personnel would have recorded their observations, the evidence, their feelings at the time, their needs, and concerns. The computer would then assess the users' input with analyses such as: "The user actually used the word 'afraid' rather than 'concern.' Thus there is fear on the part of a professional emergency responder. When he indicates fear, things are of a higher level of intensity than they are when someone else is simply considering evacuation." Out of its database the computer would select similar events--tempered by the added component of emotional content. Thus, the expert system can actually take into account the nuances of the English language and select from a vast body of data, things that can help the user towards a decision.

As more facts become available (the nature of the substance in the tank cars, for example), they will be given to the computer. The "expert opinion" contained in the database will be continually reexamined, and the computer will refine and update its "decision advisory" about the most effective forms of emergency response.

With such a system, the individual manager will still make the final decisions, but the expert experience of many emergency managers will be brought to bear on each emergency management decision.

An expert system in emergency management will not exist soon; for limited applications, one may be available in about seven years. However, right now expert systems designers can barely create an authoritative expert system about engineering using the laws of physics that Newton discovered three hundred years ago. Therefore, expert systems must remain a long-term vision of computer applications in emergency management.

Conclusion

Five years ago inexpensive computer technology was in its infancy, and applications to emergency management had barely been considered. Today, applications are available and technology is abundant. We are perhaps halfway through the development stages of computer applications in emergency management, and already the impact is considerable. The final measure of success, however, will not be the number of computers in emergency operations centers, but their application as tools to improve emergency management. Thus the principal task continues to be the thoughtful, but aggressive, incorporation of information technology into emergency planning and operations.

SECTION TWO
SIMULATION AND MODELING

HURRICANE EMERGENCY MANAGEMENT APPLICATIONS OF THE SLOSH NUMERICAL STORM SURGE PREDICTION MODEL

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Introduction

The "Sea, Lake and Overland Surges from Hurricanes" (SLOSH) numerical storm surge prediction model, developed by the National Oceanic and Atmospheric Administration (NOAA), is an example of computer technology initially intended as a meteorological forecasting tool that has been found to have even greater value as a long-range hurricane emergency planning tool. Its speed and flexibility have enabled quick and comprehensive surge predictions--its speed being of most value when it is used as an operational forecasting tool; its flexibility, when it is used for long-range emergency planning.

This paper focuses on the application of the SLOSH model as a hazard and vulnerability analysis tool in comprehensive hurricane evacuation studies, and emphasizes the model's emergency planning and management applications rather than its internal technical components and algorithms.

The following section traces the evolution and early application of the model, presents a general description of the model itself, and reviews the development of comprehensive hurricane evacuation planning utilizing SLOSH. The next section examines current comprehensive hurricane evacuation studies and the basic evacuation planning methods that are utilized in such studies. It then describes the technical quantitative methods used in the SLOSH model. Taking into account other advances in computer technology for emergency management, the final section explores potential future applications of SLOSH.

The Evolution of SLOSH Emergency Management Applications

The SLOSH model was preceded by a computerized storm surge model called SPLASH, an acronym for "Special Program to List the Amplitudes of Surges from Hurricanes" (Jelesnianski, 1972). The SPLASH model predicts hurricane surge heights only on the open coast, assumes an artificially smooth coastline, and therefore can be applied to any stretch of coastline without a detailed survey of localized coastal conditions. Although SPLASH was somewhat valuable for emergency management applications, its inability to predict surge heights inland of the immediate coastline meant that any projections of inland propagation and inundation had to rely on simple "rules of thumb" based on the general pattern of topographic rise from the coast. However, the SPLASH model did succeed in convincing preparedness experts that the vulnerability of any particular coastal segment to local storm surge is an oceanographic rather than a meteorological problem. The model showed that a hurricane of a given intensity arriving from the Atlantic and generating a 10-foot storm surge might well generate a 20-foot storm surge if it arrived from the Gulf of Mexico. In addition, it emphasized the importance of localized bathymetric conditions in predicting storm surge heights on specific segments of the coast.

From the SPLASH model evolved SLOSH--the tool that first enabled comprehensive, site-specific, quantitative hurricane vulnerability analyses for evacuation planning. SLOSH enables the evacuation planner to delineate specific land areas with potential for inland storm surge inundation by generating geographic envelopes of maximum surge height. It also indicates the potential timing of surge inundation at specific coastal locations (e.g., along evacuation routes) by generating surge height time histories.

In 1977-79, the first operational SLOSH models were developed for Lake Okeechobee, Florida and Lake Ponchartrain, Louisiana. These models computed storm surges utilizing a relatively coarse grid mesh spaced about four statute miles apart; today's SLOSH basin models provide a geographic resolution of approximately .5 to 1.5 miles over land. In addition, a computer run of the early Lake Ponchartrain model used an averaged of three minutes of processing time on NOAA's IBM 360/195 system compared to eight to ten minutes for today's typical SLOSH models.

The first application of a SLOSH model for comprehensive hurricane evacuation planning took place in the Tampa Bay, Florida region in 1980. The analysis was done by the Tampa Bay Regional Planning Council and the U.S. Army Corps of Engineers, Jacksonville District. A year later similar evacuation planning projects were conducted for the Galveston Bay, Texas region and Charlotte Harbor, Florida.

Input parameters for the model are initial meteorological conditions and time-dependent conditions including storm positions (latitude and longitude) at six-hour intervals over a 72-hour period (48 hours before closest point of approach (CPA) and 24 hours after CPA), storm central pressure, storm size (radius of maximum winds), and forward speed. Any pre-storm tidal anomaly is also an entered as the initial height of the local water surface.

The hypothetical hurricane defined by these parameters is then simulated as approaching, paralleling, reaching land, and/or exiting the multicounty coastal "basin". The system then models the storm surge striking and interacting with the numerically modeled bathymetric and topographic characteristics of the basin. These characteristics include natural and human-made barriers to the surge, such as levees, elevated roads, vegetation, intercoastal and inland water bodies.

The output utilized by the emergency manager for evacuation planning consists of surge data overlaid on a curvilinear, polar coordinate grid scheme representing the area being analyzed. This data grid affords high resolution of predicted surges in such critically vulnerable areas as the backs of bays or along irregular coastline--areas for which evacuation planning is often difficult. An example of the data grid pattern common to SLOSH models appears in Figure 1, a graphic overlay of the Delaware Bay Model.

The output includes two types of data very valuable to the emergency planner. First, the highest surges above mean sea level are given for each grid cell of land for each hurricane simulated by the model. This provides the basis for geographic delineation of evacuation zones and the formulation of response scenarios under the final evacuation plan. Second, for preselected critical grid cells, time history data (in 10-minute intervals from 24 hours before to 12 hours after simulated CPA) of surge height, wind speed, and wind direction are generated. These data allow the planner to estimate when, in relation to CPA, critical evacuation route points (e.g., causeways from barrier islands, bridge approaches, low-lying roadway segments) can be expected to become inundated from early arriving tidal surge and experience dangerously high winds.

The method of using SLOSH for evacuation planning was developed for the U.S. Army Corps of Engineers, Jacksonville District by the Tampa Bay Regional Planning Council in 1980 and used to produce the prototype Tampa Bay Region Hurricane Evacuation Plan. This methodology was employed in studies of other urban coastal regions by the Corps of Engineers and has been adopted by FEMA the current standard for comprehensive (quantitative) hurricane preparedness studies (FEMA, 1984). The evacuation planning methodology, as well as the support and contributions of the major federal agencies (Corps, FEMA, NOAA)

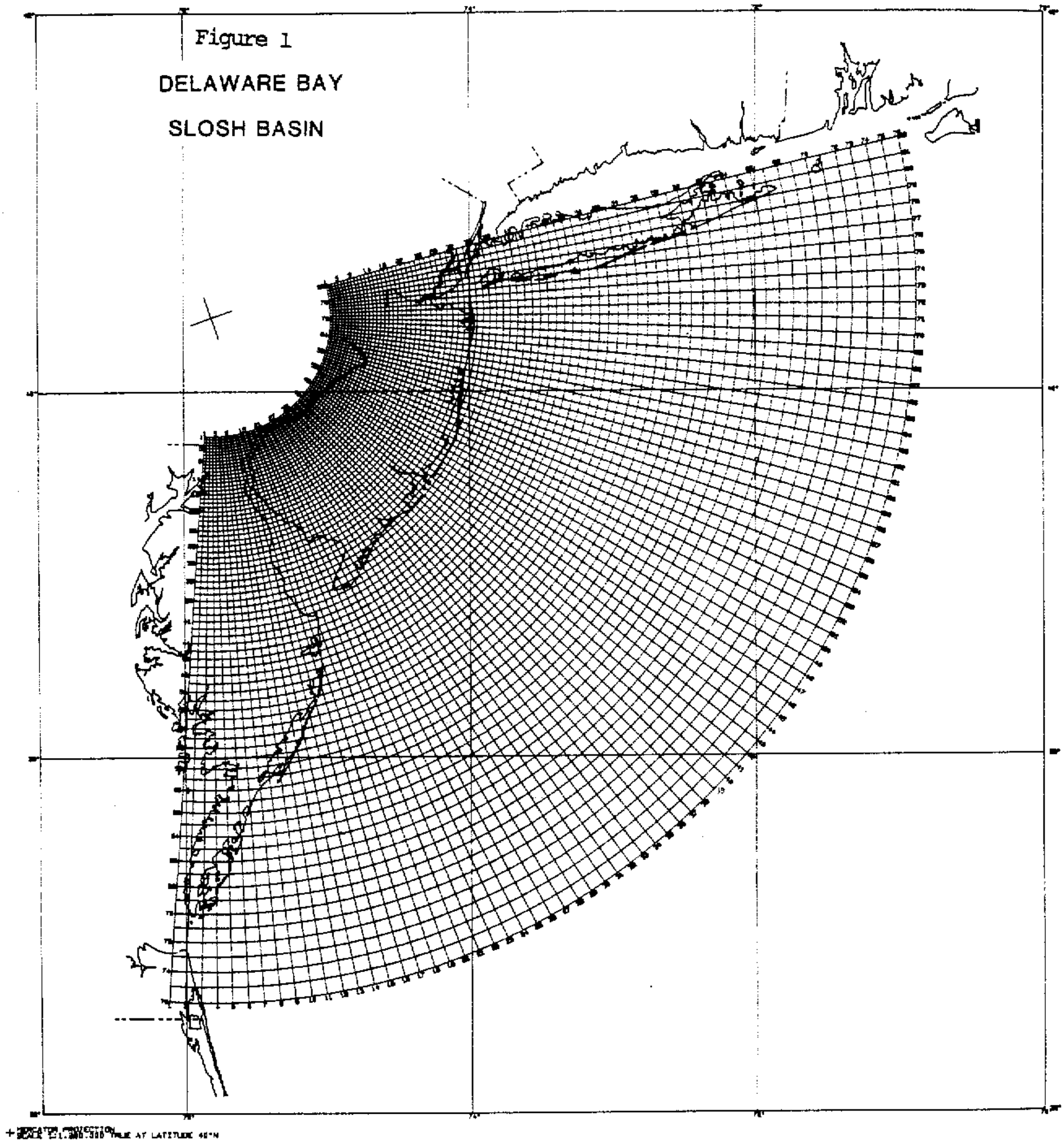
Figure 1
DELAWARE BAY
SLOSH BASIN

involved in SLOSH-based emergency evacuation planning, are documented in a House Committee on Government Operations report entitled "Federal Assistance to States and Communities for Hurricane Preparedness Planning" (U.S. House of Representatives, 1983).

SLOSH-Based Evacuation Planning Method

Utilization of the SLOSH model has allowed the evacuation planner and, in turn, the emergency manager to formulate quantitative hurricane evacuation plans. The enhanced hazard and vulnerability analyses afforded by SLOSH not only provide a thorough base of technical data, but also define the evacuation problem numerically and graphically, thus permitting the development of a clear operations plan. The calculation of the geographic extent of hurricane vulnerability defined by SLOSH also enables the emergency manager to portray vulnerable land areas to the public by producing clear, color-coded public information maps. Finally, the extensive set of data, operational strategies, and public information efforts resulting from such quantitative studies can be used to develop coherent plans that can be tested and evaluated in various types of emergency exercises.

The comprehensive hurricane population preparedness program, established by the prototype Tampa Bay Plan and adopted by FEMA (FEMA, 1984), consists of four major interrelated elements:

- **The Technical Data Report** documents the findings of all methodological, data gathering, and technical analysis tasks of the study. The report defines and quantifies the evacuation problem and the response necessary for warning, evacuation, and shelter.

- **The Evacuation Implementation Element** is a concise summary guide that includes key maps, charts, tables, and other information from the Technical Data Report, and serves as the reference document for official decision making in the emergency operations center during a hurricane's approach. A separate Evacuation Implementation Element for each local jurisdiction, tailored to that jurisdiction's standard operating procedures, is most effective.

- **The Public Information Program** consists of simple, easy-to-understand printed tabloids, pamphlets, or brochures describing to each resident his/her evacuation zone, assigned route, and shelter, and the overall concept of the plan. The tabloid should include clear, color-coded maps and instructions tailored for each major jurisdiction and printed for every household in the region. The printed tabloid should be supplemented by EBS radio and television programs during an event that convey the same graphic information.

- **The Emergency Operations Simulation Exercise** is a total system, regional hurricane evacuation exercise, simulating the actual approach and/or landfall of a major hurricane, the evacuation decision-making process, communications, and the actual emergency operations called for in the completed plan.

A comprehensive program incorporating the four elements outlined above typically takes from one to two years to complete. All elements should be updated at least every two to three years.

The basic evacuation planning methodology that is employed in such comprehensive studies integrates several quantitative analyses stemming from SLOSH-based hazard and vulnerability analysis. Briefly they are:

- **Hazard Analysis**—a comprehensive analysis of the potential hurricane hazards that could confront the region.
- **Vulnerability Analysis**—a detailed identification of the areas and population of the region vulnerable to specific hurricane hazards.
- **Population Data Analysis**—a systematic enumeration of the dwelling units, population, and available vehicles within the identified vulnerable areas.
- **Behavioral Analysis**—a statistically significant survey and historical identification of the probable tendencies of potential future evacuees of the region.
- **Shelter Resource Analysis**—a region-wide inventory of existing public shelters, their characteristics and capacity.
- **Shelter Surge Analysis**—a quantitative analysis of the storm surge vulnerability of existing as well as potential future public shelter structures.
- **Institutional Facility Surge Analysis**—a quantitative analysis of the storm surge vulnerability of all hospitals, nursing homes, prisons, and other residential facilities requiring special evacuation procedures.
- **Surge Roadway Inundation Analysis**—estimations of the time of inundation of critical points on evacuation routes relative to hurricane landfall.
- **Gale Force Winds Arrival Analysis**—estimations of the time of the arrival of gale force winds relative to hurricane landfall.
- **Shelter Duration Analysis**—an analysis of the expected shelter stay duration throughout the life of the storm.

- **Freshwater Roadway Inundation Analysis**--a region-wide identification of roadways historically inundated from rainfall flooding.
- **Evacuation Zone Formulation**--a region-wide delineation areas defined by SLOSH as vulnerable into evacuation zones based on common hazard vulnerability and common evacuation routes.
- **Evacuation Routes Assignment**--the assignment of volumes of vehicles from specific zones to specific routes in order to develop optimum intra- and inter-county evacuation strategies.
- **Shelter Assignment**--the assignment of persons within specific evacuation zones to specific shelters based on evacuation routing strategies.
- **Clearance Time Quantification**--the calculation of times for the movement of masses of vehicles associated with the evacuation of persons from SLOSH-defined vulnerable areas to specific evacuation destinations.
- **Evacuation Time Estimation**--an estimation of the total time needed to issue and implement evacuation orders based on the addition of clearance time to pre-landfall hazards (e.g., surge roadway inundation or gale force wind) arrival time .

The use of SLOSH technology in the above analyses begins with the selection of parameters to characterize each of 200 to 300 hypothetical hurricanes to be simulated in individual model runs. Each simulation represents the effect of a potential hurricane on the region. The full spectrum of probable storms--including "worst probable" combinations of intensity, track, size, and forward speed--are simulated to produce a comprehensive hazard analysis.

Before the actual simulations are run by the computer, those individual geographic grid cells representing critical evacuation points are selected (there are usually about 50), and the program is directed to create time history data for each of them in each hypothetical hurricane.

Although SLOSH technology allows for the examination of a hurricane with a specific track, intensity, and other parameters, current hurricane forecasting cannot determine a specific track and landfall point sufficiently early to aid an evacuation decision. To help produce an evacuation decision which does not underestimate the evacuation area, a focused range of a single parameter (e.g., track) is combined using a special, more generalized SLOSH run termed a "maximum envelope of water" (MEOW). The geographic distribution of surge predicted by a MEOW run represents the highest surge that could be expected in each grid cell due to any of the ten to 15 individual hurricanes simulated in the MEOW. The degree to which maximum surge height generalizations are made depends on characteristics of the basin and its historical hurricane climatology.

Before conducting a vulnerability analysis, a couple of less significant water height features must be superimposed onto the SLOSH-generated surge height by the emergency planner. These are 1) the astronomical tide range above mean sea level (MSL) (in order to consider the hurricane approach coinciding with daily high tide), and 2) a 20% stillwater addition (in order to compensate for model inaccuracy based on a current survey of model performance).

The vulnerability analysis itself entails systematically subtracting the land elevation of each grid cell from the SLOSH-generated surge height, since the SLOSH elevations are referenced to MSL.

The inundation patterns that emerge from individual SLOSH simulations and MEOWs provide the basis for various evacuation scenarios requiring significantly different emergency operational response. Each level of evacuation encompasses cumulatively more area and thus more evacuation zones that must be completely cleared if threatened by that type and/or intensity of hurricane. The actual number of evacuation levels varies from region to region, the ideal being the creation of enough levels to avoid over- or under-evacuation, yet sufficiently few to allow the development of a relatively simplified response plan and public information program. For example, the Tampa Bay Plan has five different evacuation levels, whereas the current Southeast Louisiana Study has resulted in twelve distinct evacuation levels.

The primary population data used in the analysis is the number of available vehicles in vulnerable areas, rather than numbers of persons or dwelling units, because vehicle volumes are the ultimate major factor in evacuation time estimates.

The latest human response research is also taken into account in comprehensive hurricane evacuation planning by incorporating into plans several important behavioral determinants and tendencies uncovered by behavioral surveys and studies. These include:

- How the threatened population would respond to a potential hurricane given the storm's severity, position and track, forecast time period, and the National Weather Service's "probability of hurricane conditions" issued for the population's location;

- When the threatened population would leave their residences in response to a given evacuation order or recommendation;
- The number of vehicles that the threatened households would use for evacuation;
- The number of threatened households that would require public transportation or other special assistance if ordered to evacuate;
- The preplanned destinations of the potentially threatened population and
- The general hurricane history and experience of the threatened population.

Such tendencies are quantified by combining survey findings with vehicle volumes and evacuation "trip generation" rates to create evacuation time estimates. This transportation modeling process often requires the use of another computer model to simulate the complex patterns of traffic movement and congestion inherent in urban area evacuation (see the paper by Hobeika in this volume for an illustration of evacuation based on transportation modeling).

The SLOSH model's geographic grid configuration permits a site-specific surge vulnerability analysis of existing and potential public shelters as well as hospitals, nursing homes, and other critical facilities with special evacuation needs. This analysis is accomplished by comparing ground floor structure elevations to the surge height predicted by SLOSH for the corresponding grid cell.

The geographic evacuation levels described above are further subdivided into evacuation zones, delineated on the basis of common surge vulnerability, major evacuation route(s), and familiar physical features for ease of graphic presentation in the public information program. Each evacuation zone is assigned specific evacuation routes and shelters based on a strategy that utilizes existing public shelter capacities and minimizes overall "clearance time." All evacuation vehicle volumes, trip generation, and trip assignment data are then entered into the evacuation transportation model to estimate clearance times under each of the several evacuation levels.

The SLOSH-generated surge time history data is used to develop quantitative estimates of another period of time termed the "pre-landfall hazards time." This is accomplished by examining the model's estimates of the times of inundation of selected critical points (based on the elevation of the points) on evacuation roadways. These times (referenced to CPA) are incorporated into the plan and, upon the approach of an actual storm, are compared to the estimated time of arrival of sustained gale force winds (computed from real-time National Weather Service (NWS) marine advisory information). Whichever of these times is larger represents the "pre-landfall hazards time" and is added to the "clearance time" to result in an evacuation time estimate; this estimate is crucial to the timing of evacuation orders or recommendations to the public.

Future Computer Technology Applications In Hurricane Evacuation Management

This paper has described the emergency manager's use of mainframe and minicomputer technology that has made possible a much more comprehensive process of long-range hurricane evacuation planning than was previously available. This technology, originally developed and used at the federal level, has been provided to state and local governments in the form of hard copy or tape collections of model storm output data. However, more recent microprocessing technology and the emergence of the use of microcomputer hardware in state and local EOC's are making possible a new dimension of enhanced hurricane preparedness: real-time SLOSH data generation and graphic SLOSH telecommunication to the local level.

The local level is where emergency decisions are made and where emergency operations take place. It has been proven that graphic portrayal of hurricane location and future potential conditions greatly enhances tactical decision-making capability. (The NWS "Probabilities of Hurricane Conditions" Program is an example of a very valuable program providing data for local hurricane decision making that suffers from the lack of graphic portrayal; the potential forecast error that these probabilities actually represent could be much more easily understood by using graphics.)

Hurricane evacuation decision making involves the deliberation of full-time emergency management experts as well as elected authorities rarely familiar with the specific vulnerabilities of their particular jurisdictions. Graphically portrayed real-time SLOSH inundation predictions could facilitate careful evaluation, result in quicker and wiser decisions, and improve the communication of probable conditions between federal, state, and local authorities.

A real-time system that could communicate SLOSH contour images to local EOC computer screens would have to be carefully worked out. Those implementing such a system would have to guard against potential misinterpretations by determining specific policies such as the use of MEOW contours rather than individual hurricane simulation contours. However, there is no doubt that the capability to visualize imminent hurricane inundation can complement a local jurisdiction's comprehensive evacuation plan and improve hurricane response.

The technology for using real-time SLOSH data at the local level exists, led by Research Alternatives' Emergency Information System. Local EOCs are now arming themselves with graphic microcomputing systems for event monitoring, resource deployment, and decision support; and local systems are already being linked to state and/or adjacent local jurisdiction systems through emergency management telecommunication systems. Similar telecommunication of NWS-run SLOSH simulations to the state and, more importantly, the local level would represent a true federal-local partnership in preparing for the inevitable landfall of a major hurricane.

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APPLICATION OF COMPUTER TECHNOLOGY FOR DAMAGE/RISK PROJECTIONS

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Introduction

A cost effective method is needed to aid state, county, and city government planners in determining the probable effects of various hazards under a variety of possible scenarios. Information provided through computer modeling applications may provide emergency service planners and responders with quantified estimates upon which to develop realistic preparedness planning and action decisions.

This paper, which is directed toward the local planner, discusses the planning problem from the user's perspective. It also describes an automated damage/risk modeling system and provides a summary description of its various products and their applications.

Any modeling effort is at best only an estimation of what could happen under a given set of conditions. The results of modeling efforts produce scenarios which contain damage indicators against which resource capabilities and shortfalls may be measured. When the actual event occurs, it may produce significantly different effects, and planners should be forewarned not to take modeling results too literally, but rather to treat such results as broad, heuristic indicators of a possible range of effects.

Consideration of the Planning Problem

Emergency service planners, particularly those at city and county levels, are responsible for formulating preparedness and response plans which will adequately serve the needs of the community at the time of an incident. To do this effectively, the planners need to know the possible range of damage parameters. Without this information, planners can only hypothesize the likely situation. Added to the complexity of the planning issue is the increasing frequency of human-caused disasters, the problem caused by the interaction of various disaster effects, and the need for interjurisdictional involvement in emergency response.

These conditions and situations create multiple problems for planners:

1) Without a common frame of reference, emergency problems and their resulting effects and conditions are viewed differently by different planners. Thus, it is difficult to obtain a common perspective or consensus on a given situation. This condition often results in different planning perspectives and creates inconsistent plans which do not relate to other plans either intra- or inter-jurisdictionally.

2) When unable to visualize the overall problem or the complex interaction of effects, planners tend to develop plans based on how best to deploy and use an existing resources base. The damage and the real resource requirements of a disaster are often left unconsidered.

3) For major regional events, such as floods, earthquakes, hurricanes, planners often do not have the appropriate information to adequately consider overall regional effects on major lifelines. This may significantly affect a jurisdiction's ability to respond and recover.

Consideration of the Problem Solution

Through a process of computer-based modeling, it is possible to generate damage scenarios which can form a basis for plan development. Independent machine readable data files can be merged in a variety of combinations. These data sets can then be processed by models which are automated algorithms. These models are capable of creating a wide variety of graphic and tabular data which can then be produced in various combinations to meet specific user needs.

The modeling process requires that the various machine-readable data files already exist; that the database architecture provides the capability for file matching and merging; that adequate software be developed for model processing; and that the system can produce maps and tabular reports.

The remainder of this paper will discuss the components of such a system and provide examples from an actual damage modeling feasibility study. The map and table examples described in this paper are drawn from the 1983 Pilot Project for Earthquake Hazard Assessment conducted by the Southern California Earthquake Preparedness Project (SCEPP) for the Federal Emergency Management Agency (FEMA). The author was a consultant to that project.

Components of a Damage/Risk Forecasting System

The basic components of a system to model the effects of disaster situations consist of:

1) Machine readable data files,
2) Applications Software (models),
3) A Processing System and Operating Software, and
4) Output devices (Plotters and Printers).

Together, these components form the overall system structure. The relationships between them are depicted below and further briefly described.

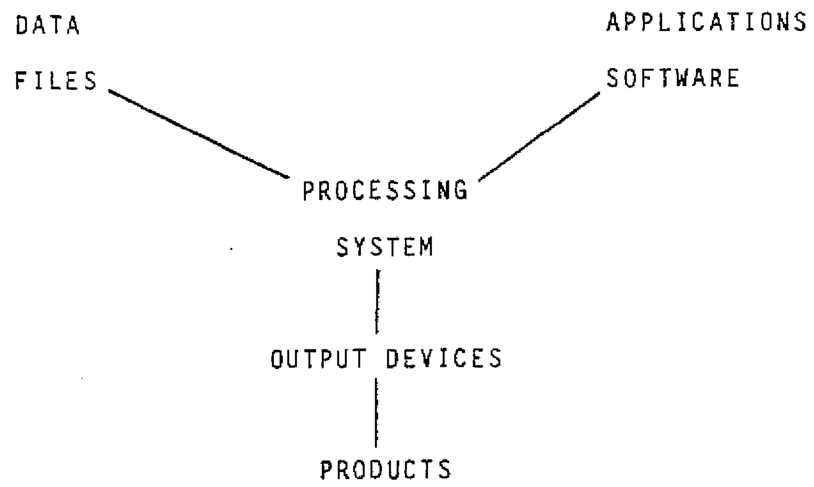

Figure 1
System Structure

Data Files

This section describes various kinds of data files which could be used in the development of the system database. The basic determination of data files is influenced by 1) the elements of information which are required for planning purposes, and 2) the availability of information already in machine readable form (or readily transformable into a machine readable state within cost and time constraints).

Five basic kinds of files are required for our example of earthquake damage/risk analysis. It should be noted, however, that there are various ways of describing these kinds of files. In some cases, based upon existing data file availability, a number of combinations and "cross-overs" could exist.

1) **Geophysical** files consist of mapped polygons (areas) of known geologic features and conditions. These files provide the basic information necessary to determine the extent and severity of ground motion. Separate files could contain data on groundwater depths, etc.

2) **Topographic** files generally portray the shape and elevation of the surface terrain. Such physical characteristics will show the location of mountains, valleys, rivers, and can include human-created features, e.g., landfills, reservoirs, land use patterns, which influence the topography.

3) **Network** files document major arterials, rail lines, underground power, fuel, water lines. Just about anything that consists of various links and nodes can be included within these kinds of data files. Grid reference or geolocator systems can also be included as network data.

4) **Structural** files can be of many varieties and are obtained or developed depending upon the planning need. Typically, these files include data on residential, commercial, and industrial buildings grouped by various occupancy classes; bridges, critical facilities, dams, power generating or storage facilities, sanitation plants, etc.

5) **Demographic** files describe the location and characteristics of the population at risk. These kinds of files are generally developed initially from census data and can be stored and aggregated in several ways. For earthquake hazard vulnerability modeling, it is convenient to use the census block as the basic demographic unit. To be useful in population damage and risk modeling, the data should be viewed over time as well as space. The night to day, home to work shift in population location in major urbanized areas can be significant and modeling only the residential night-time population can produce unrealistic results for planning daytime or at-work scenarios. (The paper by Schneider et al. in this volume describes the development and specific application of one such file.) Data files are depicted in Figure 2 on the following page.

Models

Models may be classified and described in several ways. For purposes of this description, "geophysical" and "socioeconomic" models of earthquake hazard vulnerability will be used.

Geophysical. The most common geophysical models related to earthquakes are those which provide an estimate of earth shaking intensity and/or estimates of peak acceleration of the earth. These models compute shaking intensity or

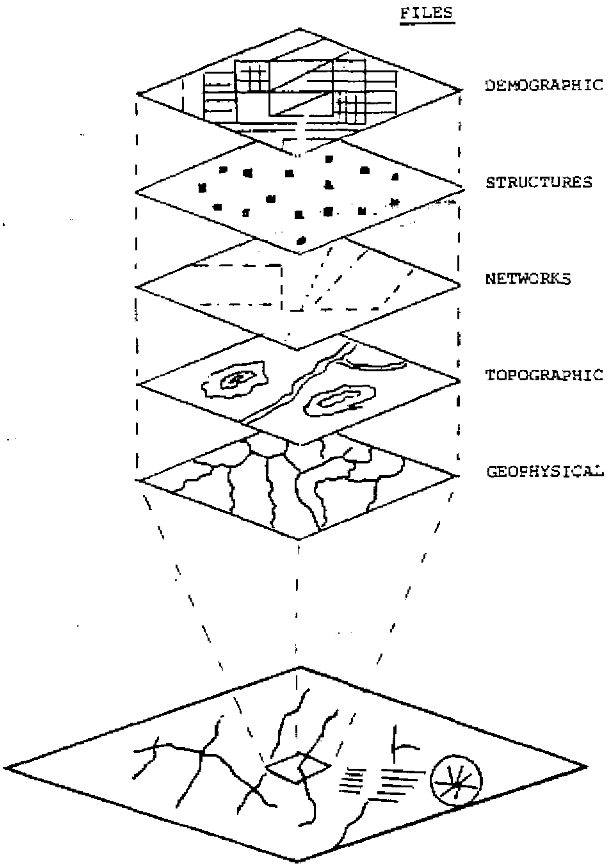

Figure 2
Basic File Structure

ground acceleration for a given point location, e.g., the centroid of a census block. They take into account fault location, location and length of rupture, level of energy release (magnitude), seismic wave attenuation through the earth, and effects of local ground conditions. The outputs of these models are generally numeric and can be related to a pre-established scale of observed or measured effects. The most commonly used scales for earth shaking intensity are the Modified Mercalli or the Rossi Forel Scale.

Another geophysical model important in damage vulnerability modeling is the liquefaction model. Developing a liquefaction model requires good information on subsurface geology, soil conditions, and groundwater depth as well as information on shaking intensity and duration. The combination of data within the model can produce results which will determine the potential for the earth to liquefy at any given location. The outputs of a liquefaction model can be descriptors such as "probable," "possible," or "negligible."

Socioeconomic. These models attempt to determine the probable effects of geophysical models to topography, structures, networks, and population. The models can be run separately or in combination so that the results of one will automatically become the input to another.

The results of these models can be reported in several ways. In general, information useful to planners could be produced as reports or maps showing:

- Number and/or percentage of structures/networks damaged,
- Estimates of actual, or percentage of dollar value lost,
- Homeless households - shown as temporary or permanent,
- Treatable injured - measured from all causes,
- Deaths.

Depending upon the model used, the above data can be aggregated at several levels: census block, census tract, or block groups. Currently there are a number of socioeconomic modeling projects underway, but as yet no acceptable standard has been developed.

The Applied Technology Council under a FEMA contract has recently developed Damage Probability Matrices (DPMs) for a wide variety of structural classifications. These DPMs could form a standard baseline for use in damage vulnerability modeling. The development of models which will show injuries and deaths from structural and nonstructural causes is progressing slowly, and more research should be done in this area.

The relationship of data files and models is shown in Figure 3 on the following page.

Processing System

The processing system which integrates data file content with model applications software must be capable of handling large volumes of data. The system to be used should have room for both data file expansion and additional models.

In the system demonstration described earlier, two processing systems were used. One of these was an IBM 370/168 mainframe and the other a Prime 750 minicomputer. This equipment was selected to take advantage of existing hard

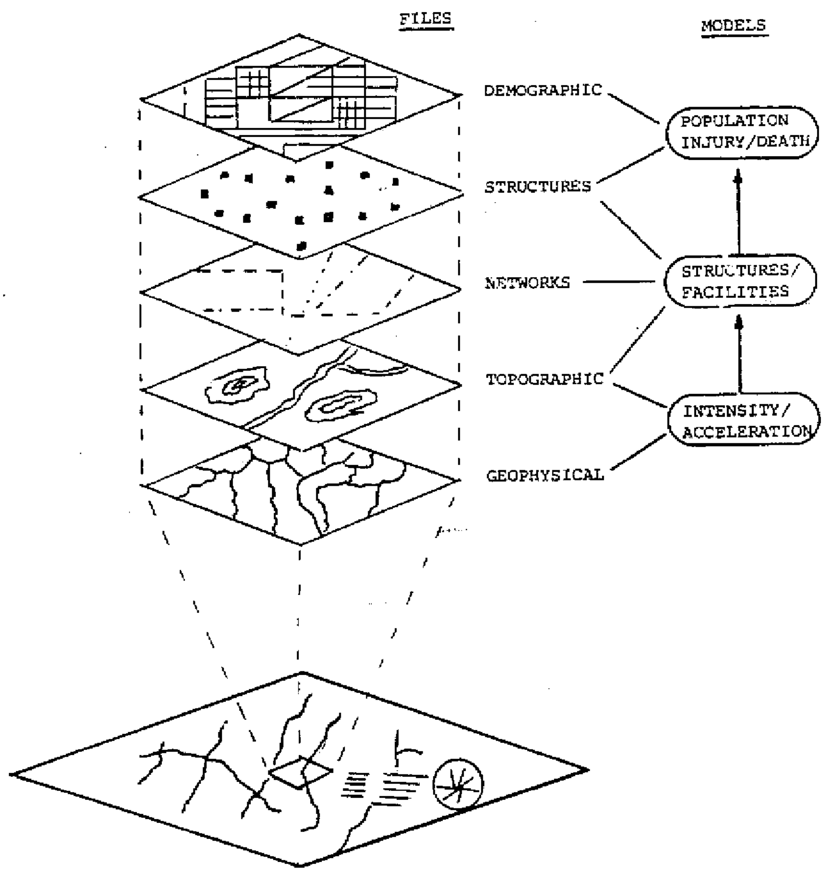

Figure 3
Data File and Model Relationships

ware and applications software that would function adequately within the time frame and cost constraints of the feasibility demonstration.

The demonstration indicated that a minicomputer with the 32 bit-word central processing capability provided an adequate processing speed. The size of the unit would be dependent upon, among other things, the size and level of detail to be modeled within the geographical area. The hardware system should be able to support the use of a variety of mass storage devices to include high density disk and tape drives. Other elements of the processing system should include a high speed printer and high resolution hardcopy printer. If remote station operation is desired, a communications interface should be provided to allow for data entry processing and display capability at remote stations.

In addition, several software components are desirable. The operating system software should be readily available from the hardware system manufacturer and should not require modification. An off-the-shelf statistical software package should be acquired for analysis applications. Based upon the demonstration project results, there is little need for special purpose software development. Also, graphics software which will allow for interactive plotting and hardcopy output should be obtained.

Products

The single most important item related to the modeling process discussed above is the usefulness of the output. The two types of output products most useful to emergency service planners are maps and formatted reports. To be most effective, these two products should be interrelated to allow users to cross reference tabular data related to map presentations.

One of the most significant features of computerized map presentations is the ability to integrate display combinations of information at essentially any scale desired. This can be accomplished through the merging of independent data layers and displaying them according to coded characteristics. An example of such a map output is depicted on the following page (Figure 4).

In this example various groundwater depth information has been compounded into a single presentation. In this form of cartographic data presentation, related theme data sets are delineated through different character shading or color. Note that there is no actual modeling associated with this presentation. It is simply a way to pull known spatial data together into a single presentation. A major feature of such an output capability is the potential to change the output parameters to depict such things as different gradient levels.

Another way processed information can be displayed on maps is to show the results of a modeling activity. In Figure 5, the previously displayed groundwater depth data has been translated by using modeling to reflect liquefaction susceptibility.

Note the similarities of the polygon definitions between the two maps. More importantly, however, note how much more meaningful from a planning standpoint is the map which reflects the projected environment. These two examples reflect the difference between simply displaying data and displaying useful planning information.

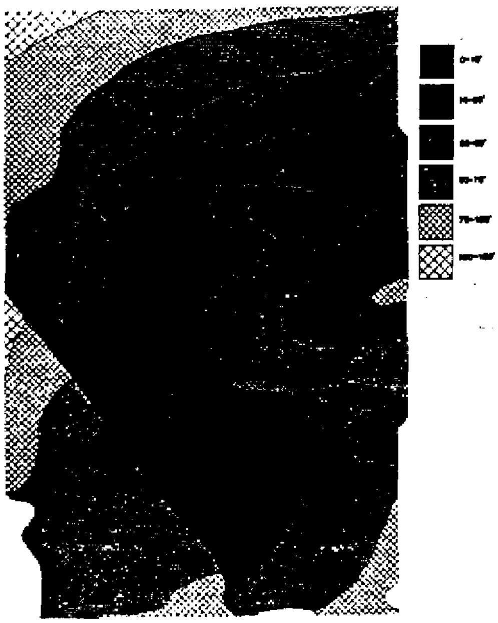

Figure 4
Depth to Groundwater Example

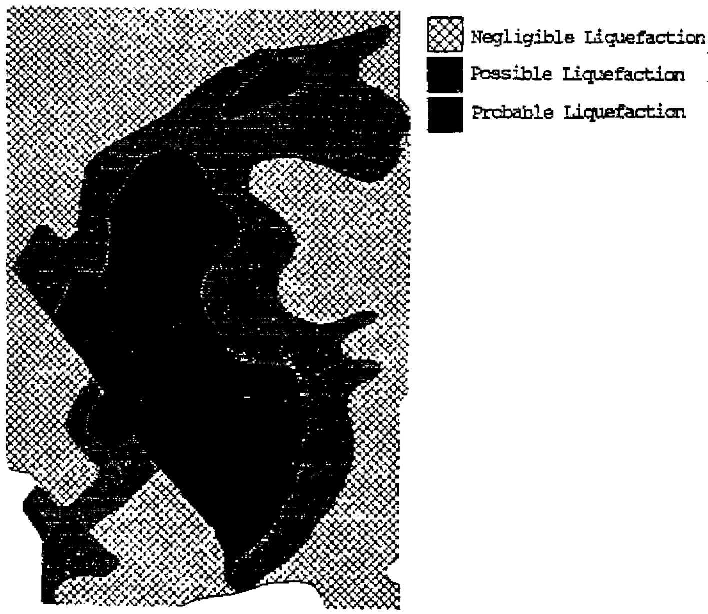

Figure 5
Liquefaction Susceptibility Map Example

Another way of showing information on a map is by the use of an overlay. Overlays can be printed directly on the map, or they can be generated by the plotter on clear film or mylar, depending upon the user's needs.

On the following page a computer generated map is shown which depicts structures damaged per census block. This information was obtained and plotted through the use of a model which projected structural damage. Overlaid onto the map are several polygons which depict areas of probable shaking intensities. Note how each polygon is labeled as well as the close correlation of the intensity polygons with the map depicting liquefaction susceptibility.

Computer generated polygons can also be produced at various scales for overlay onto other types of maps or aerial photographs. Use of overlays printed onto existing maps are particularly useful for emergency service

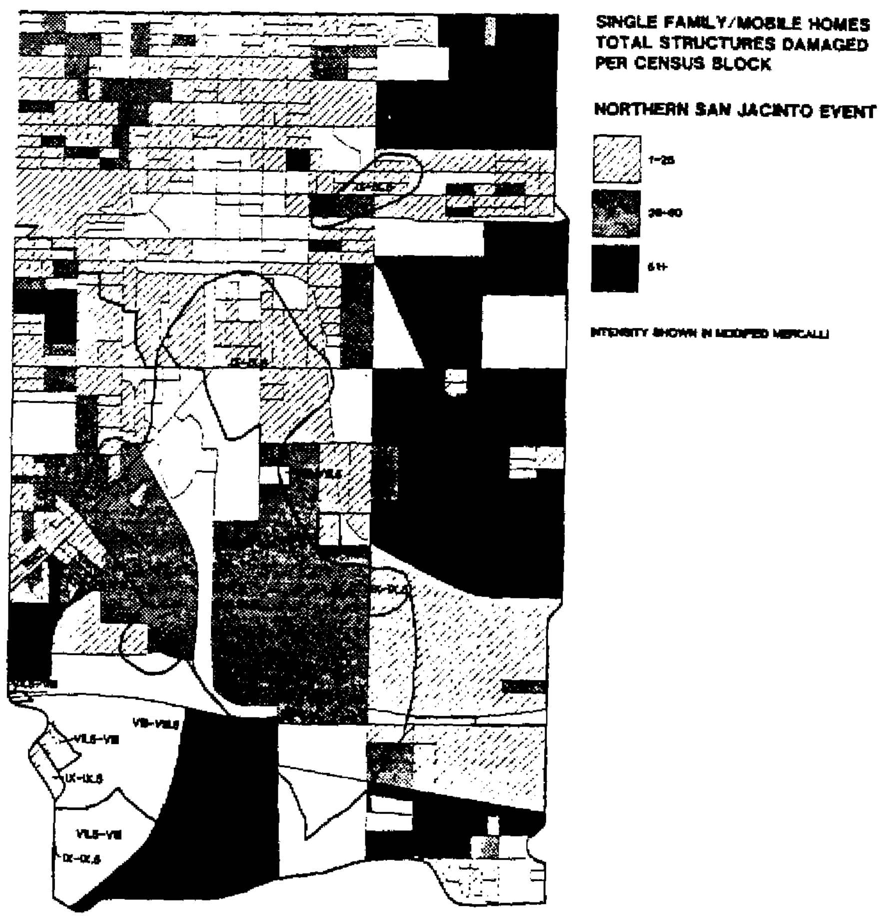

Figure 6
Map of Structures Damaged with Intensities

planning activities because they enable much better visualization of the affected area.

Care must be exercised when transposing shaking intensities or liquefaction contours from small or medium scale to large scale maps. The problem is that the capability to accurately define these areas either geologically or through the use of modeling techniques is not yet fully developed. At best, the defined areas and the boundaries between areas should only be thought of as a zone. When these zones are defined on a map by lines, (particularly on large scale maps), they tend to create the false impression of sharp demarcation.

Tabular Information

Computer modeling can produce a wide variety of information which can be easily structured into tables and various other report formats. Shown below is an example of one type of report which provides a variety of useful information (Table 1). Such reports can be used in conjunction with either computer generated maps or with overlays produced at scale for use with existing maps.

DAMAGE TO MOBILE HOMES

(THIS TABLE IS FOR DEMONSTRATION PURPOSES ONLY)

	SAN ANDREAS		N. SAN JACINTO		S. SAN JACINTO	
	No.	%	No.	%	No.	%
TOTAL DAMAGED	773	75.3	928	90.4	916	89.3
TOTAL LIVABLE	530	51.7	256	24.9	270	26.3
NON-LIVABLE RESTORABLE	234	22.8	638	62.2	612	59.7
NON-RESTORABLE	9	.9	34	3.3	34	3.3
$ LOSS	$59,879	3.7	$132,137	8.3	$127,456	8.0

Table 1
Sample Damage Report

While the report shown above deals only with numbers, percentages, and dollar values, it would be easy to construct reports which could relate damaged structures to population density. From this, numbers could be derived showing the population requiring temporary and permanent housing assistance. Such a table is shown on the following page (Table 2).

HOMELESS CASELOAD/PERMANENT HOMELESS CASELOAD

(THIS TABLE IS FOR DEMONSTRATION PURPOSES ONLY)

	SAN ANDREAS HC	SAN ANDREAS PHC	N. SAN JACINTO HC	N. SAN JACINTO PHC	S. SAN JACINTO HC	S. SAN JACINTO PHC
SINGLE FAMILY RESIDENCES HOUSEHOLDS	4	0	181	27	136	19
MOBILE HOMES HOUSEHOLDS	243	9	672	34	646	34
TOTAL HOMELESS CASELOAD	247	9	853	61	782	53
TOTAL POP. HOMELESS (2.8xHC/PHC)	717		2559		2338	
% OF TOTAL POP HOMELESS Pop. = 21,797	.03		11.7		10.7	

Table 2
Sample Homeless Caseload Report

Summary

Automated modeling of hazard vulnerability and risk assessment offers great potential for improving the state and local plan development process. The quality of data files and the accuracy and sophistication of models has taken a quantum leap forward in the past ten years. With continued improvements in these areas and the increased use and versatility of microprocessors, it is reasonable to assume that this form of modeling will soon be commonplace.

The process of modeling can best be accomplished by a team approach involving: an emergency service planner who decides the various information requirements, the desired types of outputs, and the adequacy of known data files to meet the operational need; a database manager who determines overall hardware and operating software system requirements; and a modeler who translates the requirements into applications software which, when applied to the database, produces the desired results.

User needs should be kept as the first priority, and care should be taken to keep the modeling process simple. Relatively gross indicators will often be adequate to meet planning needs, extreme levels of detail or accuracy being unnecessary.

Most public safety agencies and emergency service planners rely heavily on maps. Generally, computer produced map overlays scaled for use on existing maps would be more helpful to them than straight computer generated maps. The required map scales also vary. Scales at 1:100,000 are commonly used within dispatch and EOC environments. Larger scale orthophoto and topographic maps ranging from 1:500 to 1:24,000 are more useful in field environments.

There are a number of potential modeling applications which can be accomplished with a good geographical database. In addition to the seismic intensity and damage models depicted above, another application might be the modeling of dispersion plumes for various toxic agents. Dispersion patterns could be related to population and land use files for evacuation and protective cover planning. Similarly, the use of the database system to model fire spread could be extremely useful. Models currently exist for these applications that are as accurate as seismic effects models, and integrating them into the inventory of models would not be difficult.

There are a number of nonautomated data files that exist within jurisdictional departments which, if automated, could contribute significantly to improving the quality of data and the usefulness of modeling efforts. Jurisdictions considering the development of modeling capabilities should inventory both existing automated and nonautomated files for potentially useful data.

If at all possible, systems should be developed within the context of an overall regional design, since one of its greatest potentials is the ability to examine rapidly the impact of an emergency on multijurisdictional environments. This is a particularly important consideration within urban areas having a dense and highly mobile population and in areas which are heavily overlaid with networks. Network failures can often have significant effects on adjacent jurisdictions but are often not considered in jurisdictional planning activities.

USE OF DAMAGE SIMULATION IN EARTHQUAKE PLANNING AND EMERGENCY RESPONSE MANAGEMENT

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Introduction

Computer-based damage simulation is essential in planning for and managing the response to earthquakes. Until the size, extent, and nature of a problem are estimated, planning and management are ill-defined. This is especially true for earthquakes, because earthquakes affect large areas, have the potential to be major catastrophes, and occur without warning. Despite this lack of warning, in large part, earthquake effects can be relatively easily foreseen and quantitatively estimated. While the collapse of a specific building, for example, may be difficult to predict, it is feasible to infer statistically that "x" number of buildings in a certain district will collapse. In effect, one can deduce much information about a potential disaster: size, extent of damage, casualties, response needs, etc. The only missing parameter, admittedly vital, being the time of occurrence.

Currently available computer-based damage simulation techniques permit estimation of earthquake ground motion and its effects on people, buildings, and urban lifelines such as water, power, and transportation networks. Real-time analysis of damage reports in the immediate post-earthquake period can permit accurate damage assessment and optimal allocation of emergency resources. In order to illustrate these points, a method for estimating urban seismic risk is outlined below. In addition, several case studies and some indications of future research directions are also presented.

Urban Seismic Risk Methodology

Figure 1 presents a schematic diagram of an urban seismic risk methodology, which begins by defining the seismic hazard--specifically, expected earthquake ground motions. This can be defined for specific events for major urban areas such as:

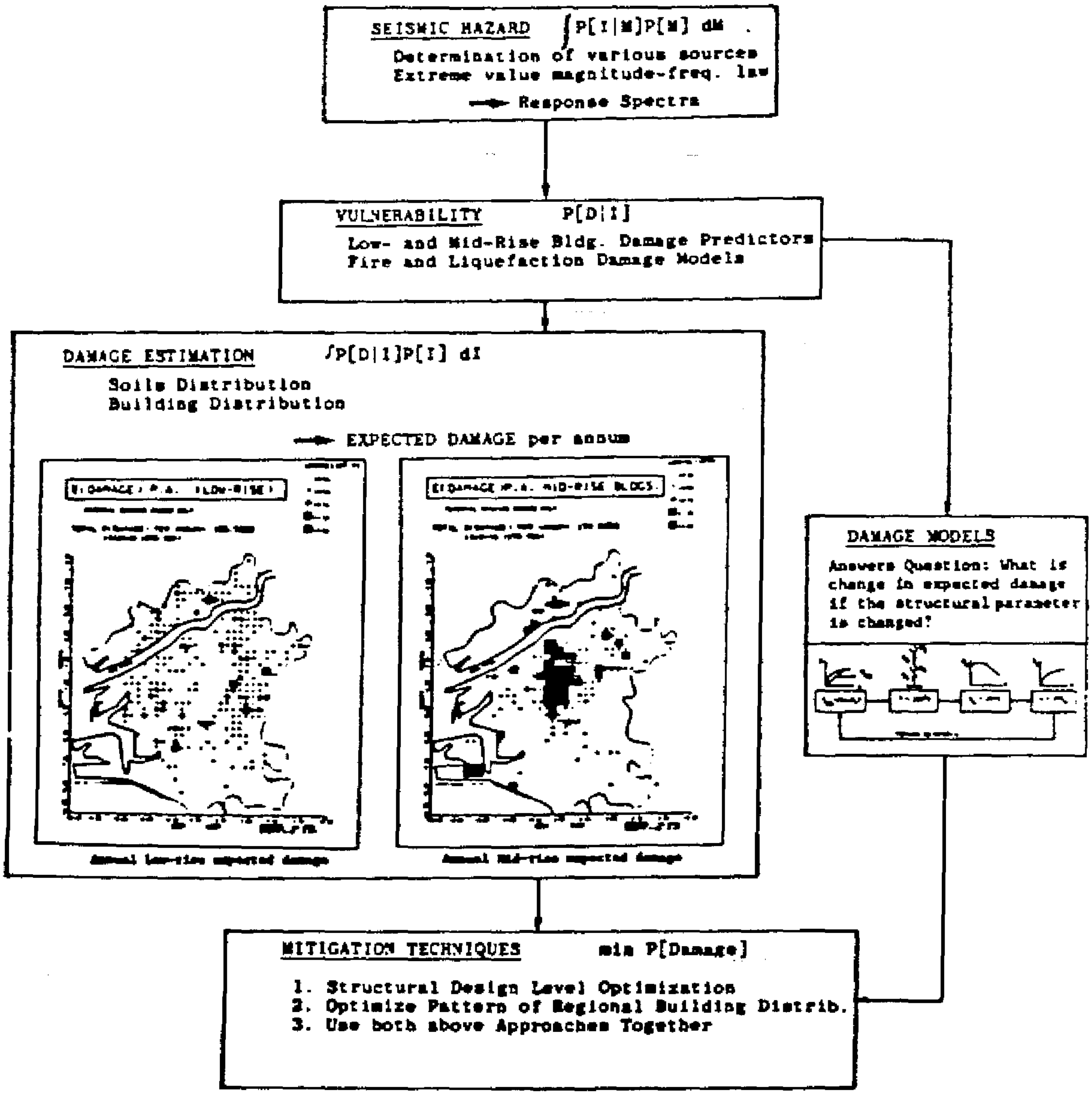


Figure 1
Schematic Diagram of Urban Seismic Risk Analysis Methodology

- San Francisco Bay Area--a repeat of the 1906 event on the San Andreas fault, and/or a repeat of the 1868 Hayward event on the Hayward fault;

- Los Angeles Basin--a repeat of the 1857 event on the San Andreas fault, and/or a repeat of the 1933 event on the Newport-Inglewood fault zone.

Evernden (USGS, 1981), for example, has provided detailed maps for each of these scenarios taking into account local soil conditions. Other regions for which analogous hazard scenarios have been defined include Puget Sound, Salt Lake City, Boston, Charleston, and San Juan. The earthquake hazard can be quantified in a variety of formats depending upon the user's needs. These include Modified Mercalli Intensity and engineering measures such as peak ground acceleration, response spectra, etc.

Seismic vulnerability, or the estimated damage to a specific type of structure attributable to the seismic hazard, is also required for accurate damage prediction. While considerable research is necessary to develop accurate vulnerability functions for various classes of buildings and structures (such as bridges and pipelines) measures presently exist (e.g., Steinbrugge, 1982) or are under development (ATC-13, 1985) which can provide much useful information. From an engineering viewpoint, these vulnerability functions should ideally be based on engineering or "damage" models so that the damage implications of improved design codes or methods of construction can be evaluated.

Estimates of earthquake damage can then be developed based on the seismic hazard, vulnerability functions and maps of building distribution, and soil types (which can amplify seismic motion as happened in the 1985 Mexico City earthquake). These estimates can be presented in map format or in tabular summaries. They can also form the basis for an effective mitigation program, optimally combining structural strengthening and land use provisions. Estimates can be primarily qualitative (Arnold and Eisner, 1984) semi-quantitative (e.g., USGS, 1975), or quantitative (e.g., Sugiyama, 1985); they can all be of benefit to a variety of users (Arnold, 1985).

Urban Seismic Damage Estimation

Using the above methodology, earthquake damage to buildings for the city of Osaka, Japan was estimated (Scawthorn et al. 1981) in order to generally assess the relative magnitude of the earthquake problem for this city of 2.8

million in a highly seismic area, and to determine the relative contribution of several possible agents of seismic damage. (Shaking, liquefaction, and fire were considered; landsliding, tsunami, and hazardous materials incidents were not.) Figures 2a through 2d present annualized seismic damage due to all possible seismic sources for the 210 sq. km. region for the several agents. Figures 3a and 3b present distribution of damage for several specific earthquake scenarios. Annualized damage estimates are of use in financial decision making, such as in determination of building code provisions, or in insurance rate setting. Specific damage scenarios are useful for emergency response planners, since they provide a forecast of the nature and magnitude of situations likely to result from a given event.

Land Use Planning

While structural strengthening has been recognized as an effective technique for reducing earthquake damage, the observed shaking and damage due to differences in soil conditions has long suggested that land use planning, seismic zonation, or "microzonation" might also be a useful technique for reducing damage and total capital expenditure. In order to explore this suggestion, the city of San Francisco (population: 700,000; area: 49 sq. miles) was analyzed, and estimates of seismic damage were incorporated into an urban economic locational framework (Scawthorn, 1984).

In this process, damage due to expected earthquakes is estimated and included in the total cost of providing usable building floor space at a particular location in the city. Other costs that are considered include the cost of construction (dependent on building height), the cost of land, and the cost of transportation of goods and workers to and from the building location. These costs are determined for each location in the city, and the total cost of all buildings is minimized for the city, resulting in an "optimal" city. By comparing building distribution and costs for the city formulated in this manner, with and without seismic damage included, one can study the effectiveness of land use planning as a technique and compare it with the traditional structural strengthening.

Figure 4 shows some results in which the change in land use planning for San Francisco is portrayed at several layers of detail. Bar height indicates relative change in land/building use (black is an increase in a use category, white a decrease). The study indicated that annual total "operating" costs for

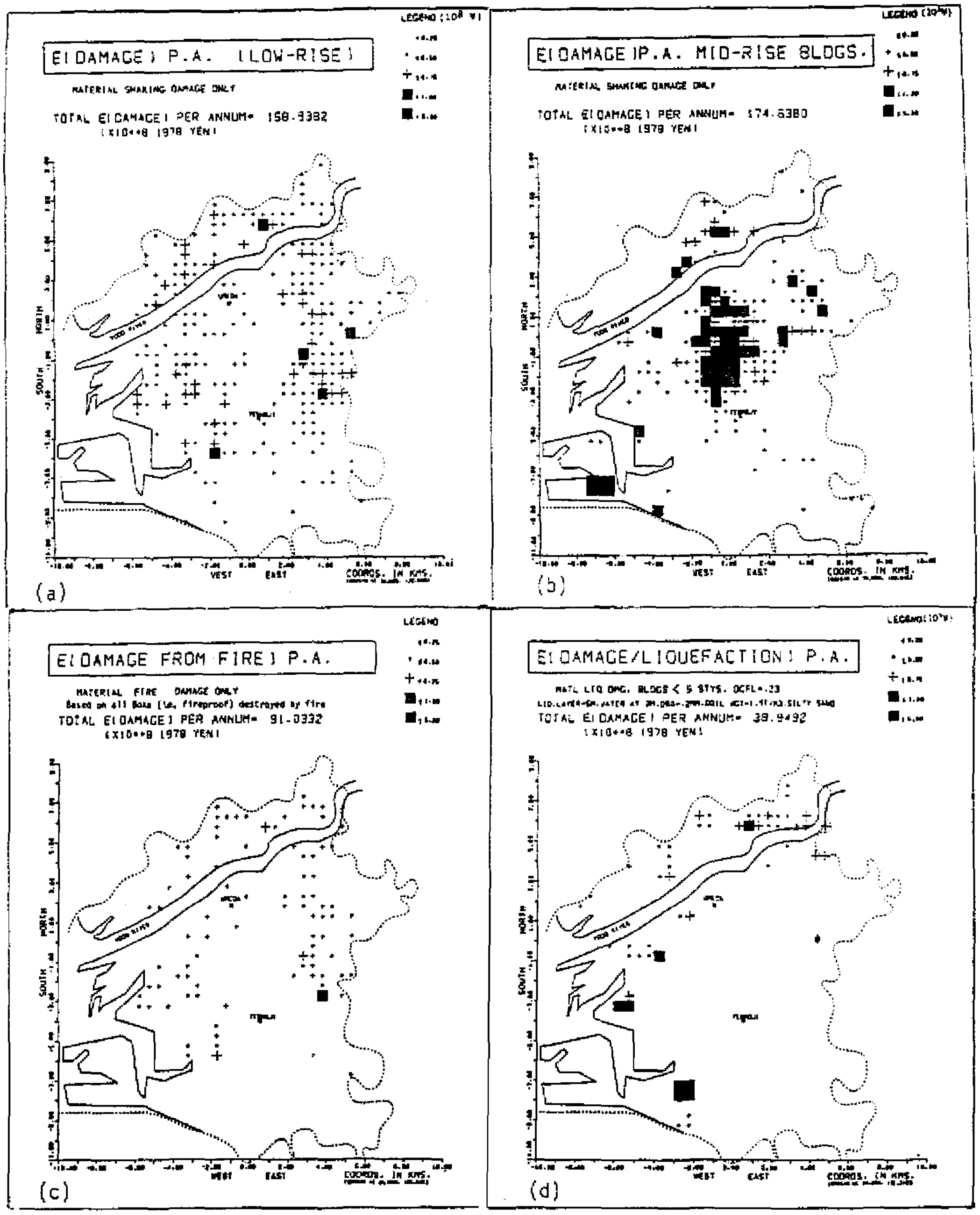
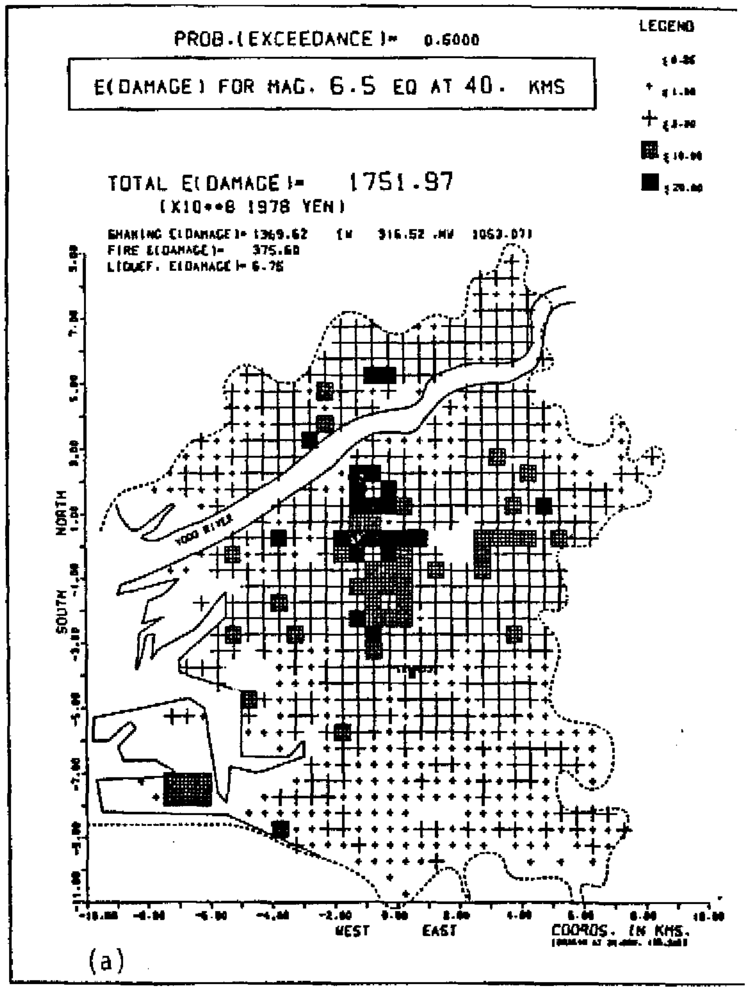


Figure 2
a) Expected Damage Per Annum for Low-rise Buildings in Osaka
b) Expected Damage Per Annum for Mid-rise Buildings in Osaka
c) Expected Damage Per Annum Due to Fire in Osaka
d) Expected Damage Per Annum Due to Liquefaction in Osaka



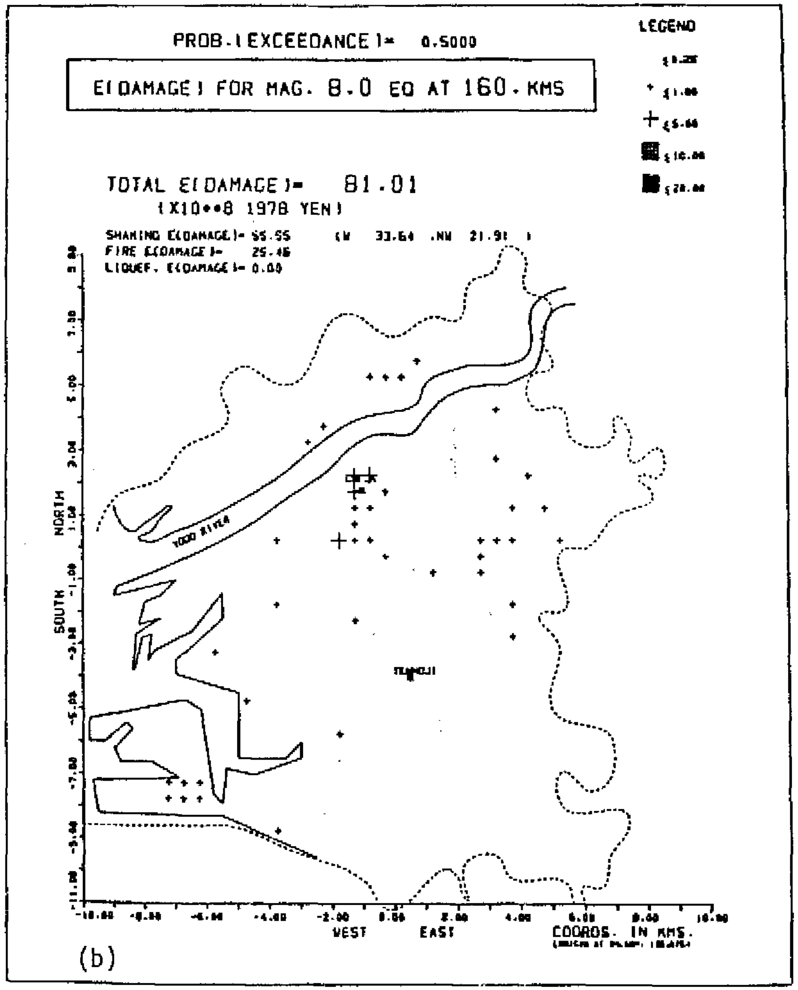
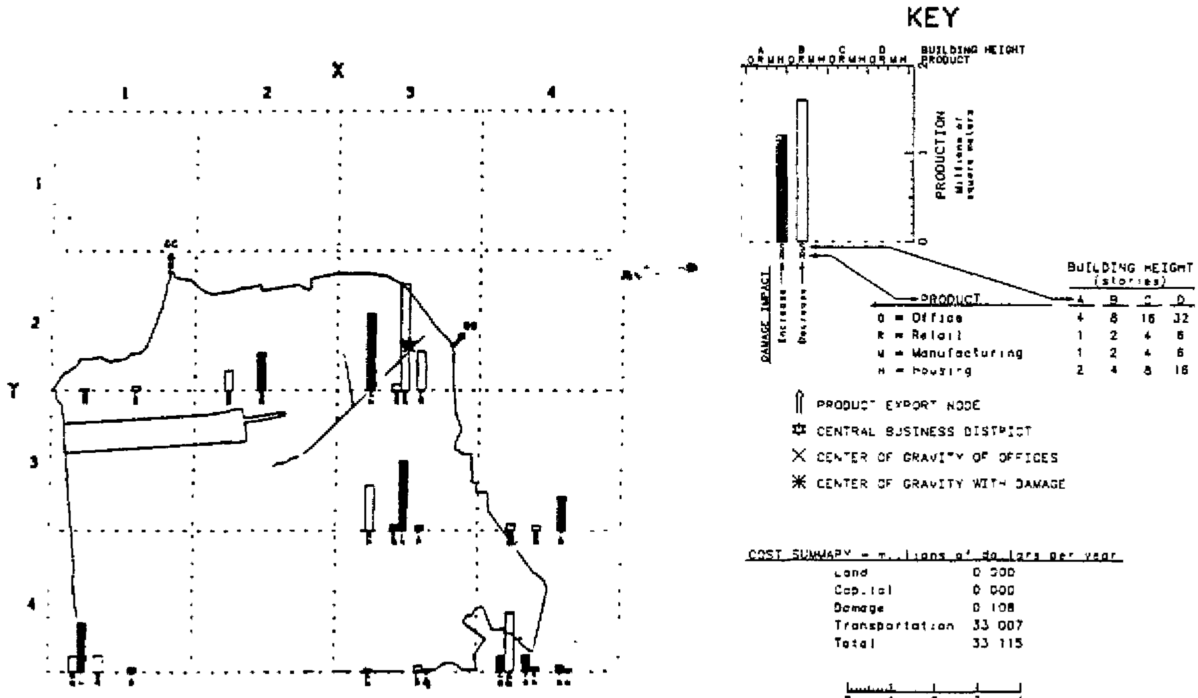
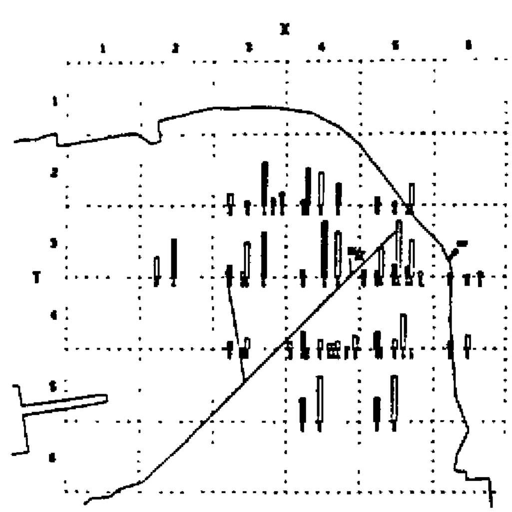


Figure 3

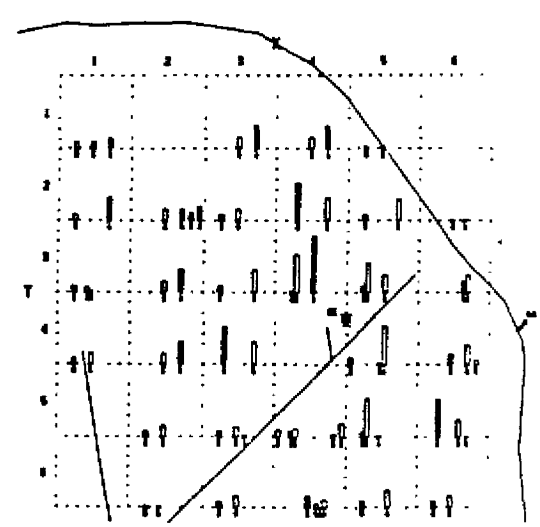
a) Expected Damage in the Event of a M6.5 Earthquake at 40 kms.
b) Expected Damage in the Event of a M8.0 Earthquake at 160 kms.



a) Differences in Land Uses Between Figures 2 and 3 (4 km. grid)



b) 4X Enlargement of City (1 km. grid)



c) 2X Enlargement of Central Business District (.5 km. grid)

Figure 4

San Francisco were about $1.7 billion, and annualized seismic damage about an additional $312 million. By relatively minor changes in land/building use, seismic damage was reduced to $236 million, a decrease of about 25%, and net total cost to the city reduced by about 4.5%. Note that this reduction does not even take into account secondary costs, such as business interruption in the event of an earthquake.

Emergency Response

Earthquakes pose a major test for civil emergency response services. The great fires which destroyed San Francisco in 1906 and Tokyo in 1923 demonstrate the disastrous consequences of failing this test. An understanding of likely prevailing conditions, problems to be encountered, and required resources is clearly required if future post-earthquake conflagrations are to be avoided. Yet, quantitative assessments of probable earthquake damage and potential fires are lacking for fire departments in seismic areas in the United States.

At present, research using the city of San Francisco as a case study is being conducted in order to develop a method to deal with this complex problem (Scawthorn, 1985). Figure 5 shows the computer plot of anticipated seismic intensity (Modified Mercalli Intensity units) due to a magnitude 8.3 event on the nearby San Andreas fault, and estimated initial outbreaks of fires based on seismic intensity, building distribution, and other factors. Outbreaks are estimated on the basis of a random Poisson process; they typically average about 30 for the city. However, San Francisco has 41 active fire engine companies and a total of 59 engines, if all reserves are placed in service. It is estimated that about 100 engines, and perhaps twice as many trained fire fighters as are normally on duty, would be required to deal with these fires. The preliminary conclusion is that substantial damage will be caused by several large fires in San Francisco in the next large earthquake. Acquiring knowledge of the pattern of fire outbreaks, potential water supply impairment, and other factors affecting fire creation and suppression is the first step in mitigating this situation.

Future Directions

The utility of seismic damage estimation in defining and mitigating the problem of earthquake hazards in urban regions seems clear. Future work is required in several areas:

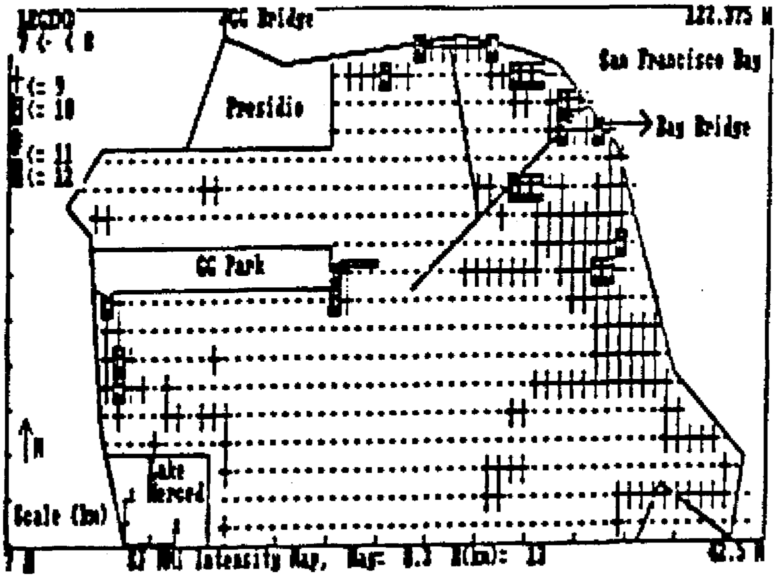


Figure 5a
MMI Intensities for San Francisco due to a M8.3 Earthquake
on the San Andreas Fault

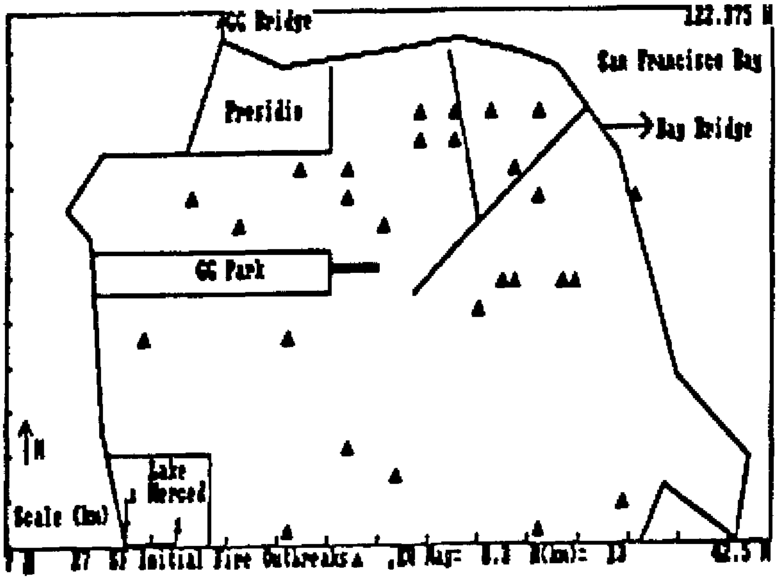


Figure 5b
Initial Outbreak of Fires Based on the Estimates of MMI Intensities

- Development of computer-based building and urban asset inventories. Surprisingly, we have only a vague picture of the distribution of the buildings and other assets at stake. We need to compile and maintain inventories which will form the basis for accurate quantitative damage estimation.

- Development of seismic vulnerability estimation functions. Substantial work has been done in this area (e.g., Steinbrugge, 1982), but much work remains to be done.

- Investigation of interaction problems, such as fire, hazardous materials, or business interruption. These problems are exceedingly complex and are best studied by computer simulation techniques.

- Development and implementation of real-time emergency decision support systems. Several excellent examples, such as the Firescope program in California, exist. Earthquakes, due to the number of problems created, will overwhelm centralized systems designed for more typical situations. Inexpensive, microcomputer-based, systems (e.g., Belardo et al., 1984) incorporating artificial intelligence techniques that efficiently update damage assessments and allocate resources offer decentralized stand-alone benefits and appear to be required.

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ESTIMATING THE LOCATION OF THE POPULATION OF A CITY IN TIME AND SPACE

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Concepts and Rationale

This paper describes the design, implementation, and testing of a computer program called the Population Estimator in Time and Space (PETS). The program calculates estimates of the number of people in designated zones in a large metropolis at each of many successive observation times during an average weekday. Estimates of the number of people in each zone at each point in time are generated in four categories: total population (TPOP), people in buildings (BPOP), people in moving vehicles (VPOP), and pedestrians (PPOP). TPOP is equal to the sum of the other three categories. In some cases, calculations can be made directly showing the total number of a population category in a particular zone at a particular time. In other cases, estimates are made indirectly using an allocation procedure.

There are 27 categories that are used to describe the status of the population in any zone at each time point. The first category describes people who stay in their residence zone and make no trips during the day. The next six categories describe people who make only internal trips within a zone. The next 16 categories describe the home-based movements of resident workers leaving and returning, visiting workers arriving and returning, nonworking residents leaving and returning, and nonworking visitors arriving and returning. Then, two types of non-home-based trip makers are described. Finally, estimates of the people passing through each zone are made (see Table 1). The estimates of TPOP in each of these 27 categories are then processed to obtain a breakdown of the number of people in each of the three subcategories (people in buildings, people in vehicles, and pedestrians). This produces a total of four estimates for each zone at each observation time during the day.

Table 1
Definition of Population Status Categories for the Home Zone at Observation Time n

Population Category	Total Population (TPOP)	Population in Buildings (BPOP)	Population in Vehicles (VPOP)	Pedestrian Population (PPOP)
	Population Status Variables			
1. STAY	P1	B1	V1	P1
2. RWIA	P2	B2	V2	P2
3. RWIT	P3	B3	V3	P3
4. ROIA	P4	B4	V4	P4
5. ROIT	P5	B5	V5	P5
6. NHIA	P6	B6	V6	P6
7. NHIT	P7	B7	V7	P7
8. RWLA	P8	B8	V8	P8
9. RWLT	P9	B9	V9	P9
10. ROLA	P10	B10	V10	P10
11. ROLT	P11	B11	V11	P11
12. VWRA	P12	B12	V12	P12
13. VWRT	P13	B13	V13	P13
14. VORA	P14	B14	V14	P14
15. VORT	P15	B15	V15	P15
16. RWRA	P16	B16	V16	P16
17. RWRT	P17	B17	V17	P17
18. RORA	P18	B18	V18	P18
19. RORT	P19	B19	V19	P19
20. VWAA	P20	B20	V20	P20
21. VWAT	P21	B21	V21	P21
22. VOAA	P22	B22	V22	P22

Table 1: Continued

23. VOAT	P23	B23	V23	P23
24. NHEA	P24	B24	V24	P24
25. NHET	P25	B25	V25	P25
26. THRUA	P26	B26	V26	P26
27. THRUT	P27	B27	V27	P27
TOTALS	TPOP	BPOP	VPOP	PPOP

Table 1 Key

Population Category and Variable Name		Description
1	STAY	Stayers (people who do not leave the home zone during the day)
2 - 7	RWIA RWIT ROIA ROIT NHIA NHIT	Resident workers and resident non-workers who make home-based work (HBW) and home-based other (HBO) trips within the home zone (I = internal trips) by Auto (A) and transit (T). Also includes non-home based (NH) internal trips.
8 - 23	RWLA RWLT ROLA ROLT VWRA VWRT VORA VORT RWRA RWRT RORA RORT VWAA VWAT VOAA VOAT	Column 1 R = residents V = visitors Column 2 W = home-based work trips O = home-based other trips Column 3 L = leaving residents R = returning residents A = arriving visitors R = returning visitors Column 4 A = auto T = transit
24 - 25	NHEA NHET	Non-home based trips, E = external (to and from) home zone, A = auto, T = transit.
26 - 27	THRUA THRUT	People passing through the home zone in vehicles, A = auto, T = transit.

If estimates are desired every ten minutes of a 24-hour day, 4 x 6 x 24 or 576 estimates are needed for each zone in the metropolis. If there are 500 zones, then the output of the simulator would consist of 500 x 576 = 288,000 numbers. These numbers represent a summary of a much larger set of numbers calculated internally by PETS but not printed out.

The approach described in this report requires that these calculations be done for each zone, one at a time. The zone being calculated is called the "home zone" and all trips made within it, to it, from it, and through it are calculated over the entire day. All other zones in the metropolis are aggregated into one superzone called the "elsewhere zone." The PETS program deals with each zone in the metropolis, one at a time, and calculates its daily interaction pattern with all other zones in the metropolis.

The rationale, assumptions, and computational strategy used to implement this approach are presented in the following section. The variables used in making the calculations are defined in Tables 1 and 2 and the computational procedures used are described in Figure 1 and Table 3. Throughout this report,

Table 2
Definition of Macro-Variables Used to Define
Simplified Computation Process

Population Category*	Total	BPOP	VPOP	PPOP
1				
2 - 7	X			
8 - 23				
24 - 25				
26 - 27	U		U	
Totals	TPOP	BPOP	VPOP	PPOP

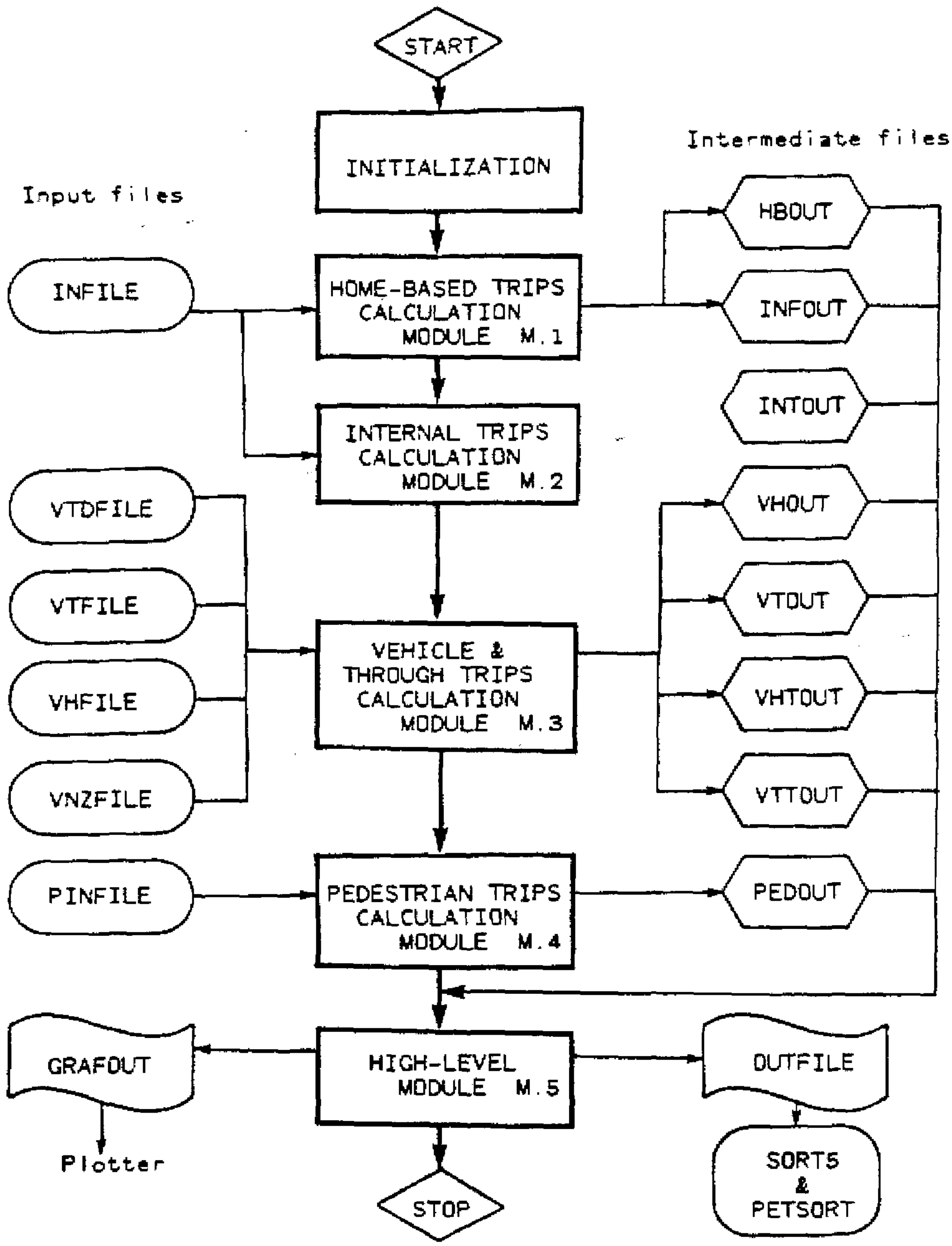


Figure 1
Overall Flow Diagram of PETSIM

Table 3
Definition of the Five PETSIM Modules Used to
Calculate Values of Macro-Variables Listed In Table 2

Population Category	TOTAL	BPOP	VPOP	PPOP
1	M.1			
2 - 7	M.2			
8 - 23	M.1			
24 - 25	M.1			
26 - 27	M.3		M.3	
Total	M.5	M.5	M.3	M.4

A brief description of the functions of each of these modules is as follows:

M.1 This module computes estimates of the total population of the home zone at each observation time by adding or subtracting the people arriving or departing during time period mn to or from the population estimate at time point m.

M.2 This module computes estimates of the number of internal tripmakers that are in motion in auto or transit vehicles, in the home zone at each observation time.

M.3 This module computes estimates of the number of persons who are in motion, in auto or transit vehicles, who are in the process of arriving, departing or passing through the home zone at each observation time.

M.4 This module computes estimates of the number of people who are pedestrians (not in buildings) in the home zone at each observation time.

M.5 This module is a high level routine that integrates the results from modules M.1 - M.5 and produces the overall TPOP, BPOP, VPOP and PPOP tables and graphs for each zone.

reference will be made to Tables 1 and 2 which list and define the 27 population categories used and generally indicate how the estimates are calculated. The four variables at the bottom of Table 2 (TPOP, BPOP, VPOP and PPOP) are the desired output of PETS, estimated by zone and time point.

Time is a major structural variable in PETS. Throughout this paper, a time interval is referred to as "mn." This means that time interval **mn** begins at time point **m** and ends at time point **n**. PETS is designed to accept time intervals of ten minutes or multiples of ten minutes (i.e. twenty or thirty). If the interval is ten minutes and the starting time is 3:00 a.m., the first time interval will begin at 3:00 a.m. and end at 3:10 a.m. Population estimates are calculated for both the 3:00 a.m. and 3:10 a.m. observation times. It is important to understand that most of the calculation in PETS is directed toward estimating movements of people within the home zone, between it and the elsewhere zone, and through the home zone during time period **mn**. But the population estimates are for time points and represent the net result of the movements during the time interval. In other words, the movements during time period **mn** determine the population levels at time point **n**. These population estimates are like a series of snapshots taken from a helicopter hovering over the home zone for an entire weekday.

These population estimates are intended to be of assistance to emergency response planners. They could be used with injury and death estimates to help planners to assess the spatial pattern of the medical aid requirements due to disasters of various types assumed to occur at particular times and at particular intensities. The injury and death estimates would be tailored to fit a specific type of disaster and its likely effects on people in buildings, in vehicles, and moving about as pedestrians.

Description of PETS Computational Strategy

It was necessary to avoid having to calculate estimates for each of the 4 x 28 = 112 variables defined in Table 1. If we were to do so, we would have to calculate 112 x 6 x 24 x 500 = 8,064,000 estimates for a 500 zone city with ten-minute observation times. While this is not an impossible task, it is a formidable amount of calculation and would exceed the computer capabilities of many units of local government. Therefore, a simplified approach has been devised and is shown in Table 2. The new set of macro-variables defined in Table 2 are used to describe the simplified computational process.

Essentially, programs have been written to calculate estimates of X, U, VPOP and PPOP directly. Once U is known, TPOP can be found. Once TPOP is known, BPOP can be estimated and the computation is complete.

Algebraically, the overall computation process is as follows:

1) X, U, VPOP and PPOP are calculated directly
2) X + U = TPOP
3) TPOP - VPOP - PPOP = BPOP

Figure 1 shows the overall flow diagram for the modules that make up the PETS program.

Some Details of the PETSIM and PETSORT Programs

There are two major components of PETS. PETSIM (see Figure 1 and Table 3) is the component that simulates the movements of the population and produces the population status estimates for each zone throughout the day. The other major component is called PETSORT. Figure 2 is an overall flow diagram of PETSORT. It sorts the output from PETSIM and allows the user to create histograms and a time-zone matrix to aid the identification of "worst cases" as well as to generally assist the user in comprehending the results from PETSIM. Another computer graphics program called ASPEX has been used to create three-dimensional plots from PETSIM results to assist further user comprehension.

Some Results From An Initial Application of PETS

PETS has been tested using hypothetical but realistic data for a 25-zone city called Mistville. The general geographic layout and transportation network for Mistville is shown in Figure 3. Figure 4 shows the results from PETS for Zone 2 of Mistville, plotted at thirty-minute intervals. Plots at ten minute intervals can be produced by PETS, but cannot be fit easily on one page. Figure 4 shows how the TPOP, BPOP, VPOP, and PPOP estimates vary for Zone 2 during an average weekday. For a city with 500 zones, PETS could produce 500 plots of this type (if desired). Figure 5 shows the same type of plot for the city as a whole. This plot shows that most of the population is in buildings most of the day. Figure 5 shows that BPOP is a minimum between noon and 2:00 p.m. when VPOP and PPOP values together include about 32% of the total population of Mistville (225,000).

An example of the type of summarized output available from PETSORT is shown in Figure 6. Here only a small portion of a 144 x 25 cell table, that

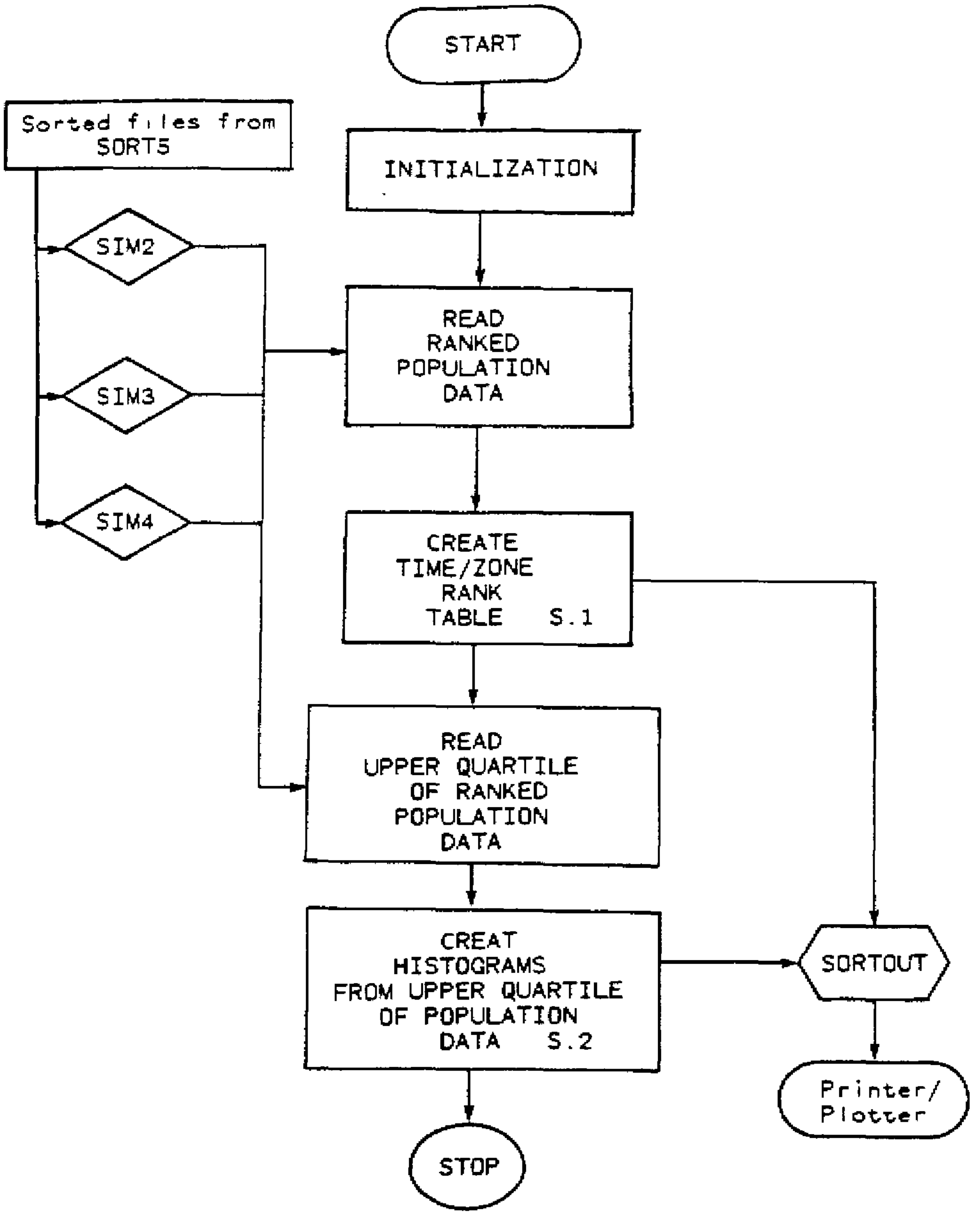


Figure 2
Overall Flow Diagram of PETSORT

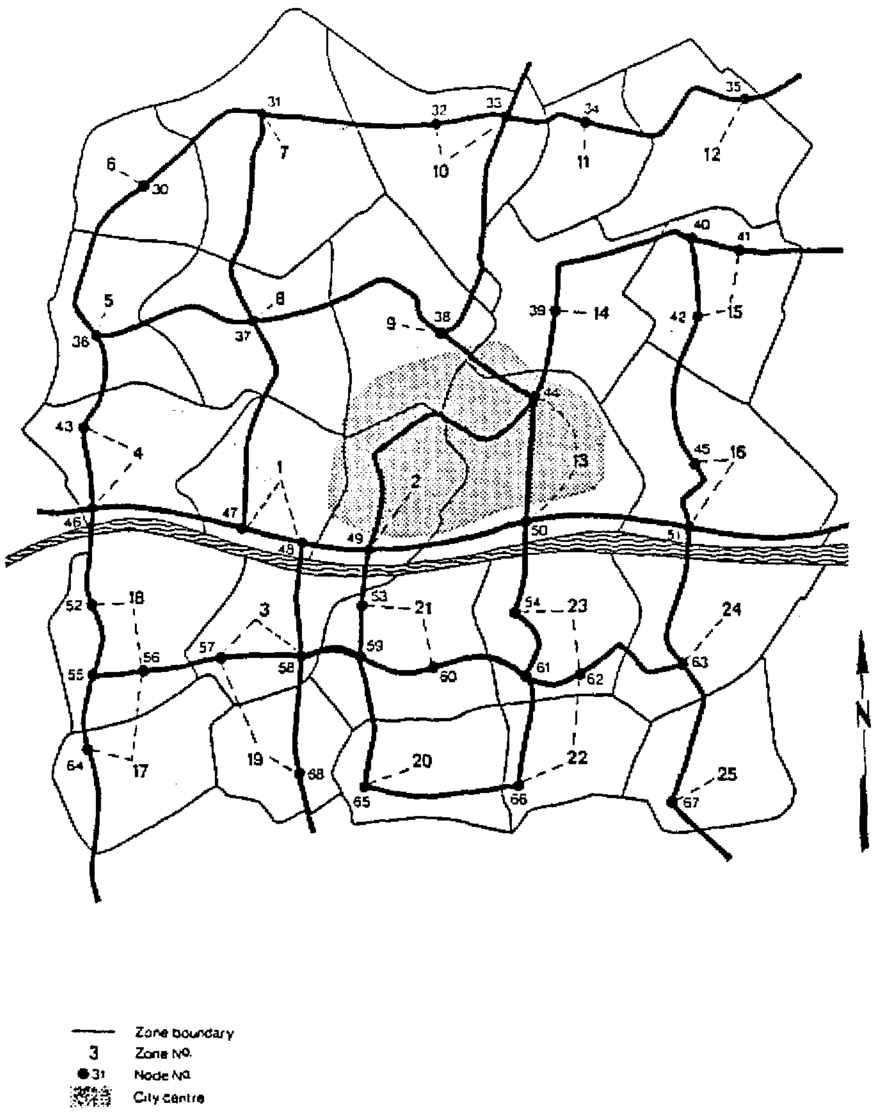


Figure 3
Geographic Layout of Zones and Transportation Network for Mistville

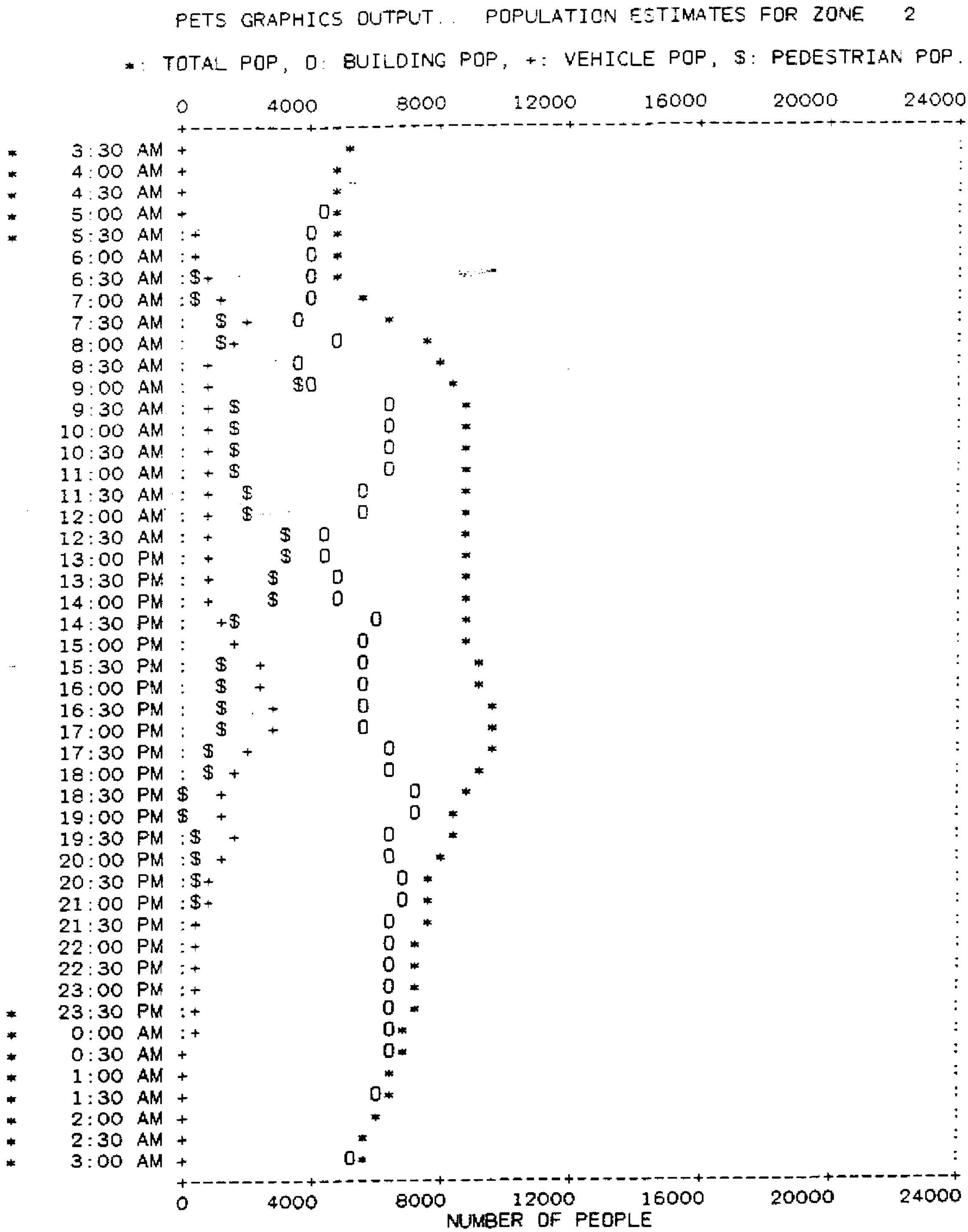


Figure 4
Line Graph of PETSIM Results for Zone 2 in Mistville

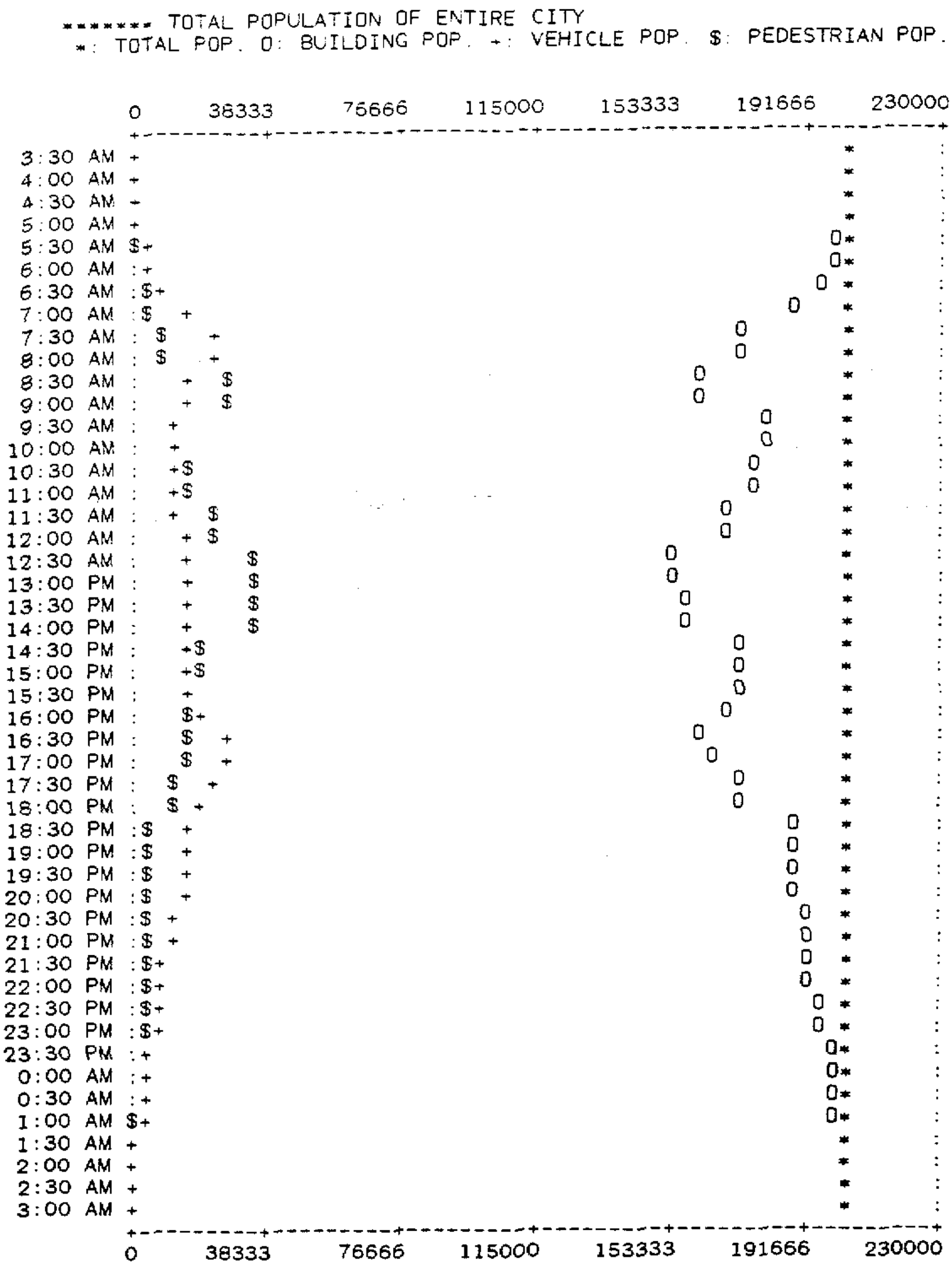


Figure 5
Line Graph of PETSIM City-wide Results for Mistville

ZONE	7	8	9	10	11	12	13	14	15	16	17
	582	665	496	*****	*****	*****	*****	57	*****	15	572
6:20	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	591	671	499	*****	*****	*****	*****	61	*****	18	590
6:30	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	593	674	501	*****	*****	*****	*****	63	*****	20	586
6:40	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	607	693	505	*****	*****	*****	*****	73	*****	23	652
6:50	*****	*****	*****	*****	*****	*****	546	863	*****	*****	*****
	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	641	719	514	*****	*****	*****	*****	79	*****	27	717
7:00	778	*****	*****	*****	*****	*****	322	591	*****	761	*****
	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	729	767	575	*****	*****	*****	*****	150	*****	50	*****
7:10	318	514	*****	*****	*****	*****	195	203	*****	388	*****
	865	*****	824	*****	*****	*****	744	857	*****	*****	382
	753	796	588	*****	*****	*****	*****	164	*****	67	*****
7:20	207	366	*****	*****	*****	*****	101	138	*****	247	848
	870	*****	823	*****	*****	*****	707	856	*****	*****	381
	798	814	603	*****	*****	*****	*****	180	*****	85	*****
7:30	150	238	839	*****	*****	*****	49	86	*****	183	724
	869	*****	827	*****	*****	*****	664	855	*****	*****	384
	806	930	615	*****	*****	*****	*****	187	*****	118	*****
7:40	147	235	835	*****	*****	*****	35	84	*****	181	704
	868	*****	826	*****	*****	*****	609	858	*****	*****	383
	812	840	627	*****	*****	*****	*****	191	*****	151	*****
7:50	166	277	*****	*****	*****	*****	43	103	*****	204	752
	867	*****	828	*****	*****	*****	608	854	*****	*****	379
	821	882	637	*****	*****	*****	*****	196	*****	172	*****
8:00	185	329	*****	*****	*****	*****	53	122	*****	239	788
	866	*****	825	*****	*****	*****	607	853	*****	*****	380
	*****	*****	804	*****	*****	*****	*****	278	*****	210	*****
8:10	286	518	*****	*****	*****	*****	130	194	*****	405	*****
	325	594	241	*****	*****	*****	156	319	624	610	4
	*****	*****	808	*****	*****	*****	*****	288	*****	230	*****
8:20	353	615	*****	*****	*****	*****	162	231	*****	484	*****
	330	593	243	*****	*****	*****	149	320	626	615	3
	*****	*****	811	*****	*****	*****	*****	292	*****	250	*****
8:30	422	689	*****	*****	*****	*****	209	288	*****	560	*****
	329	592	242	*****	*****	*****	148	322	627	614	2
	*****	*****	822	*****	*****	*****	*****	298	*****	275	*****
8:40	432	692	*****	*****	*****	*****	210	298	*****	566	*****
	328	591	245	*****	*****	*****	147	321	625	613	1
	*****	*****	827	*****	*****	*****	*****	304	*****	291	*****
8:50	506	763	*****	*****	*****	*****	228	372	*****	652	*****
	327	590	244	*****	*****	*****	146	324	623	612	6
	*****	*****	831	*****	*****	*****	*****	305	*****	302	*****
9:00	595	830	*****	*****	*****	*****	253	438	*****	737	*****
	326	589	246	*****	*****	*****	145	323	622	611	5
	850	886	698	*****	*****	*****	*****	215	*****	261	763
9:10	721	*****	*****	*****	*****	*****	265	573	*****	841	*****
	713	888	681	*****	*****	*****	487	687	*****	*****	160
	845	890	702	*****	*****	*****	*****	216	*****	268	730
9:20	801	*****	*****	*****	*****	*****	308	667	*****	*****	*****
	712	887	663	*****	*****	*****	488	666	*****	*****	159

Figure 6
Part of Matrix Showing Location in Time and Space
of Upper Quartile Ranks of BPOP, VPOP, and PPOP Estimates for Mistville

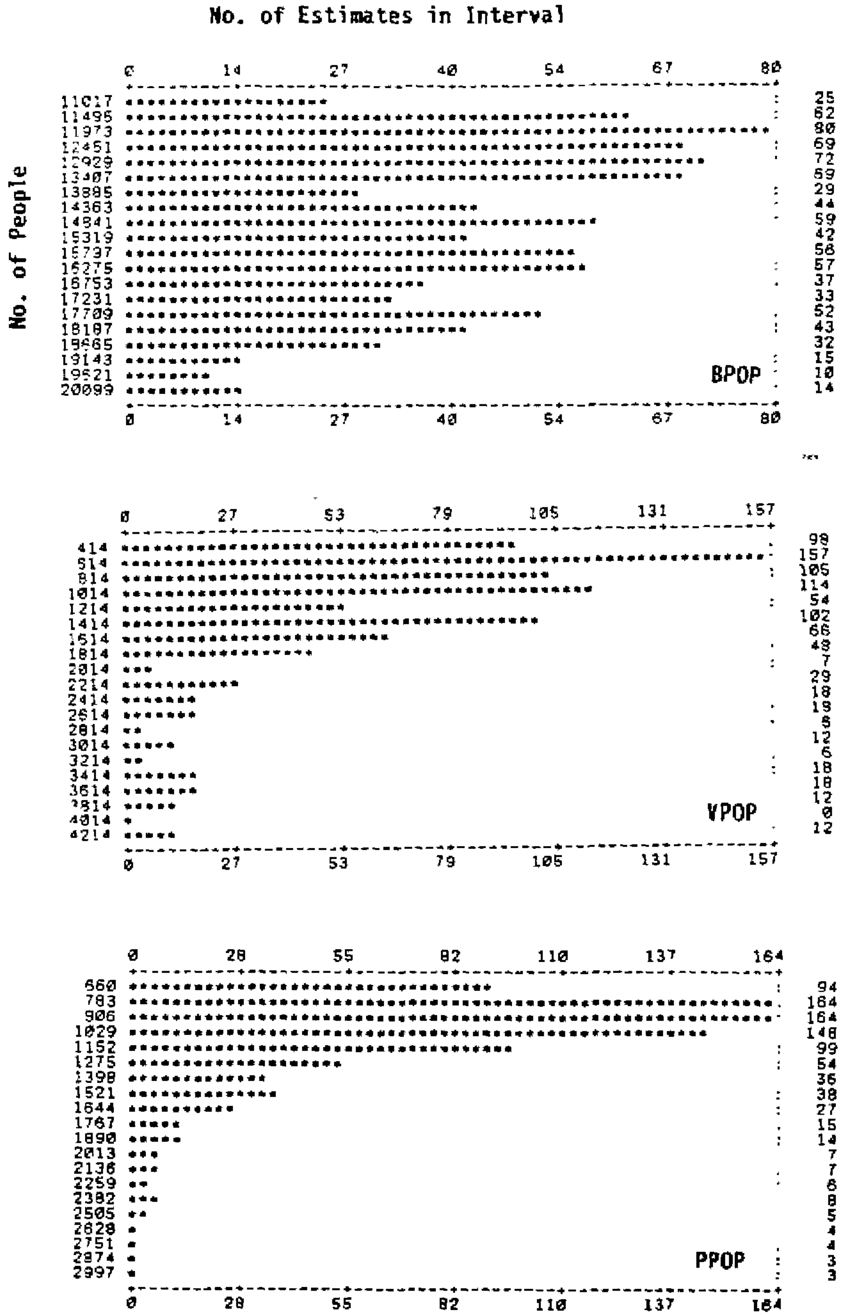
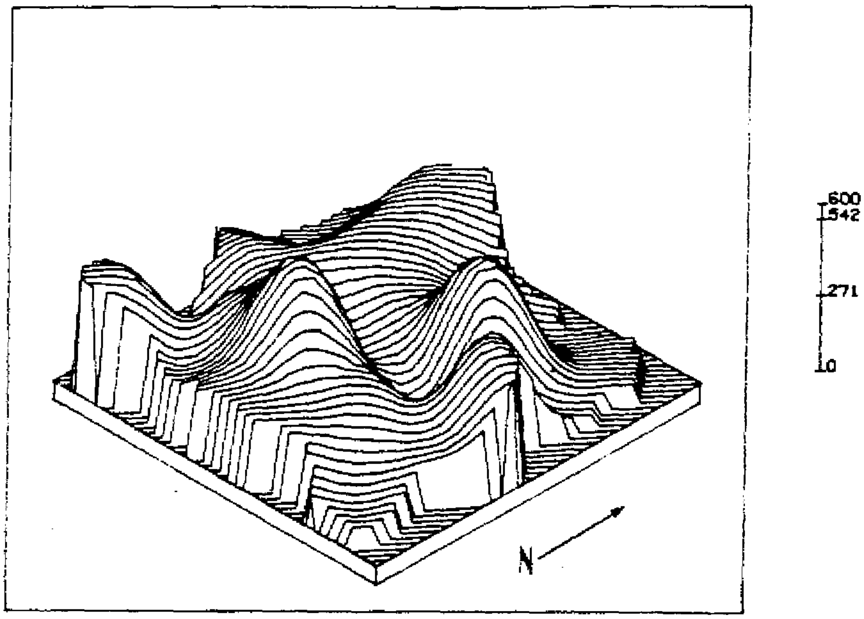


Figure 7
Histograms of Upper Quartile BPOP, VPOP, and PPOP Estimates for Mistville

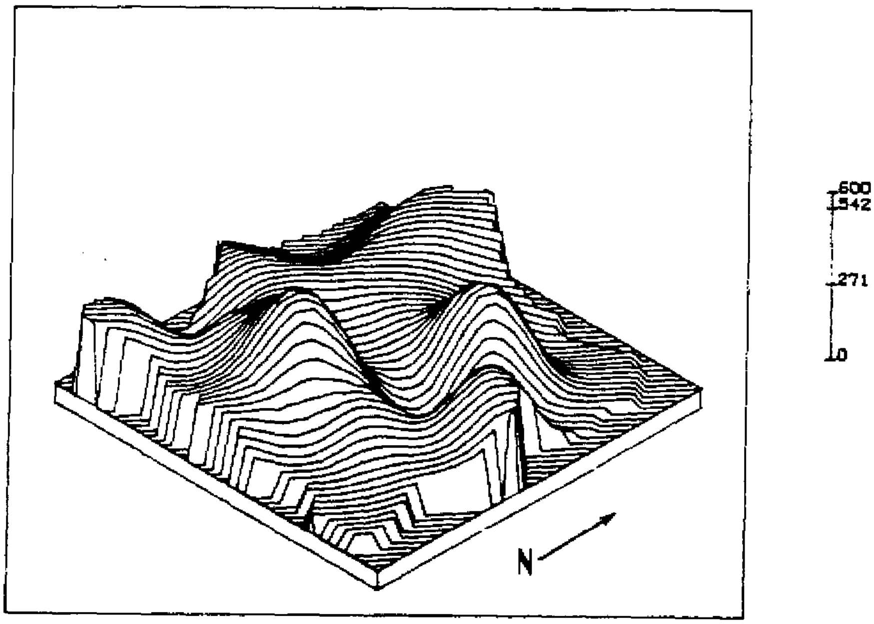
shows how each of the twenty-five zones in Mistville ranks according to the absolute values of BPOP, VPOP, and PPOP by time of day, is shown. It covers zones seven through 17 from 6:20 a.m. to 9:00 a.m. There are three rows in each cell of this matrix. The numbers are the rank (1-900) of the BPOP, VPOP and PPOP estimates for the associated observation time. Only the top 25% of these values are included in this table (i.e., the largest 900 of the 3600 values in each category that arise from 25 zones and 144 observation times). For example, figure 6 shows that the highest PPOP value was in zone 17 at 8:40 p.m., while the BPOP and VPOP values at this time ranked below 900 (i.e., were not large enough to be in the top 25% as indicated by a row of asterisks). Another example is zone 14, time 7:40 p.m. Here the respective rank values for BPOP, VPOP and PPOP are 187, 84, and 858, indicating that VPOP is relatively high in this zone at this time of day. This table can be used to quickly identify zones where the highest values occur. This information can be used to identify "worst case" zones and times for more detailed analyses and pre-disaster planning studies.

A second type of graphic output from PETSORT is the histogram of the upper quartile values of BPOP, VPOP, and PPOP. By looking at these histograms one can quickly see how many large values occur for each category of population. Figure 7 presents these three histograms as derived from the Mistville test. The BPOP histogram shows that there is a slight decline in the number of zone-time cases that have large values as the size of the population estimate increases (e.g., there are 14 zone-time cases where the BPOP estimate is about 20,000 in the test city). The histograms for VPOP and PPOP show a much sharper reduction in cases as the values rise with only a few zone-time cases having the highest values in the upper quartile of the overall distribution. These histograms enable the analyst to get an overview of the "worst case" and can aid the identification of further, more detailed zone-time analyses.

PETSIM results can also be displayed in three-dimensions using the ASPEX program or one of several other 3-D graphics programs. Some examples using Mistville results are shown in Figures 8 and 9. From the line graph of figure 5, we can see that BPOP is highest at 3:00 a.m. and the lowest at 12:30 p.m. Figure 8 shows the values of BPOP at these two times of the day. Figure 9 shows the distribution of VPOP and PPOP at those times when their highest values occur.

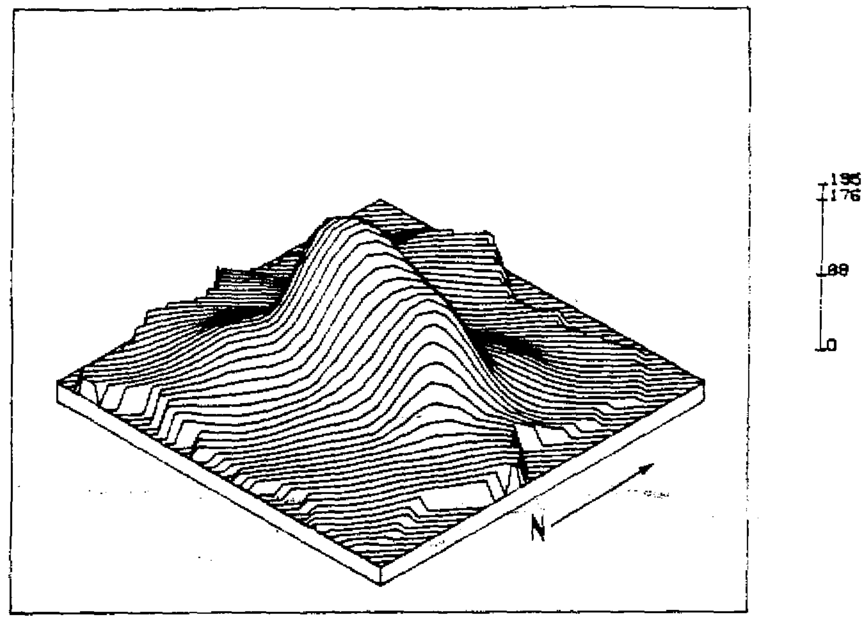


BUILDING POPULATION DENSITY AT 03:30 HRS

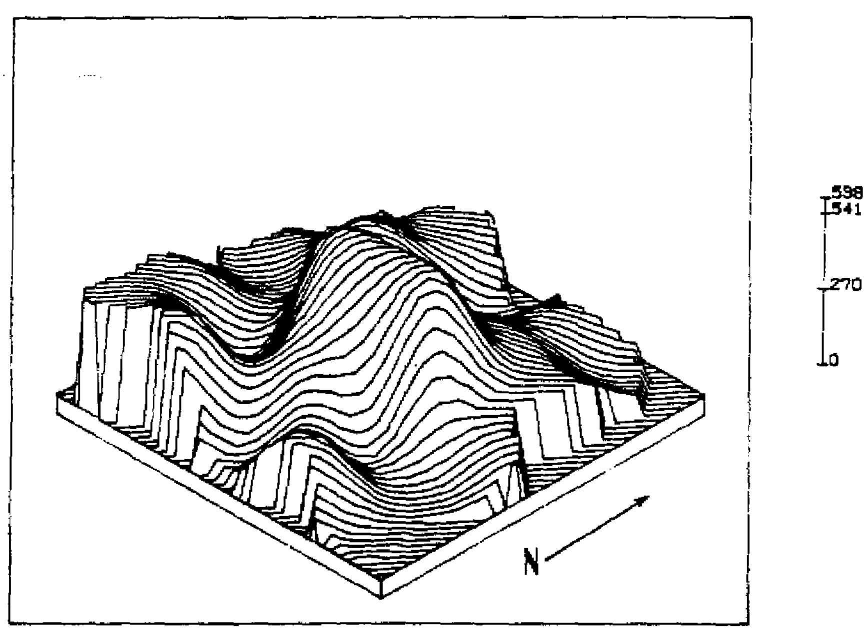


BUILDING POPULATION DENSITY AT 12:30 HRS

Figure 8
Three Dimensional ASPEX Displays of BPOP Data at Two Observation Times



VEHICLE POPULATION DENSITY AT 16:40 HRS



PEDESTRIAN POPULATION DENSITY AT 12:30 HRS

Figure 9
Three Dimensional ASPEX Displays of VPOP and PPOP Data at Two Different Times

In addition to the line and 3-D graphics, PETS produces a lengthy printed output that contains tables of numbers for each zone for each of the four population categories. For a 500 zone city, and ten minute time interval, this tabular output would contain 500 x 4 x 144 = 288,000 numbers.

Conclusions and Recommendations

It is anticipated that when PETS is actually used, disaster preparedness planners would examine the graphic displays initially to help them comprehend the population dynamics that occur in their city on an average weekday. During this examination, they would note that certain zones have large populations in the higher risk categories (e.g., pedestrians in zones with many buildings that are likely to produce falling objects during an earthquake). Conversely, they could note those zones that contain few people during much of the day and present minimal death/injury potential. They would then be able to select certain zones for a more detailed analysis and bring in additional data on building structural characteristics and other hazards that can assist the preparedness planning process. Injury/death ratios could be applied to the PETS estimates to determine the "worst case" spatial pattern of deaths and injuries that would result from an earthquake of a given intensity at a given location and time of day. These injury/death estimates would provide a better base for preparedness and response planning than is now generally available.

PETS is currently operational on a CDC Cyber 185 computer at the Academic Computer Center at the University of Washington in Seattle. Graphics displays are produced on Tektronix 4014 and 4114 terminals and Laser and Zeta plotters are used to prepare hard copies of the graphic displays. It would probably be very beneficial if PETS were made operational on one or more mainframes around the country and operated as a service to cities who want to use it. These cities could send their data to these central sites and receive tabular and graphic output in return. Ideally, such a computation should be performed annually or every other year so that updated estimates are available in the cities concerned.

Acknowledgement

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MASSVAC: A COMPUTER SIMULATION MODEL FOR EVALUATING EVACUATION PLANS

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Introduction

One of the major activities in emergency management is evacuation planning and operation. Indeed, evacuation is a cornerstone to both the preparedness and response phases of emergency management. It is the strategy most often used to protect people threatened by disasters, and most importantly, it is a controllable one. Despite mitigation activities such as the better siting and improved design of structures, in many cases evacuation still becomes necessary.

The need for a good transportation evacuation plan is emphasized by White and Haas (1975) in their assessment of research on natural hazards:

> Money spent on warning system development is wasted if people are allowed to live in vulnerable places without adequate means to escape where danger threatens (p. 3).

In a more recent study by Quarantelli et al. (1980), "Evacuation Behavior and Problems: Findings and Implications From the Research Literature," in which more than 150 literature sources are examined, the authors conclude that

> the research base about evacuation phenomena is not strong. Evacuation has not been a major focus of systematic study, and knowledge of the phenomena is often surface and very uneven (p. ii).

Evacuation is not a new phenomenon; it is probably as old as human settlement. However, the inclusion of evacuation planning in emergency preparedness and scientific studies of evacuation are both fairly recent phenomena. This paper is based on one such research project conducted by the author for the National Science Foundation and entitled "Transportation Actions to Reduce Evacuation Times Under Natural Disasters."

The MASSVAC Model

Highway network clearance time is a main component of evacuation times--the times needed to clear people and property to safe shelter areas (Figure 1). The focus of such clearance is on preventive, preimpact highway evacuation aimed at removing people before disasters such as floods, hurricanes, tornadoes strike.

A computer simulation model called "MASSVAC" was developed to analyze and evaluate evacuation plans for urban areas in order to calculate highway network clearance times. Input to the model consists of area and disaster characteristics, demographic conditions, highway network topology, and traffic control operation procedures. Using a traffic assignment algorithm, the program determines the optimum route for people to follow from a potential disaster area to shelters, the expected traffic bottlenecks, and the total evacuation time needed for all evacuees to clear the threatened area.

The model has two levels of analysis--macroscopic and microscopic. The macroscopic level simulates the evacuation process on the highway network by looking at the major road arteries as a complete and integrated system. This macroscopic analysis yields an estimate of the maximum network evacuation time under different disaster intensities and different combinations of severe traffic conditions. Furthermore, traffic bottlenecks are identified, and possible solutions can be introduced into the simulation model to study their effectiveness. The microscopic level simulates in detail evacuation traffic on any small highway network that shows potential for congestion; the potential cause(s) of the congestion could be the failure of highway intersection controls, lane blockage due to accidents, or any other impediment. This simulation level is used to test different traffic control and operational management strategies that might improve evacuation.

The MASSVAC model is written in FORTRAN IV language, and runs on an IBM-370 mainframe computer. A microcomputer version of the MASSVAC model has been successfully adapted to run on an IBM-PC with 256K random access memory (RAM).

Literature Review

Several models have been developed to simulate traffic flow in urban areas under normal (non-disaster) conditions. Among these are NETSIM--Network Simulation Model (Gibson and Ross, 1977), TRAFLO--Traffic Flow Simulation Model (Lieberman and Andrews, 1980), TRANSYT-7--Traffic Network Study Tool (Wallace et al., 1981), UTPS--Urban Transportation Planning System (UTPS, 1985), and

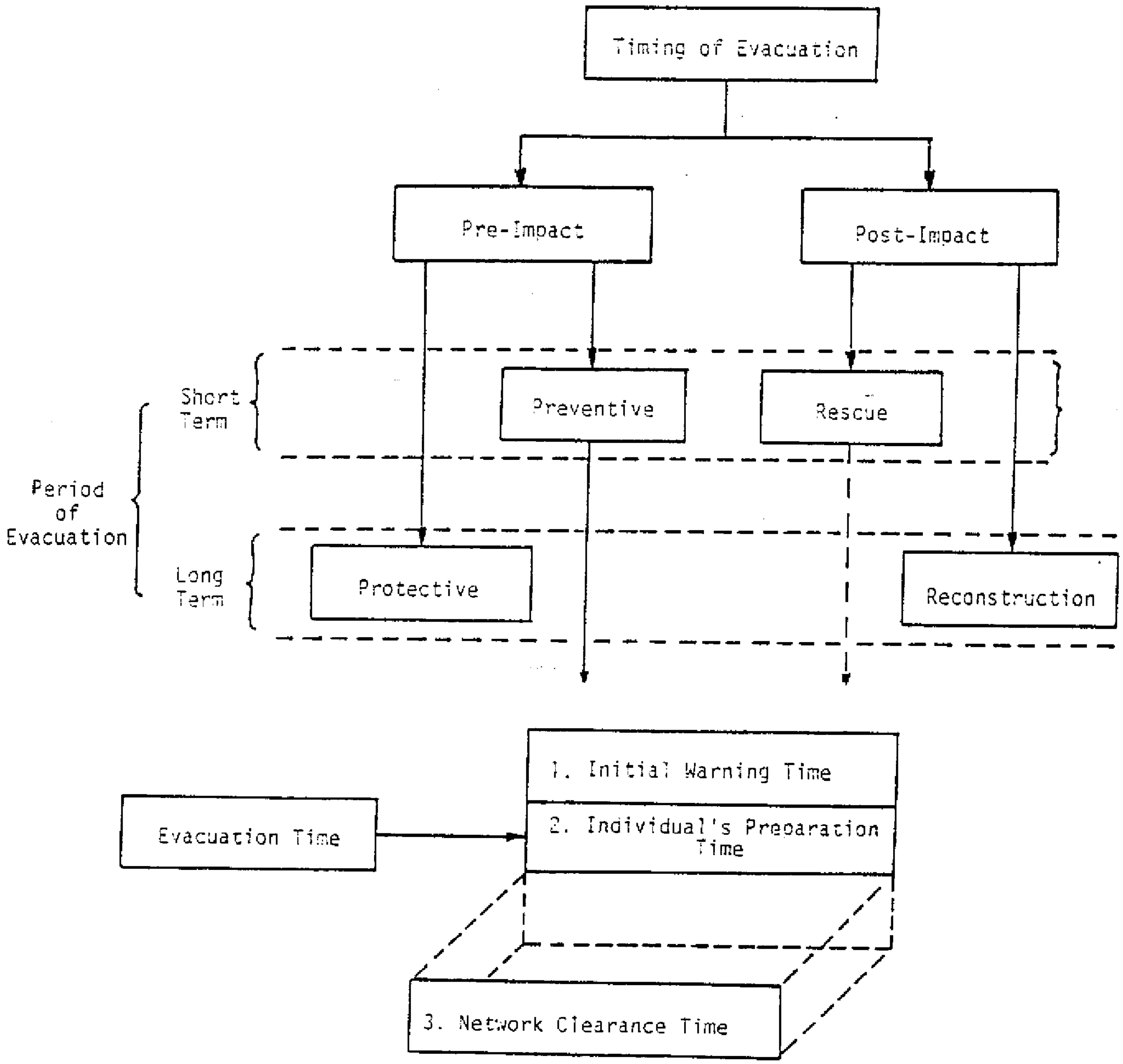

Figure 1
Network Clearance Time as Part of Evacuation Planning

EMME/2--An Interactive-Graphic System for Modeling Multimodal Transportation Networks (Florian and Nguyen, 1985). However, these models are not designed primarily to produce the data needed by the emergency planner, such as cumulative evacuation time for a particular zone, the number of people reaching a safe shelter area, the expected use of different shelters, and other information. They must be extensively restructured before they can be used in evacuation planning; moreover, they employ an extensive data base beyond that used in evacuation and therefore consume an inordinate amount of computer time. Some of them, such as NETSIM and TRANSYT-7, are basically used for developing traffic signal timing plans and for optimizing different traffic control management strategies.

There are a limited number of traffic flow simulators designed for evacuation planning under disaster conditions. Among those are the PRC Voorhees Evacuation Planning Package (EVAC PLAN PACK) (PRC Voorhees, 1982); the Simulation of Traffic In Emergency Evacuations model developed by Wilbur Smith and Associates (Cosby and Powers, 1982); The Dynamic Network Evacuation (DYNEV) computer model developed by KLD Associates, Inc. (KLD Associates, 1982); the Network Emergency Evacuation (NETVAC) simulation model developed by MIT (Sheffi, Mahmassani, and Powel, 1980); and the Calculating Logical Evacuation And Response (CLEAR) model developed by Pacific Northwest Lavoratories for the U.S. Nuclear Regulatory Commission (Houston, 1975).

All the above models are designed to estimate vehicular traffic evacuation time in order to develop evacuation plans for the areas around nuclear power plants. Thus they are applicable to point-source disasters, and they treat traffic flow at the macroscopic level. Shelters are defined as anything beyond the hazard area boundary, and there is no constraint on capacity. Evacuation routes are based solely on traffic flow conditions, and no risk factor dependent on available evacuation time, direction of disaster propagation, or route topography is attached to them.

Description of the MASSVAC Model

The MASSVAC model uses a capacity-constrained traffic assignment algorithm to simulate the vehicular flow during an evacuation period. The evacuation simulation program breaks the total evacuation period into small time increments. Within each time increment, vehicles begin trips starting from zone centroids according to the departure time distribution provided as input, and then move through the network. As a vehicle progresses along its evacuation route, it is contrained first by the operating speeds coded for each roadway section. As demand exceeds capacity on specific links, queues form on approach links. As queues build in the system, they effect upstream links by delaying traffic on those links until the queue is reduced and space exists for a vehicle to proceed along its evacuation route.

Risk factors are determined for each route and consequently influence traffic assignment on the routes. The model produces several kinds of evacuation information, such as the total evacuation time, the best evacuation routes, the percentage of trips reaching safety by a given time after the start of the evacuation, and the location of congestion points. Incidentally, shelters can be within the threatened community as well as outside of it. Figure 2 illustrates the general framework of the MASSVAC model.

Model Framework

The MASSVAC model is composed of three interrelated modules:

1) **The Area and Disaster Characteristics Module** which defines the natural disaster characteristics, the community boundaries, the vulnerable areas, and the shelter sites,

2) **The Population Characteristics Module** in which the spatial distribution of permanent/transient population and their demographic characteristics are identified and then internally used to develop the trip generation schedule, and

3) **The Highway Network Evacuation Module** which employs highway network topology, public disaster response behavior, and the traffic assignment algorithm to simulate traffic flow. It then yields output statistics such as evacuation times, evacuation routes, and the location of traffic bottlenecks.

Model Input

There are two major types of input required for the MASSVAC model:

1) **Community type and disaster characteristics** which include community type, such as urban or rural; population density classified by age and household; car ownership; and type of disaster, such as flood, hurricane, or hazardous materials spill. In addition, the hazard area boundaries are also required as basic input.

2) **Highway network topology and traffic simulation strategy** which include network geometry, characteristics, nodes, distances, speeds, existing volume, and capacity of each link. The traffic simulation parameters fed by the user are vehicle assignment parameters, the

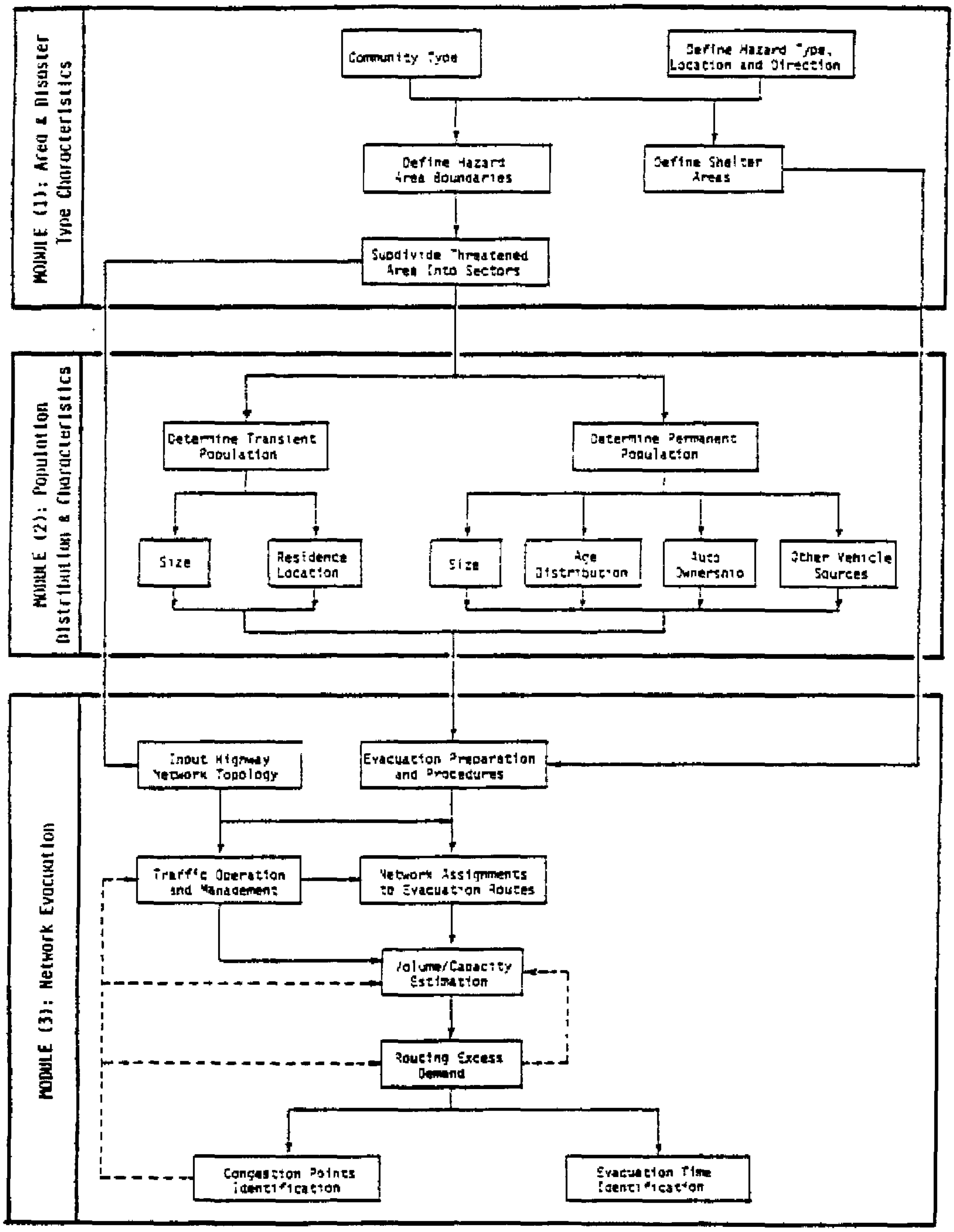

Figure 2
General Framework of the Evacuation Model

incremental time interval to be used, risk factors, traffic control management strategies, and the type of simulation—macroscopic or microscopic.

Model Output

The output of the MASSVAC model varies depending on the options specified by the user. In general, the following data could be obtained:

1) **Origin/destination trip table.** A trip from any origin to designated shelters is produced at the end of each loading interval (loading percentage of evacuees) and at the end of the simulation run.

2) **Evacuation routes.** The best evacuation routes from any origin to the assigned shelters are identified.

3) **Congested links and network characteristics.** Volume/capacity ratios, link densities, and link travel times are provided as network performance indices.

4) **Network evacuation time.** The time needed to evacuate people from the threatened area to shelters is calculated for each loading interval and for total network clearance.

Program Structure

The MASSVAC traffic simulation program consists of one main program and seven subroutines. The structure of the whole model and the relationship of subroutines to main program and to each other is shown in Figure 3. The function of each subroutine is briefly described below:

1) **Main program.** The main program initializes some of the variables and also calls the subroutines INPUT and STOCH. At the end of each simulation run, it makes sure that all the trips from any origin to any destination are assigned to the network; otherwise, it again calls the above two subroutines in order to assign the remaining trips.

2) **Subroutine INPUT.** The INPUT subroutine a) calls the RLINK subroutine to read the required data, b) reads the parameters necessary to determine the loading rate on the network, and c) depending upon the user's choice, either reads the trip table or reads the origin and destination capacities in order to generate the trip table internally.

3) **Subroutines RLINK and SORTL.** The RLINK subroutine reads the input data describing the network geometry (origin and destination of each link), type, name, zone, distance, speed, existing volume, and capacity of each link as well as the risk factors. It then calls the

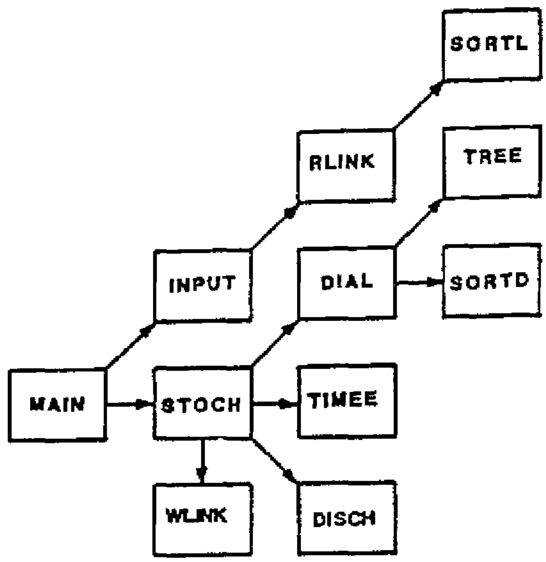

Figure 3
Program Structure of the MASSVAC Model

SORTL subroutine which sorts the links based on their origin and destination nodes. Links with lower origin and destination nodes are located at the top. Finally, the subroutine RLINK checks for duplicate links and missing information for each link.

4) **Subroutine STOCH.** The STOCH subroutine performs the actual model simulation. It determines efficient paths, loads trips on the selected routes, keeps track of congested links, and finally calculates network clearance time.

5) **Subroutine TIMEE.** This subroutine is called from STOCH. It updates the travel time based on link type and traffic simulation option (macro or micro level).

6) **Subroutine DIAL.** The DIAL subroutine assigns traffic onto the network with the restriction that no additional volume is assigned to oversaturated links unless those links could release some of that volume in subsequent time intervals.

7) **Subroutines TREE and SORTD.** Both TREE and SORTD are called from the DIAL subroutine. The main task of TREE is to build the shortest path tree from any origin to all the nodes. SORTD sorts the destination nodes of links according to their minimum travel times; the destination node requiring the least travel time will be located at top of the sorted list.

8) **Subroutine DITSCH.** Called from STOCH, the main function of the DITSCH subroutine is to dissipate the vehicular queues at intersections with signals and on freeways and expressways.

9) **Subroutine WLINK.** A user option, the WLINK subroutine can produce as printed output the characteristics of the links with positive volumes of traffic. Such characteristics range from initial input information about the link, to updated travel time, speed, and overall volume assigned to the link.

Methodology

The MASSVAC model is a time-dependent simulation utilizing an incremental traffic assignment technique. The model therefore employs 1) a shortest route finding algorithm, 2) a traffic assignment algorithm, 3) a vehicle discharge method, and 4) disaster response factors.

1) **Shortest route finding algorithm.** A review of the literature shows that there are two main types of algorithms for computing the shortest path between any two nodes: a tree building algorithm or a matrix algorithm. For large networks it has been proven that, with respect to computer storage, a tree building algorithm is much more efficient (Steenbrink, 1974).

   The most commonly used tree building algorithm in transportation studies is the Dijkstra's algorithm. It is easy to program and comparatively efficient in execution, and was therefore used in the MASSVAC model.

   The basic operation in Dijkstra's algorithm is described by the equation:

$$D(k,j) = \text{Min } [D(k,i) + D(i,j)]$$

   where: $D(k,j)$ = length of the shortest path from node k to node j
   $D(k,i)$ = length of the shortest path from node k to node i
   $D(i,j)$ = length of the link from node i to node j

2) **Traffic assignment algorithm.** Two major options are available for a capacity-constrained traffic assignment algorithm: the minimum-path routing method and the multiple-path routing method. A highway system, particularly when operating at or near capacity as might be the case during an evacuation, presents many alternative paths for going from a given origin to a given destination, and these vary only slightly with respect to their travel times. A realistic model would apportion trips to all of these paths in a probabilistic manner reflecting their relative likelihood of use. In the MASSVAC model, a probabilistic multipath traffic assignment model--Dial's model--is used to make traffic assignments. Dial's model uses a two pass Markov process in which probabilities of trips using certain highway links are calculated at one pass and then trips are assigned to the network in a second pass (Dial, 1970).

   To assign Y trips between origin node O and destination node D, the following items must be known for each node i:

   a) $p(i)$ = the shortest path impedance from O to i
   b) $q(i)$ = the shortest path impedance from i to D
   c) $I(i)$ = the set of all links whose initial node is node i
   d) $F(i)$ = the set of all links whose final node is node i

Letting link e=(k,j) have length t(i,j), each link's likelihood "e" is calculated:

$$a(e) = \exp\,[p(j) - p(i) - t(i,j)]$$

if $p(i)<p(j)$, and $q(j)<q(i)$, otherwise, $a(e) = 0$

Using link likelihood a(e) as link weight, trips are then assigned to the network by a forward or backward pass method.

3. **Vehicle discharge method.** To dissipate the vehicular queues at intersections with signals and on freeways and expressways, two different methods are used depending on the highway category. At the macroscopic simulation level, a modified Laporte regression linear model for mixed vehicles is used to determine the rate of dissipation of the traffic on freeways and expressways. The model first finds the density of the congested link then uses an equation to determine the vehicle discharge:

$$\text{Flow } (Q) = \text{Density } (K) \times \text{Speed } (U)$$
$$\text{Flow } (Q) = 74.3 \times \text{Density} - .75 \times (\text{Density})^2$$

For intersections with signals, a simplified formula is employed to determine the vehicle discharge volume:

$$DA = (V1/(V1+V2)) \times 1800$$

where: DA = Discharge volume per lane at direction A on road 1,
V1 = Critical lane volume at major road 1,
V2 = Critical lane volume at minor road 2, and
The saturation flow rate is assumed to be 1800 veh/lane.

For the microscopic level, the same procedure is applicable except for 2-way and 4-way stop intersections. The number of vehicles to be discharged is determined using the gap delay technique for a 2-way stop intersection. For 4-way stop intersections, up to 900 vehicles per hour are allowed to be discharged. Delay and travel time at intersections are determined using Webster's model (Webster and Cobbe, 1976).

4) **Disaster response factors.** A panic factor, suitability factor, and loading factor are used to model the evacuees' response behavior within the progam. The panic factor is used to eliminate certain links as time gets short. After 75% of the trips are loaded, the travel time of links with a panic factor equal to one is set to infinity to prevent further assignments to that link. This avoids unreasonable abnormal queue and delay on some specific links and also helps shift trips to alternative paths. The suitability factor represents both the closeness of the link to the origin of the disaster and its possible physical failure due to the hazard. Endangered links are assigned a suitability factor of one, and their travel times are set to infinity at the beginning of a simulation. The loading factor represents the accessibility of links to their nearest shelter. The loading factor of a link is set to one if more

alternative paths are needed to load traffic towards a specific shelter.

Another method employed to simulate disaster response behavior is to incorporate into the program the evacuees' rate of loading onto the network. Research has shown that the cumulative percent of evacuees plotted over time takes on an "S-shape" logit curve. To incorporate different ranges of behavior, the MASSVAC model adopted three curves with different slopes (steep, medium, and flat).

A steep logit curve is chosen for quick response with short evacuation lead time; for slow response with long lead time, a flat curve is used. For intermediate situations, the user can specify the medium curve. The percentage of total population to be loaded on the network at each time interval is calculated using the equation:

$$\text{Loading Rate} = 1/(1 + \exp(-A \times (DT - B)))$$

where: A = the slope of the logit curve
B = the assumed time at which half of the total trip ought to be loaded on the network
DT = the current clock time in the simulation run

Model Application

The MASSVAC model was applied to the city of Virginia Beach, Virginia, in order to determine evacuation times under various flood/hurricane conditions (Hobeika et al., 1985). The city was divided into four regions based on topography, land development, and highway network. Different hurricane intensity levels (1 to 4) and various demographic scenarios were considered for each region. In each case the network evacuation times were obtained, and the bottlenecks and major problem spots on the network were identified. Table 1 shows the evacuation times under the critical scenario C. This scenario, which is a three-day summer weekend scenario, assumes that only 60% of the overnight and 10% of the daytime transient population need to be evacuated. It also assumes that 60% of the evacuees would leave the threatened region for places and shelters outside the region, and that the remaining 40% would seek shelters inside the region's boundaries. The results indicate that the evacuation times are critical in regions 1 and 2 which are the oceanfront areas, especially for hurricane levels 3 and 4. The evacuation times above 15 hours were not acceptable to public officials and decision makers. As a result, several traffic operation strategies--such as the use of shoulders on freeways and expressways, one-way flow at intersections with low volume on side streets--were tested to determine their effects on reducing evacuation times. Table 2 shows the evacuation times after the adoption of the designated strategies. The results show that these minor changes could significantly reduce the evacuation times, making them reasonable and acceptable to the responsible officials.

Evacuation Region	Hurricane Level	Loading Period (hour)*	Evacuation Time (hour)
1	1	8	15.32
1	2	16	17.15
1	3	16	22.15
2	1	4	7.97
2	2	16	13.25
2	3	16	23.57
3	1	4	6.17
3	2	8	7.65
4	2	8	7.38

* Loading period 4 represents the steep curve while loading period 8 represents the flat curve and loading period 16 represents the lazy curve.

Table 1
Evacuation Times At Virginia Beach Under Scenario C

Evacuation Region	Hurricane Level	Operational Strategies	Loading Period (hour)*	Evacuation Time (hour)
1	1	One-way Great Neck	8	13.00
1	2	One-way Great Neck	8	15.00
1	3	One-way Great Neck	16	15.00
2	2	1-way Sandbridge & Ocean & N. Landstown	8	7.38
2	4	1-way Sandbridge & Ocean & N. Landstown	16	12.95
3	2	None	8	7.65
4	2	None	8	7.38

* Loading period 8 represents the flat curve while loading period 16 represents the lazy curve.

Table 2
Evacuation Times with Operational Strategies

Conclusions

In general, the model proved to be sensitive to population size, disaster conditions, highway characteristics such as road capabilities, shelter availability, and specific traffic operation strategies. It provided reasonable and reliable estimates of evacuation times.

Acknowledgements

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SECTION THREE

PROBLEMS OF THE PRESENT

VISIONS OF THE FUTURE

AUTOMATED EMERGENCY MANAGEMENT: A FRAMEWORK

Madhu Beriwal
Innovative Emergency Management, Inc.

Emergency Management and Uncertainty

> Emergency management is the art and science of uncertainty control. Uncertainty is the complement of knowledge. It is the gap between what is known and what needs to be known to make correct decisions. Dealing with uncertainty is not a byway on the road to responsible business and governmental decisions. It is central to it. The subject is complex, elusive, omnipresent (Mack, 1971, cover page).

How does uncertainty affect decision making? There are some grave costs arising from uncertainty. In uncertain situations, decisions tend to be focused narrowly on a few alternatives, innovation is undermined, or decisions may not be made at all. Once decisions are made, if uncertainty is high, actions may not follow or may be poorly implemented and ultimately ineffective as the lack of conviction is correctly sensed by other individuals. As Mack (1971, p. 5) states, "[t]here appears to be a tendency for uncertainty to produce a bias toward overconservatism, toward routine ways to solve problems, toward doing nothing."

Uncertainty, properly contained and used, imparts to life and situations the keen edge that is needed for creative thoughts, actions, and the essential sense of being alive. The greatest role of an automated system such as the one envisioned in this paper would be in the containment of uncertainty, in reducing the vast area of doubt. Such a system may free emergency management to pursue thoughtful and purposeful action.

Learning and Automation

In daily life, we learn through experience. This form of learning is problematic in emergency management, especially at local levels where management must be most effective and robust (Raker et al., 1956). Although local officials learn from past disasters, several factors militate against a smooth accretion in management capabilities. Disasters are infrequent, and officials trained by one disaster may not be working in an official capacity when a similar disaster recurs. Even if the decision makers remain the same, "preparations at a later point in time become organized in terms of the earlier problems and circumstances" (Parr, 1969, p. 26). These circumstances may not be repeated in quite the same form in a later disaster, e.g., compared to an earlier storm, a hurricane's speed and intensity may vary, or it might strike a different area. Indeed, research casts serious doubt on whether or not learning takes place at all as a result of past disaster experiences (Kates, 1962); it appears that learning only takes place when there is "high certainty" about events and impacts. However, disasters and their effects are increasingly uncertain as the links of society create "ripples" far away, both geographically and functionally, from the impact region.

This is where automation can be most helpful. The ability to simulate disasters, while maintaining some of the complexity of a real event, is crucial to learning how to manage emergencies. Simulation allows the best form of learning--learning by doing; as a Chinese proverb says:

I hear, and I forget.
I see and I remember.
I do and I understand.

It follows that simulations can best assist in learning by being as realistic as possible and by requiring active user interaction. The latter requirement means quite simply that simulation systems must be interactive. The former requirement needs greater elaboration. Of necessity, the ideal emergency management (EM) system must be location-specific, function-specific, and time-specific. The locational peculiarities of each region must be meshed with functional software, and the events simulated should be calculable in "real time."

Location-Specific Databases

Taking the most easily visualized factor first, location specificity demands a geographic information system (GIS), and among the digital files incorporated within that emergency GIS should be databases depicting political boundaries, hydrography, topography/bathymetry, land uses, population, and transportation. Secondary features may include detailed attributes of each of these files, e.g., population in time and place (Schneider et al., 1984), locations of elderly/handicapped persons, critical facilities, bottlenecks in evacuation routes (for examples see chapters by Hobeika, Morentz and Schneider in this volume).

Why are these particular files important to an emergency management GIS? Political boundaries are often the units by which emergency action is taken. Although hazards spill over political lines, decisions and actions to counteract hazards are generally taken by the leaders of individual political units. Hydrographical data is important because it shows the location and characteristics of water. Water is both a purveyor of risk from region to region and a principal hazard in its own right. Topographical data is vital because many hazard effects flow over land—either borne by water in which case they are directly affected by land contours, or borne by wind in which case their transmission is modified by site topography. The expression of structural risk is clearest in a functional determination of land uses, modified by incorporating local (historical and current) building practices and regulations for different classes of structures. Damages and injuries result from the vulnerability of structures, and thus of persons, to hazards (although some technological hazards may do no harm to structures while creating fatal risks to humans). Population data is indispensable for the calculation of persons-at-risk. Transportation data is necessary for calculation of time needed for emergency options, i.e., evacuation, emergency rescue, resource assembly times.

Scale of Planning

These GIS databases should be detailed enough to allow discrete planning. The scale of the information is critical. "While those maps at a scale of smaller than 1:63,360 may prove useful as descriptive tools, gaming aids or political attention-getting devices, they are of little use in actual planning. . . . The safety plan director and committee should pay considerable attention to the question of mapping scale for hazard microzonations. . . the scale selected should be large enough to make full use of the available data and to permit individual sites and structures to be identified if possible (Foster, 1980, pp. 62-63)." The U.S. Army Corps of Engineers has been using 1:12,000 or 1:6,000 scale for flood plain mapping. The TVA promotes the use of 1:4,800 as a minimum standard for urban areas (U.S. Office of Emergency Preparedness, 1972). The use of such detailed mapping scales in combination with the vast amount of data to be processed makes manual interpretation unwieldy. Automation of this data on a suitable system can allow the planner/decision-maker to "zoom-in" or "pan-out" on particular areas and simultaneously view the "forest" and the individual "trees."

Function-Specific Software

Function-specificity demands that EM systems be designed to assist in particular emergency functions. Although specific actions may differ from hazard to hazard and from region to region, some actions remain constant. These are the actions that are implicit and explicit in the prototype Emergency Operations Plans (EOP) (see Table 1).

ALERTING	COORDINATION
PUBLIC INFORMATION	PERSONNEL MANAGEMENT (ORGANIZATION AND ASSIGNMENT OF RESPONSIBILITIES, TRAINING, AND EDUCATION)
WARNING	COMMUNICATIONS
EVACUATION	EOC DEVELOPMENT
TRANSPORTATION	DIRECTION AND CONTROL
MONITORING	OVERALL CONCEPT OF OPERATIONS
LAW ENFORCEMENT	RESOURCE MANAGEMENT
SHELTERING	PUBLIC WELFARE
MEDICAL SERVICES	
SEARCH AND RESCUE	
ENGINEERING SERVICES	
DAMAGE ASSESSMENT AND REPAIR	

Table 1
Emergency Management Functions

Functional capabilities must primarily include the ability to perform hazard assessments. This requires hazard-specific simulation software capable of local implementation, e.g., the SLOSH model for hurricanes (described by Griffith in this volume), plume models for nuclear power plants, flood simulation models. The hazard model outputs must often be processed in different ways depending on whether preparedness, response, recovery or mitigation is being examined. For example, preparedness scenarios must incorporate uncertainties inherent in hazard forecasting and thus must envelop a large sphere of hazard probabilities. Response planning scenarios must be more narrowly focused to a range indicated by actual, developing conditions. Recovery planning, with the luxury of hindsight, must be based on very specific hazard events. Mitigation planning must account for probabilities of recurrence, local perceptions of acceptable risk, and the feasibilities of various hazard reduction techniques.

Thus a mesh of both hierarchical and sequential files is indicated. The archiving of hazard model outputs should allow the primary selection (through simple menus) of the level and type of data required. The interaction of hazard-specific composite scenarios with local characteristics would result in hierarchical file structures that permit easy manipulation and rapid simulation. The sequential files are necessary because of the mandated sequence of emergency actions, e.g., persons are warned first, evacuated next, and then sheltered.

There are many functional models that need to be considered for development; the basic theoretical knowledge necessary exists in a wide variety of disciplines. A few possibilities from all four phases of emergency planning can serve as examples:

Optimal traffic assignment and evacuation time estimate models could assist preparedness planning (see, for example, Hobeika's paper in this volume). Other models could facilitate the determination of optimal evacuation zones based on shelter capacities in consonance with "service areas" theories. These theories arose in the late 1950s from the transportation model and its derivatives (Henderson, 1955a, 1955b, 1958). Simply stated, the models provided a mechanism for the analysis and normative planning of "flows" in capacitated or constrained networks. For example, Gould and Leinbach (1966) used a derivative to draw optimal service areas for hospitals. Shelter assignments could be based on behavioral models of response, mental perceptions of distances and traffic obstructions, and shelter capacities, meshed with a developed hierarchy of shelter usage. Dispersion and network models of varying sorts could enhance resource management, and dispersion models based on site characteristics could aid in the identification of areas outside the reach of outdoor communication systems such as sirens. There is also a widely-accepted need for decision-support systems--tailored to generic and hazard-specific events--that will assist direction and control functions.

In response planning, a shelter monitoring model could greatly alleviate personal hardships and facilitate the reunion of families after disasters.

Recovery planning, involving the provision of relief, could benefit from a system that assigns manpower to disaster assistance centers based on calculated populations-affected and queueing theory. In addition, remote sensing through satellites or aircraft could assist in rapid damage estimation, basic data gathering for relief operations, and verification of simulated information.

The mitigation process could benefit from programs using algorithms that reveal the effect of various mitigative measures in reducing total hazard potential, populations-at-risk, or economic and social damage.

Time-Specific Software

"Timing is often a pivotal factor in disasters and is important to everyone; yet it is rarely an integral part of disaster planning" (Disaster Research Center, 1968, p. 11). An automated EM system should allow the calculation of temporal losses. The requirement of time-specificity in uncertainty management necessitates a system capable of dynamic modification based on simulated event sequences or actual circumstances. Most functional software can have the ability to calculate such losses; however, the weak links in the chain are behavioral assumptions. Considerably more needs to be known about possible changes in responses of individuals, families, organizations, and communities in varying disaster situations (Mileti et al., 1975). Time estimation will be shaky until the behavioral assumptions that it rests upon are firmly established.

Some Questions in Emergency Management

The neatly segmented and sequential process of a "paper" Emergency Operations Plan breaks down into tiny particles that regroup into differing forms within an automated EM system. In this new form, a new synthesis of data--requiring innovation and flexibility--is needed. The following is an example of such a reformulation drawn from hurricane planning.

Hurricanes are devastating events. Most persons commonly assume that the primary hazard involved in such storms is their high winds. However, nine of ten deaths related to a storm occurrence are directly or indirectly caused by storm surge--the large dome of water that is propelled ashore by storms. Thus the inundation of structures by rising waters is the principal hurricane hazard, and one of the first steps of hurricane emergency management is the development of storm surge inundation profiles. The National Weather Service storm surge model (SLOSH: Sea, Lake and Overland Surge from Hurricanes) provides the surge data by using a non-interactive model (see the paper by in this volume by Griffith for details about SLOSH). The surge profiles provided by this model show depths of inundation by location for a variety of storm conditions. However the assumptions involved in using this data are many. For example there is the potential for a critical forecast error in predicting storm landfall locations. Since the area of storm surge and damage is a function of, among other things, storm landfall location and specific basin characteristics, the incorporation in the program of possible forecast error is necessary. By creating a "bundle" of storms that compress the characteristics of individual storms, the range of possible storm forecasting error is covered, and a storm surge evacuation scenario can be created.

Such a scenario is depicted in Figure 1 for Southeast Louisiana. The surge inundation profile shows the depth of flooding to be expected by the combination of storms contained in the scenario. However, the planning process cannot rest solely with this "hazard assessment." It must be related to the emergency management functions already discussed.

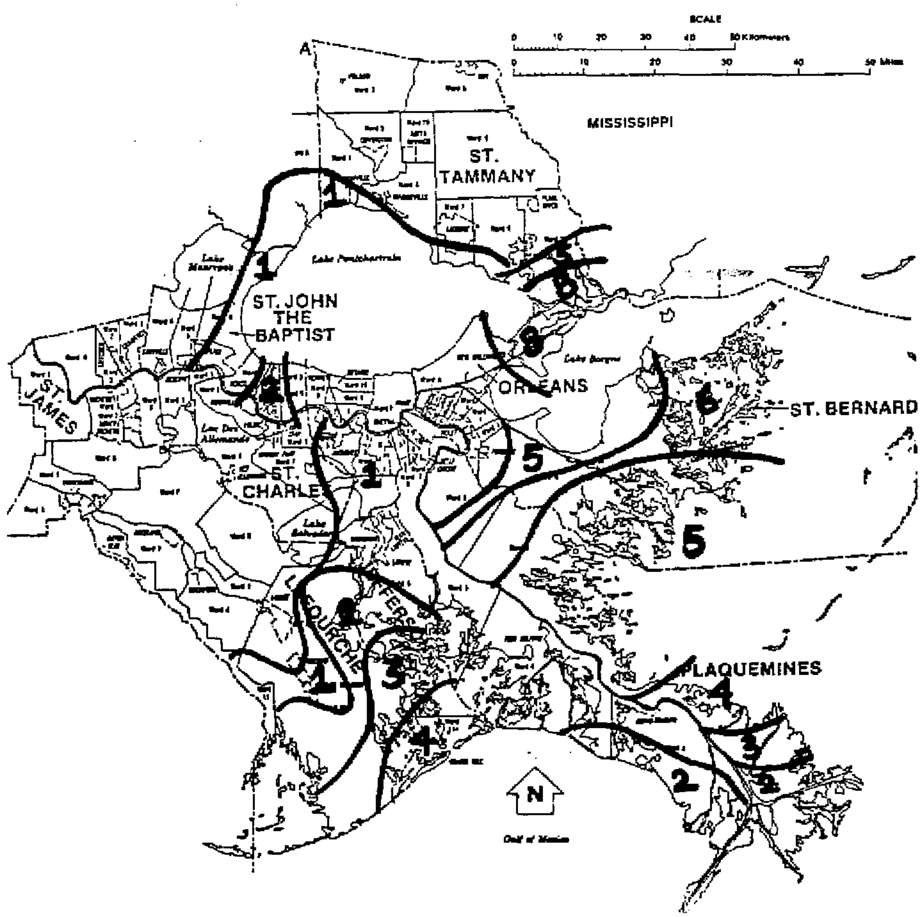

Figure 1
Surge Inundation Contours in Southeast Louisiana

In an ideal world, all that would be needed would be the communication of the hurricane's danger to the population at risk, and they would take prompt and effective preventive action--action usually interpreted in traditional emergency management as evacuation. Individuals would move to safe shelters sufficiently fast enough to prevent death and injury.

Obviously, this scenario is not realistic. The stimulus-response model is not applicable to the actions of individuals and families. Some persons do not receive warnings; some receive them but interpret them differently. For a variety of reasons, others may decide to stay. Enough people may decide to leave that they create unmanageable traffic congestion. Shelters may become crowded with people who forget to leave behind their pets and forget to bring their medicines. All the wonderful vagaries of life are displayed in disasters.

The implication for emergency management is tremendous. To achieve the goals of the various EM functions, the neat mapping of surge depths must be considered along with the "untidy" affairs of human beings. However, emergency management capabilities are limited.

Consider a manager weighing the possible effects of an approaching storm. It is obvious that persons faced with a possible 12-foot surge may not face the same risk as those faced with three feet of surge. However, the situation becomes more complicated if the latter persons receive the surge earlier or live in highly vulnerable mobile homes. Sheltering alternatives may be available for those at higher surge risk but not those at lesser risk. On the other hand, the lower risk individuals may be largely composed of groups that often do not receive warnings or misinterpret them, or groups that are more vulnerable to inundation (e.g., persons on life-support systems). Where should the emphasis be in such a case? An additional dimension of complexity can be introduced into this scenario by including the probability of specific disaster events. If there is a low probability of a catastrophic event that would require a massive effort versus a higher possibility of a relatively "minor" disaster, what scenario should be followed? Remember, uncertainty creates "a bias toward over-conservatism, toward routine ways to solve problems, toward doing nothing" (Mack, 1971, p. 5).

This uncertainty regarding the actions to be taken for varying hazard levels may be diminished if the cumulative knowledge of how persons, structures, and institutions respond is meshed with hazard levels. A strategy for this kind of surge planning has been proposed (Beriwal, 1985); it consists of an Emergency Management Scale for storm surge preparedness which attempts to relate every foot rise in surge depth to the expected corresponding problems in each of the EM functions. For example, an expected surge level of ten feet or greater may result in problems of disbelief among the warned populace, especially if the region has not experienced such a storm in recent memory. Additionally, a surge of ten feet has damage implications for "typical dwellings" and quite different implications for search and rescue operations. Thus, the type and intensity of emergency management efforts in areas should be dependent upon expected surge levels and the vulnerability of area structures and residents to the hazard.

Stepping back, other problems are apparent. For example, in the myriad of scenarios that might be necessary to cover the variety of conditions for a given hazard, how can a decision maker recognize the dimensions of the problem, the changing, shifting form of the developing emergency? With the proper technology at his/her fingertips, the right answers can be found if the right questions are formulated. In turn, the formulation of the right questions requires the recognition of emerging patterns and the ability to relate them to known or expected patterns. Such pattern recognition is a significant need: the use of simulation models and other emergency management strategies requires the comparison of actual reality and simulated reality. Thus, both hazard-specific and hazard-generic pattern recognition techniques need to be developed, and they must be incorporated into systems used at the local level. Without pattern recognition, the systems developed will not be implementable and will eventually be abandoned. This is one of the most intractable issues in emergency management and planning.

Information Triangle

The ideal EM system rests on the "information triangle." The three angles of the information triangle require that knowledge be collected, analyzed, and transmitted. The types of data to be collected and the methods of analysis have been briefly touched upon. Transmission of information to the correct agencies and persons requires an elaborate, interrelated EM system. A fully geographically and functionally integrated system may require upwards of 30,000 data links. Technology to create such a high-speed, high reliability data transmission network exists; however, willingness and resources to do so may not. The level of integrated planning and resource commitment that such a system would require will probably hinder its development.

The Role of Business Software

A relatively minor misunderstanding should be pointed out. In some quarters of the emergency management community there has been confusion over "emergency management software." The automation of emergency management has been equated with the use of generic, microcomputer-based software. These latter tools can offer some help and guidance in the performance of personnel record keeping, budgeting, program management, and other managerial tasks. However, they are designed to manage the routine, generic functions of particular businesses. The balancing of a budget, the keeping of neat records about personnel, and the creation of detailed breakdowns of the locations of resources would still not yield answers to most emergency management questions. Although business software can undoubtedly enhance the flow of paperwork in emergency management, it cannot substantially reduce uncertainty or promote learning.

Conclusions

Would an emergency management system as envisioned above be cost-prohibitive? The benefits have to be considered with a view to the losses. Natural hazards annually cost 1,000 lives. Costs associated with property losses, mitigation, preparedness, and response account for about 1% of the gross national product (Harriss, Hohenemser and Kates, 1978). Technological hazards have been estimated to account for 20 to 30% of all male deaths and 10 to 20% of all female deaths. The medical and other costs of these lives translate to 2.5 to 3.7% of GNP. Losses may total as much as $200 to $300 billion or 10 to 15% of the GNP (Tuller, 1978).

The advantages of automation are manifold. However, the most important benefit is the ability to view the problem in its many facets by combining elements in several different formats and presenting the results graphically, allowing decision makers to understand and absorb complex data. This is a critical need as the complexity of emergency conditions more and more requires managers to comprehend possible events and to design innovative solutions.

The systems now used inherently waste resources. Directing resources toward an integrated emergency management strategy would greatly increase system efficiency. Efforts to develop more "hard" information on emergency management and concurrent "software" would aid the transition phase. However, one note of caution should be sounded.

Innovation in Emergency Management

What are the questions to which the emergency manager needs answers? Questions as well as answers have not been explored to a great depth. Only recently have questions come into vogue about such things as evacuation time, differential response to warnings by various subgroups, probable distribution of death and injury by socioeconomic group and structural type. Even these inquiries yield clear-cut answers only if other complex and detailed questions are asked. The questions must consider a number of policy and semi-technical assumptions to derive single answers.

> At the start of any investigation it is necessary to choose whether one intends to be the prey of answers or of questions. If one elects to submit to answers, the questions must be such as to permit tidy (however complicated) answers. If on the other hand, the material is given free rein to find its way to the central questions, the answers will inevitably be less neat (Mack, 1971, p. vii).

Emergency management questions must come from the "right" brain. This constitutes the normative portion of emergency management, the art of emergency management. The possible answers to these questions, provided neatly and concisely, can come from the automated system using the "left brain." This creative synthesis is critical if the field is to progress to a science. The least important of all the links in an automated emergency management system is the hardware. Thoughtful, deliberate action is needed, not another massive effort to create and acquire technology.

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EFFECTIVE COMPUTER SYSTEMS FOR EMERGENCY MANAGEMENT

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Introduction

Computers are becoming essential components of both routine and emergency management systems. We can now greatly enhance our ability to assemble, evaluate, and communicate large amounts of information among individuals, agencies, and jurisdictions. This additional information enables us to make informed, objective decisions based on facts and assumptions which can be tested and verified. In emergency management, this technology has the potential of giving public officials the power to analyze a wide variety of hazards and manage a full range of resources while coping with an ever more populous and complex society.

Emergency Managers Require Effective Tools

Within our increasingly dynamic physical and social environment, emergency managers must prepare for extremes of nature as well as the acutely harmful by-products and events of humankind. The information they need regarding hazards, disaster impacts, response resources, preparedness measures, training activities, and recovery processes increases daily. Therefore, modern information processing technology must be used in emergency management to ensure effective emergency preparedness and response.

The priorities and tactics for maximizing personnel and other resources to respond adequately to a wide variety of possible disasters are extremely difficult to determine, and we lack experience in dealing with problems of such magnitude. Failure to do "what a reasonable person or organization would do" to prepare for expected natural or technological disasters could endanger citizens and expose government organizations and/or individual officials to liability and litigation.

Where improved government services are required (such as in emergency management) advanced technology, rather than increased staff, may be sufficient to define and address the problems. Many agencies of state and local government are now contemplating designing, acquiring, or otherwise implementing computer-based emergency management systems. Emergency management professionals should take advantage of this transition period to standardize maps, terminology, and other key elements of a potential unified federal/state/local system (see Figure 1). They should set technological standards but allow flexibility and not specify specific hardware or software. Each government entity could then use its own data bases, models, and simulations; but these could be freely communicated, evaluated, and applied or modified to fit other jurisdiction's hazards and priorities.

Computers Can Help Meet The Demands

Applying advanced technology to emergency management could result in many benefits:

- **Improving Efficiency In Day-To-Day Activities.** Many of the daily functions of all emergency offices rely upon ready access to information from various data bases, including resource inventories, legislation status reports, incident summaries, descriptions of available training, and status reports of state and local plans. In addition, word processing and spread sheet analysis is frequently required.

- **Meeting Mandated Legal Requirements.** Fulfilling an increasing number of legally mandated duties is being significantly hampered by the lack of adequate computer support within emergency services offices. Currently, systems for status tracking and records management are severely out of date in many programs. Development of centralized hazardous material incident and other reporting systems could greatly improve local response. Processing of federal disaster funds could also be improved.

- **Improving Effectiveness Of Emergency Planning.** Planning for any type of event, whether earthquake, tornado, or technological disaster, requires the consideration of secondary hazards such as fires or flooding, and interpretation of consequences on many different levels. Computer models could help both policy makers and operations planners address these difficult problems.
  Also, with efficient word processing and access to a variety of data bases, emergency plans could be maintained more easily. Indeed, modifications to all components of the emergency preparedness system could be made more rapidly.

- **Improving Delivery Of Emergency Services.** With improved data base management, emergency managers could better formulate and maintain resource inventories, emergency personnel rosters, damage assessments, and emergency event and message logs. In fact, they could better monitor the emergency situation as a whole and the corresponding dispatch of aid.

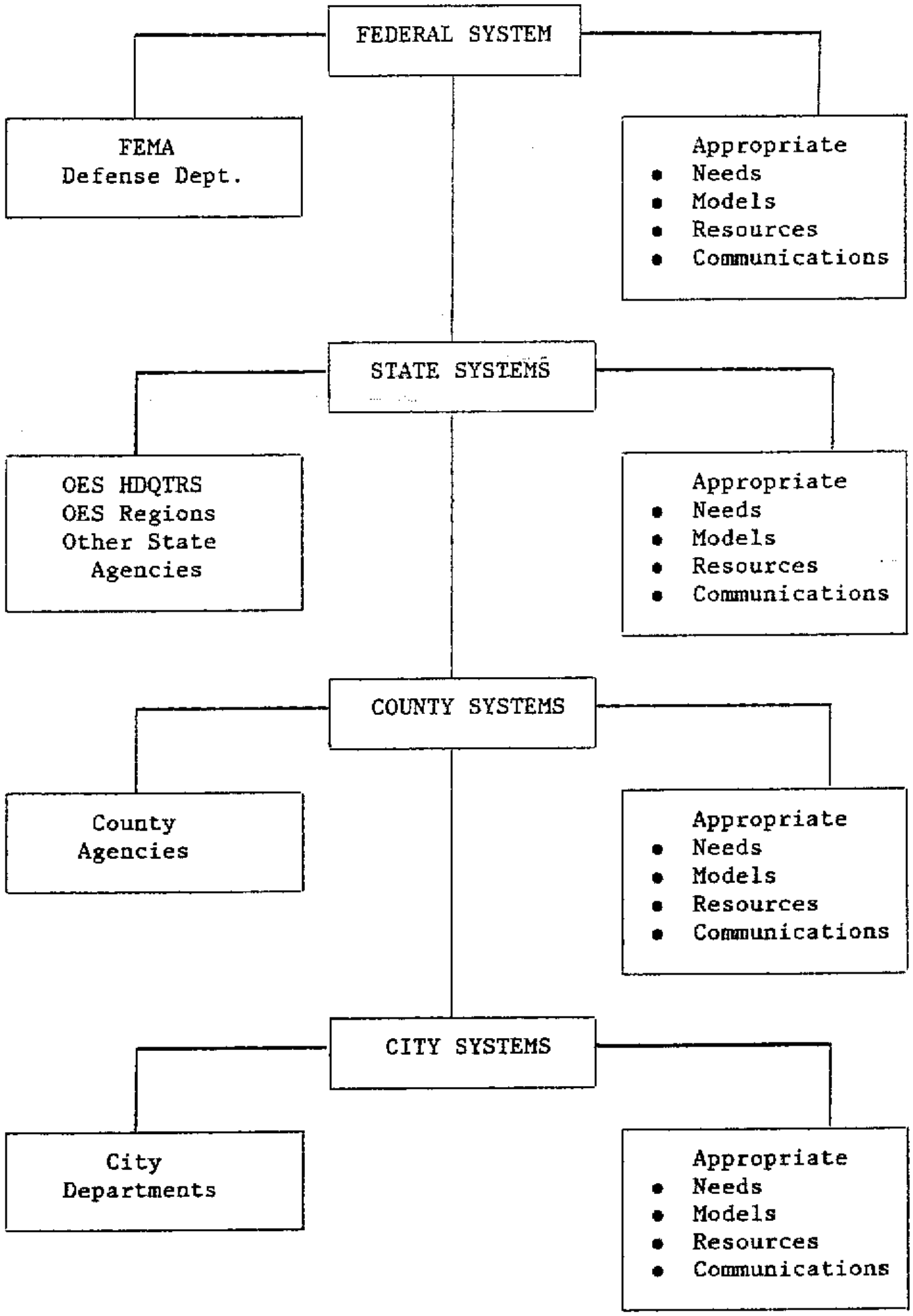

Figure 1
Proposed Computerized Information Coordination System

- **Improving Training Capabilities.** The ability to model and simulate in conjunction with access to large amounts of data could significantly improve training capabilities.
- **Making Emergency Operations Centers More Effective.** With the ability to track developing emergencies more easily and with access to data on damage and resources, the personnel staffing emergency operations centers will be able to manage responses more effectively. In addition, with more complete and objective information, decision makers will be able to better formulate policy.
- **Improving Coordination And Communication Among Jurisdictions.** By sharing data, governments will enhance coordination and promote comprehensive resource allocation at all levels.

CSTI Survey

The California Specialized Training Institute (CSTI) has conducted extensive research into the uses of computers in emergency management, current strengths and weaknesses of computer systems, and possible priorities for future systems development. A survey of 278 individuals and agencies conducted by CSTI in 1984 proves that interest in using computers for emergency management is extremely high, and that, although they do not know all of the specific possibilities, individuals involved with emergency services recognize that computers can help them.

The survey shows that most departments support the use of computers in emergency management. Yet, close to half of the agencies examined do not use computers in day-to-day operations. Additionally, only a few agencies use computers extensively (Figure 2).

Most microcomputers are designed for business and office operations. If emergency agencies simply use their machines to perform these day-to-day tasks, the microcomputer could ease much of the agencies' workload.

As Figure 3 demonstrates, most agencies are not using computers in either minor emergencies, major emergencies, or training exercises. There are several possible reasons for this:

1) Lack of training and/or knowledge in the use of computers has hampered progress in automation.
2) Fear of computers is inhibiting their incorporation into everyday office practice.
3) There is insufficient money to support full-time system design, implementation, maintenance, and upgrading.
4 Bureaucratic indecision is hampering the acquisition of necessary equipment (e.g., managers cannot decide what system(s) to invest in).

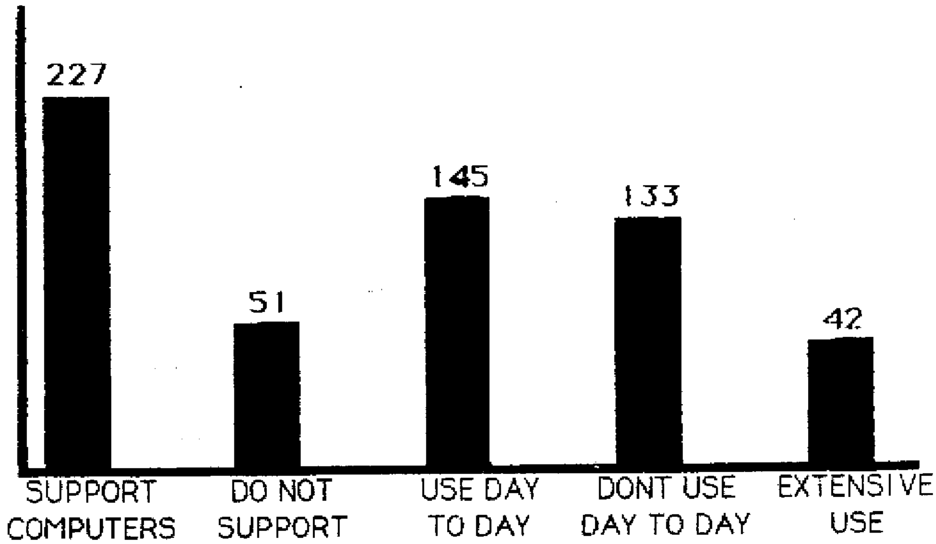

Figure 2
Agencies' Attitudes Toward and Use of Computers

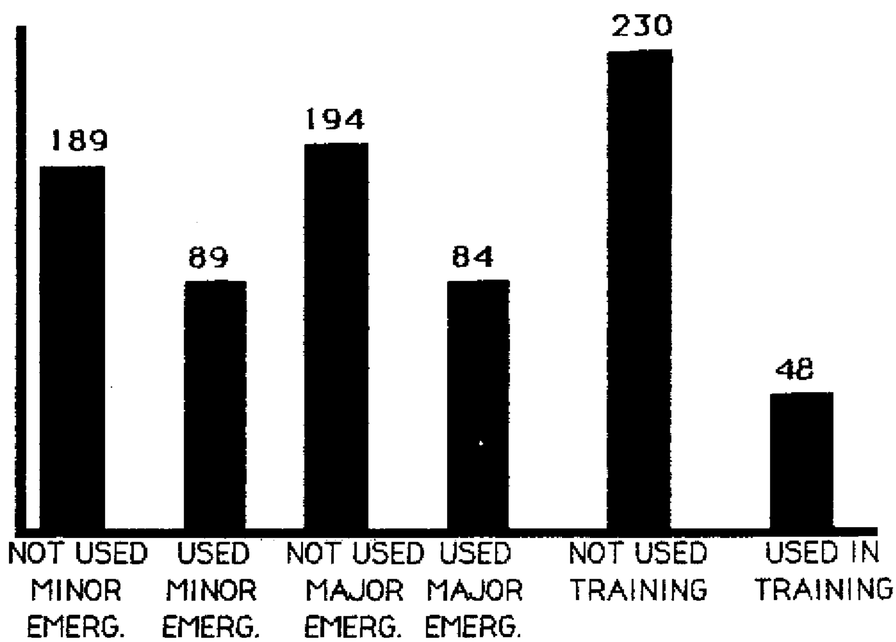

Figure 3
Utilization of Computers in Emergency Services

Current low computer usage could also possibly indicate that the computers now in service are too old (i.e., too small and too slow) to accomplish what is needed today, that the computer configurations being used are not flexible enough to accommodate changes or modifications in the agencies, that initially the systems were not correctly designed to support the functions of the agencies, or that the system is not properly maintained by a full-time analyst. (Over 68% of computer overall costs result from maintenance—both of hardware and software—with software requiring the greatest amount of upkeep.)

In particular, computers are not being used in training. This omission leads one to question the utility of existing systems and emergency plans, for, outside of actual emergency operations, it is only in training exercises that these systems are truly tested and shortfalls identified and corrected.

Figure 4 indicates the number of respondents using computers to perform six different functions. In no case do more than one-third of the agencies surveyed use a computer to perform an indicated function. Generally, resource

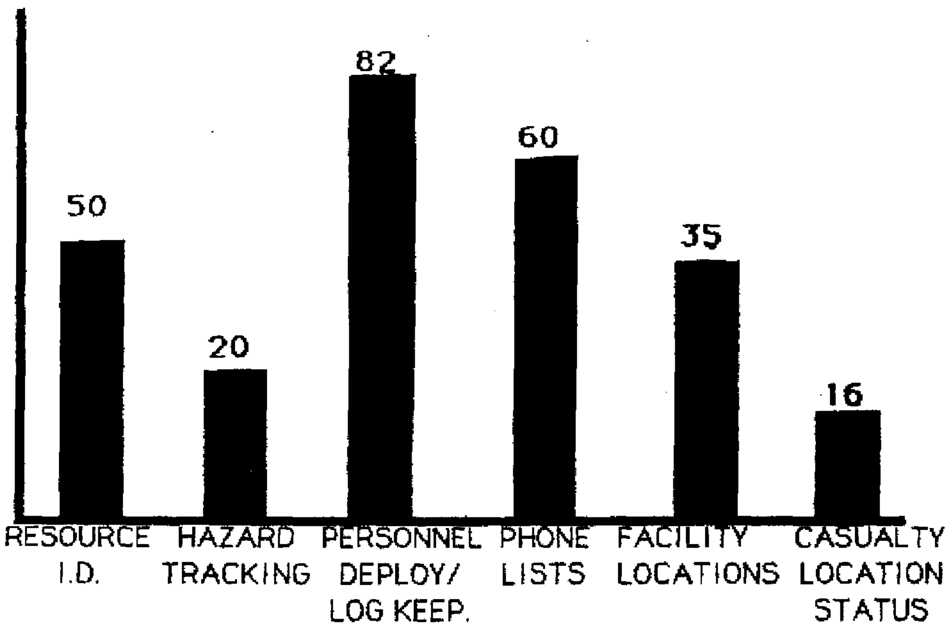

Figure 4
Usage of Computers

identification is one of the areas in which computers are most useful. The availability of good database software should encourage agencies to use that function. This did not prove to be true.

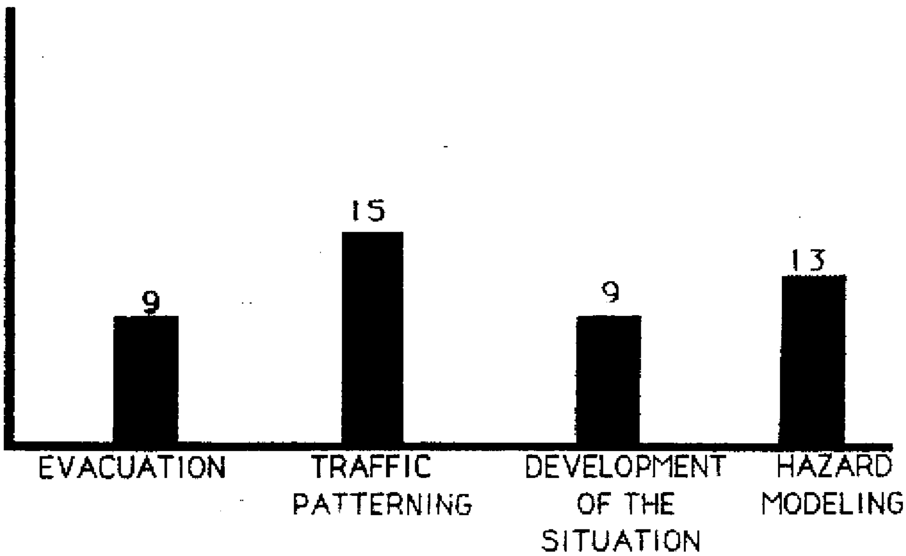

Figure 5
The Use of Computers for Modeling in Emergency Management

Few emergency management offices use computers for modeling (Figure 5). In part, this may be because modeling projects are often large and require mainframe or minicomputers. Microcomputers cannot handle the great number of instructions and large amount of data needed to generate sophisticated models. In addition, the high costs and specialized manpower needed to run such systems may also deter their use.

Common microcomputer software like word processors, spread sheets, database managers, and electronic mail could perform all of the functions indicated in Figure 6. The cost of hardware, software, and training to develop a computer system capable of performing these functions would not be great; thus, it is surprising that more agencies do not take advantage of already existing programs.

The survey also examined user attitude about their systems' effectiveness.

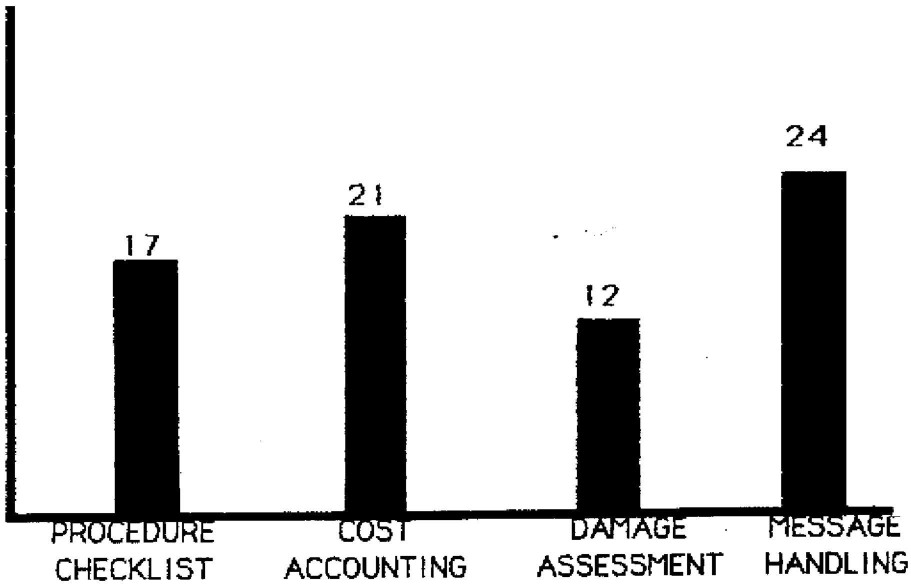

Figure 6
Application Software Usage in Emergency Management

The results show that the computers now being used in emergency management are rated by their users as only "average" in overall effectiveness. (This too maybe partly due to insufficient use of the computer in training exercises). Persons surveyed were also asked to rate the effectiveness of computers in emergency management in fifteen other specific areas. The results are shown in Figure 7.

Twenty-six percent of the agencies rate their computer's performance as only average. The highest rated computer systems are those that were designed by a sales representative and/or private consultant. However, the majority of the computer systems were designed by personnel internal to the agency. This may be one cause of the low opinion of existing computer systems. Those agencies that used sales representatives or independent dealers to set up their systems rate the system's performance higher than do those agencies who designed the systems themselves.

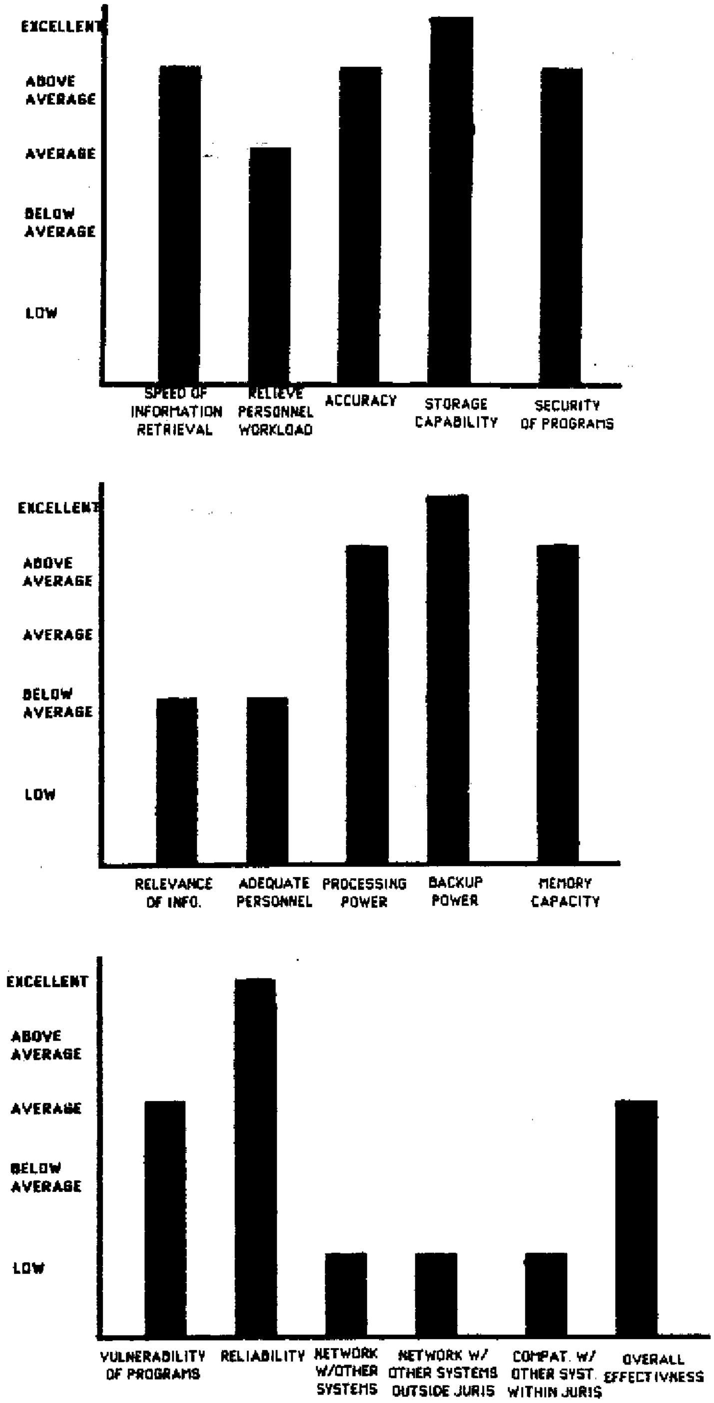

Figure 7
Levels of Effectiveness of Computers in Emergency Management

Additionally, those agencies that have personnel working on their systems full-time gain efficiency. Conversely, the less time a given person works on the computer the lower his/her efficiency. Unfortunately, only 22% of the agencies studied have a person working full-time with state-level agencies responsible for most of that 22%.

There is at least one bright spot, however. Seventy-one percent of the agencies plan on expanding their computer applications in the next five years. The prospect for the future of computers in emergency management is very good.

The Desirable Characteristics of An Emergency Management Computer System

Based on the California Specialized Training Institute's research that included not only the survey but also interviews with emergency service personnel and experts in the computer field, and based on the experience gained from conducting training and simulation exercises for over 30,000 emergency personnel, the institute's staff feels that a cost-effective computer system will be:

- **Capable of Handling Multiple Uses and Users.** The commitment of funds, resources, personnel, and time to develop a computer system dictates that the system be usable in all phases of emergency management—preparedness, mitigation, response, and recovery. Such continual usage would also promote data base updating and the maintenance of accuracy. Additionally, an ideal system would permit usage both from within the jurisdiction and from other levels of government.

- **Capable of Handling Integrated Programs.** The system would be able to run multiple functions without "reloading" programs. It would also be able to provide varying levels of detail depending on user needs.

- **Capable of Maximizing the Use of Existing Resources.** Hardware and software already owned by the agency or jurisdiction, available data bases, operating systems, and information resources would all be used as much as possible. Therefore there would be a strong need to communicate insights, procedures, and applications as they are developed in the emergency operations field. Limited resources would need to be as widely applicable as possible, and programs could not be overly specific or parochial.

- **Flexible.** The old method of carefully defining a specific problem and developing a system to exactly fill that need is today impracticable and costly. Agencies cannot discard whole computer systems and purchase new ones as new problems or solutions arise; the ideal technology therefore would be capable of adapting to new requirements.

- **Expandable.** A closely related characteristic of the computer system would be expandability. The system would be able to grow as requirements increase, and to connect with other sites on a regional, state, or national basis.

- **Modular.** An emergency operations office would be able to change or upgrade components to meet new requirements without having to purchase new software or an entire new "system."

- **User Friendly.** The relation of machine to human would permit the system to be used by any available person with a minimum of orientation. The output of the system would be in formats, such as graphic displays, that could be easily understood by decision makers in high-stress crisis situations.

How to Get It Done

There are two major obstacles to implementing modern information management systems. The first is persons who fear technological innovation and cannot envision real benefits from using computers. Yet, rather than turning citizens into automatons, computers will allow us to build emergency management services which will be more in tune with the real needs of the people.

The second obstacle is those persons who are so involved in organizing and manipulating data that they fail to apply their craft to reality. The best use of computers is to understand and appreciate human behavior and group dynamics in order to make emergencies less traumatic.

These impediments indicate that the first step in implementing a successful computerized system involves reaching a consensus, and thus an informed commitment, on the part of those involved in using the system. The commitment must acknowledge that computers will change the methods of emergency operations from now on, and that, in adopting computers, an emergency operations office is not engaging in a short-term, quick fix project, but one which will require specific efforts by individuals now and in the future. An organization taking this step must be willing to wager that this investment will allow a reduction in or more effective use of other resources.

These are serious decisions and should not be made without due consideration. In most organizations, no single individual can make the "best" decision; a small working group usually provides the best perspective. In addition, an implementation plan is a must. Communicating the plan and recognizing milestones will help promote acceptance.

Ten Years Down The Road

Ten years ago, "computer" meant "mainframe"—a large, centralized repository of data. Input was accomplished in the "batch" mode, primarily by using punched cards. Uses were either low-end (such as sorting and basic word processing) or high-end (such as such as solving complex design problems). Computers were primarily a technical, not a management, tool.

Ten years from now, computers will be essential and effective tools used by emergency managers. We will routinely assemble, study, and communicate large amounts of information; we will be able to make informed, objective decisions; we will be able to analyze a variety of hazards and manage a full range of resources; and, most importantly, we will be better able to prevent property loss and human suffering.

IMPROVING ORGANIZATIONAL DECISION-MAKING CAPACITY IN EMERGENCY MANAGEMENT: A DESIGN FOR AN INTERACTIVE EMERGENCY INFORMATION SYSTEM[1]

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The Problem: Information Processing in Emergency Management

Decision makers in emergency management operate under recurring problems caused by information overload. As the size and scale of an emergency escalate, the incoming information and demands for response repeatedly overwhelm the information processing capacity of the emergency response system and the emergency service personnel who are responsible for directing public action (Comfort, 1985b). This is a critical problem in emergency management, because the effectiveness of decisions made and actions taken depends directly upon the currency, accuracy, and completeness of the information available to decision makers. While uncertainty is inherent in the unpredictable nature of emergencies, a primary means of improving the effectiveness of organizational decision making in emergency management is to design an emergency information system that fits the conditions of the problem and the needs of the decision makers.

The characteristics of decision making under emergency conditions make the design of an appropriate information system a severe challenge. The problems to be managed are ill-structured; environmental conditions are rapidly changing and dynamic; complex interactions are triggered within and between organizations; solutions may be unavailable or uncertain; and the simultaneous occurrence of multiple incidents requiring emergency response generates a cumulative buildup of demands upon the decision making system that inevitably contributes to delay and error in response (Comfort, 1985b). These conditions are usually

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magnified by a scarcity of resources at local jurisdictional levels and the urgency posed by life-threatening events. For example, when a metropolitan area experiencing rapid population growth and a related increase in high-risk technologies that produce toxic waste is suddenly exposed to a severe natural disaster such as an earthquake, unanticipated chain reactions can escalate into 'system failure' and become truly catastrophic (Perrow, 1984). It is the interaction between populations, technology, and environmental hazards that has produced a sobering potential for large disasters in our increasingly interdependent society (Perrow, 1984).

Not only is there a marked increase in the number and complexity of demands made upon decision makers under emergency conditions; additionally, the ability of humans to process the information needed to manage complexity tends to decrease under stress (Mitchell, 1983). The 'bounded rationality' of human decision makers, given limited, short-term memories, is rapidly exceeded by the information demands of complex emergency events (Simon, 1981). Given the responsibilities of public service personnel, these problems compel a continuing search for means to maximize effectiveness and reduce error in emergency management. Current information processing technology offers a promising means for extending the 'memory' or knowledge base of decision makers involved in emergency operations and for managing systematically the information essential to timely and appropriate decision making under the dynamic conditions of emergency events. This paper proposes a design for an interactive information processing system to support public decision makers in emergency management. This system focuses on earthquake preparedness in California and utilizes computers to facilitate both information processing and user interaction. A preliminary design for a knowledge base and set of information search processes for problem solving is proposed for a city. However this could be the initial step in building a larger emergency information system that may be extended to other jurisdictions within the state and eventually to other states within the region and the nation.

The Goal of the Emergency Information System

The goal of the system is to provide a base of knowledge and interactive information support for working decision makers in emergency management. The system will serve as a vehicle for organizing the relevant knowledge needed for emergency decision making for a given jurisdiction. It will present that information in a standard format that is easily accessible by multiple decision makers at multiple locations. Accomplishing this task will facilitate a secondary function essential to effective emergency management--the coordination of action within and between multiple organizations having complementary responsibilities for a given jurisdiction in the event of a major disaster.

This information system will be more restricted than the recognized 'expert' systems. It is not intended to 'replace' human problem solvers with machines, but rather to use machines to extend the capacity of humans operating under conditions of complexity and stress. Nor is the goal of this system to model the problem solving processes of 'expert' decision makers, as undertaken in other policy areas (see for example, McDermott, 1980, 1981; Van Melle, Shortliffe, and Buchanan, 1981; Pople, 1981). In emergency management, problems are too massive, participants are too many, and the conditions are too variable to allow the determination of undisputed experts in the field. Yet the underlying assumption of this system is the same as for the 'expert' systems--that is, "knowledge is power" (Hayes-Roth, Waterman, and Lenat, 1983). By making the relevant information available to public service personnel in a timely, interactive way, the system will likely increase the power of decision makers to make appropriate choices. In turn, as interaction with the system increases the capacity of individual decision makers to take informed action, the effect, synergistically, will likely be to increase the power of the entire emergency system in that jurisdiction to effectively respond.

The Design of the Emergency Information System

In considering the design of an information system using artificial intelligence concepts and technology, Edward Feigenbaum (1980) identifies three issues as central to successful application in the field. These issues are: 1) knowledge acquisition, 2) knowledge representation, and 3) knowledge utilization (Feigenbaum, 1980, p. 2). The issues are interrelated, but will be discussed individually in reference to the design of the proposed emergency information system. Nonetheless, a primary objective drives the design of this emergency information system and serves to integrate the three issues: the system is designed for use by those actually administering emergency services.

Knowledge Acquisition

Building an information system for use by practicing service personnel optimally involves those personnel in the collection and organization of information to be stored in the system's knowledge base (Hayes-Roth, Waterman, and Lenat, 1983, p. 245). This axiom is particularly applicable in the field of emergency services, where much of the relevant knowledge for a given jurisdiction resides in the collective memories of experienced personnel in specific agencies, but may not be known across agency lines. This knowledge needs to be explicated and summarized in a form that can be used easily and systematically by other personnel in the jurisdiction. Since multiple users having complementary emergency responsibilities at multiple locations are involved, it is essential that the knowledge be compiled clearly and uniformly, using terminology and formats understandable to all users. The design of an emergency information system provides a valuable opportunity to collect and organize the relevant information extant in a given community and to analyze the processes of emergency problem solving.

In the design of the emergency information system, it is proposed that a series of simulated emergency operations exercises be used to gather the initial body of knowledge. The simulation exercises may be conducted in conjunction with the legally mandated training required of public agencies with emergency responsibilities (Federal Emergency Management Agency, 1981). Such exercises are a familiar means for training emergency service personnel and are supported by the Federal Emergency Management Agency. By using an already recognized professional development activity for the acquisition of knowledge, potential users can be involved in the design of the system, and the best knowledge available for a given jurisdiction can be obtained. The participants in the exercise will include all personnel from the jurisdiction who have major emergency responsibilities, as well as relevant personnel from county, state, or federal agencies who may participate on an advisory basis.

Prior to the scheduled simulation, each participant will be given a model of the emergency information system and will be asked to provide the relevant information for his/her agency. In a preparatory session, participants will be given the opportunity to review the model, its design, its representation of knowledge, and its inference or problem solving processes. Participants may suggest changes or clarifications which, with the consensus of the group, will be incorporated into the system. Information gained through this process will then be programmed into a preliminary information system to be used in the simulation exercise.

The simulation will use the scenario of a catastrophic earthquake in

California. A similar event could be used in different geographic, social, and economic settings to investigate different kinds of problems which, nonetheless, would still involve the primary goals of emergency response: protection of life and property and the prompt restoration of civil order and public services. During the simulation, the number, order, and complexity of problems introduced into the collective emergency decision making process will be monitored closely in order to track the strategies developed by the participants and to assess the favorableness of decisions actually taken.

After the simulation exercise, in a post-operations review, all participants will be given the results of their performance. Each participant will be asked to review systematically the kinds of information that decision makers needed, what sources they wanted to consult, what formats they wanted and when they wanted them. These findings will then be used to modify and correct the initial knowledge base for use in a second simulation.

Knowledge Representation

Knowledge representation in the design of this emergency information system is critical from two perspectives. For the users, it is important that the knowledge be organized in a form that can be easily understood by them and quickly accessed to meet their needs in emergency operations. For the computer, to ensure ease, efficiency, and speed in computation, it is important that the data structures fit the problem solving tasks involved as appropriately as possible (Feigenbaum, 1980, p. 2). An initial schema for organizing the knowledge required for an emergency information system for a city jurisdiction is presented in Figure 1. The technical computer specifications of the data structures are beyond the scope of this essay. Figure 1 presents, rather, the kinds of knowledge needed and the search processes defined by standard emergency operations procedures. It serves as a preliminary plan for ordering the data and identifying the processing tasks, from which a set of technical procedures for representing the data within the computer can be specified. It assumes a 'blackboard' architecture (Nii, 1980; Hayes-Roth, B., 1983; Hayes-Roth, Waterman and Lenat, 1983), that permits separate knowledge sources to interact with the global database as the the emergency progresses temporally.

The knowledge to be stored in the computer is organized in separate units corresponding to the organizations which have responsibilities under the jurisdiction's emergency plan. These organizations all have information regarding

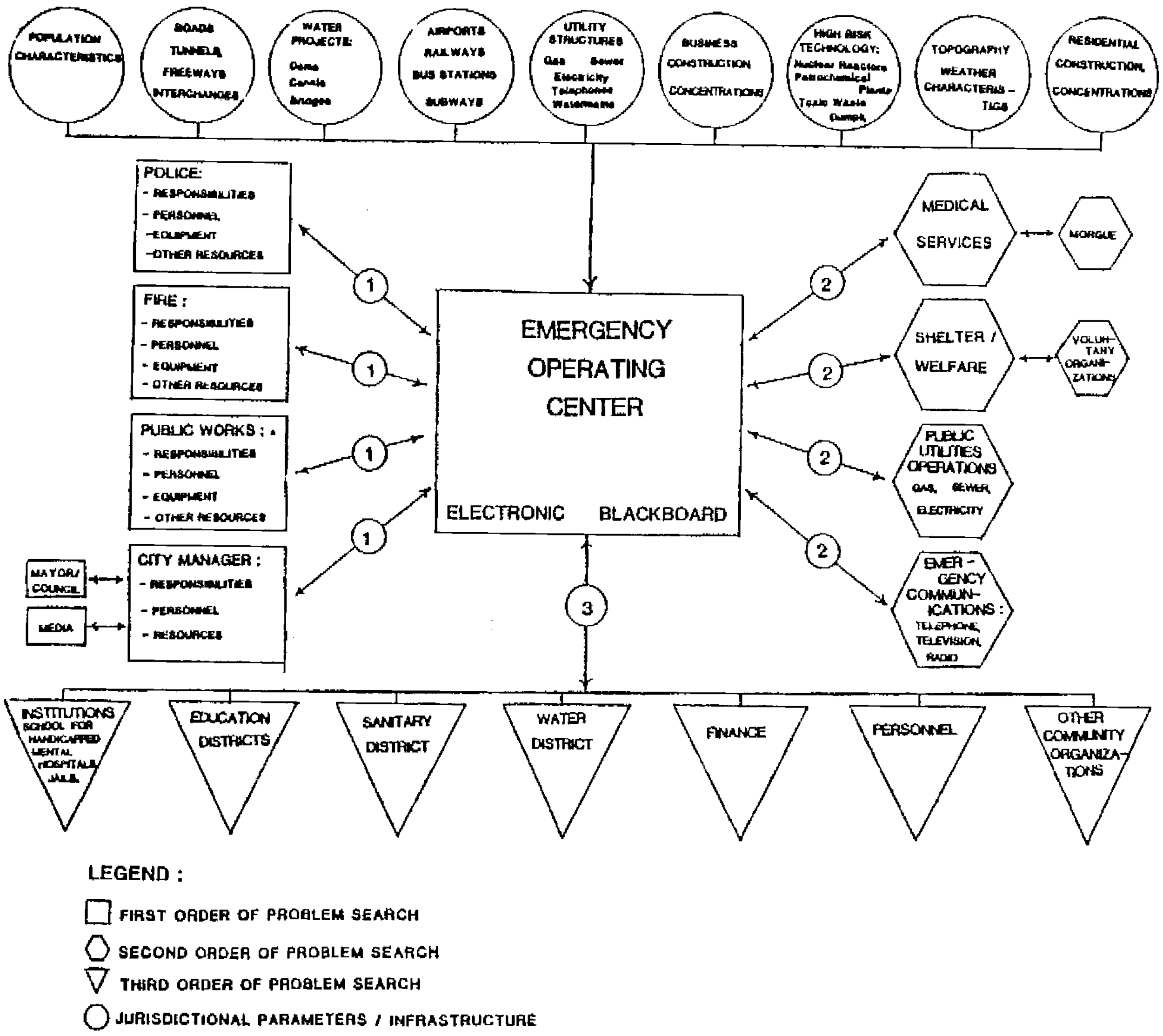

Figure 1
Emergency Information System Schema

their specific responsibilities, personnel, equipment, and other resources which can be stored in the computer. Three orders of priority for problem search and identification are specified to be followed in the event of an actual emergency. These priorities are shown in Figure 1, with the first order listing of organizations at the left of the diagram, the second order listing at the right of the diagram, and the third order listing across the bottom of the diagram. All organizations will have members participating actively during the simulation exercise and interacting with the 'blackboard' or global data base to request information, enter new information, or initiate search strategies for problem solutions.

Across the top of the diagram are types of information about the population and infrastructure of the jurisdiction which serve as limiting parameters for the kinds of solutions to emergency problems that can be designed for that specific jurisdiction. Included in this information will be hazard assessment data which estimate the vulnerability of the jurisdiction's infrastructure to varying severities of earthquake.

The 'blackboard' is shown in detail in Figure 2. It will correspond, in emergency management terms, to the Emergency Operating Center (EOC). That is, all critical information regarding the progress of the emergency will be reported to the EOC and entered into the emergency information system to be recorded on the 'blackboard'. The blackboard will serve as the global data base for the system. It will record, search for, and identify possible strategies for action in response to problems posed, given the existing parameters of the jurisdiction. It will also monitor the status of actions taken and record the problems that have been solved or stabilized. The 'blackboard' will be organized into five distinct units. First, the 'plan', will represent the emergency plan for the given jurisdiction, its goals, objectives, operating procedures, and assigned responsibilities. Second, the 'agenda for action' will list the specific incidents, arranged according to the emergency plan priorities, requiring response. Third, 'decisions taken' for allocation of resources, personnel, and equipment in response to emergency requests will be recorded, with provision for updating the status of these actions as new information is reported from the field. Fourth, all problems which have been reported 'solved or stabilized' will be recorded and removed from the agenda or record of actions in process. Fifth, and very important to the functioning of

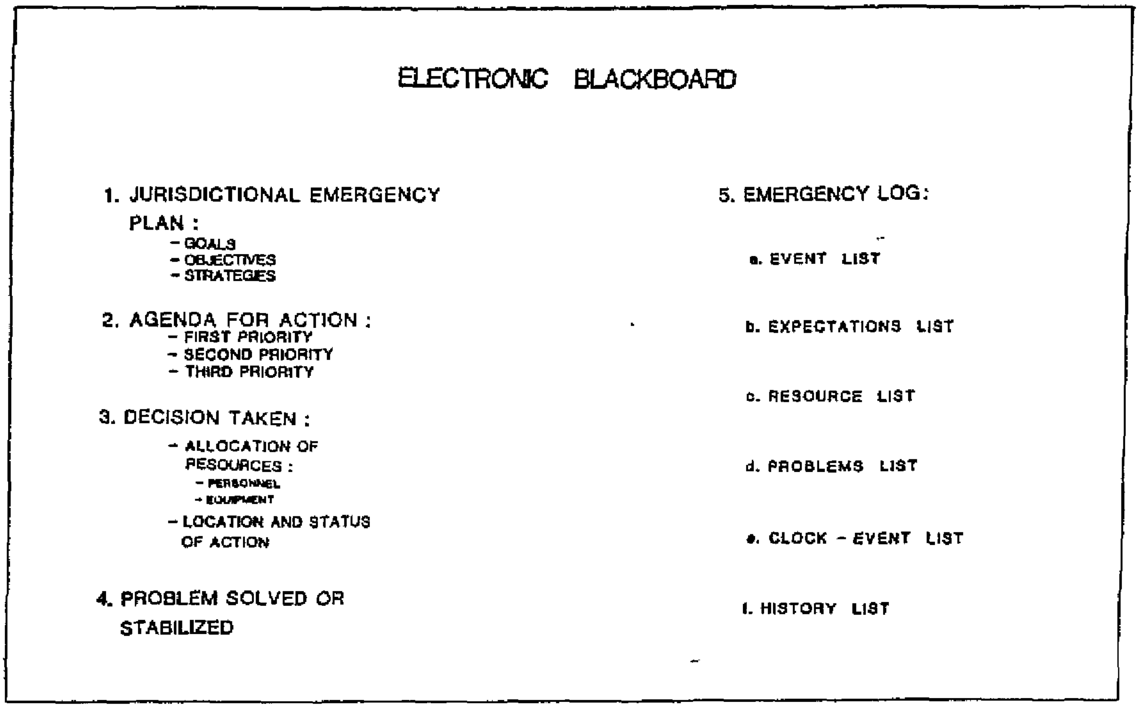

Figure 2
Emergency Information System Electronic Blackboard

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the blackboard, is the continuous 'log' of emergency events and developments. This log will contain six separate lists[2], all vital in monitoring the progress of the emergency. They include:

- **Event List:** This list will record all events reported to the Emergency Operating Center during the emergency. The agenda for action will be set from this continually changing list.

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[2] This log is adapted from a similar set of lists that H. Penny Nii (1980, pp. 16-17) included in her discussion of the blackboard model. Ms. Nii's model focused on information about the system needed for computer processing. This set of lists specifies information needed for monitoring the progress of the emergency as well as the operation of the system.

- **Expectations List:** This list will combine information entered during the emergency with data regarding the jurisdiction's parameters in order to generate expectations about possible hazards to be detected and confirmed.

- **Resource List:** During the emergency, multiple decision makers allocate resources from their respective agencies to multiple locations. This list will monitor which resources are allocated to which locations and report the remaining available resources for the entire jurisdiction.

- **Problems List:** This list will contain a description of the various problems encountered by the stored information units or "knowledge sources" in responding to search requests and will list information needed from the user in order to complete the search.

- **Clock-Events List:** Because emergency events may change rapidly with time, this list will post check lists, for specific knowledge sources or organizational units, to be reviewed periodically against incoming information. The postings will serve as a timely reminder for operating emergency personnel to check the status of their immediate responsibilities.

- **History List:** This list will record all processing actions performed by the computer during the course of the emergency. It will serve both as a record of emergency events and of the strategies undertaken to meet the demands made upon the emergency system. It will be very useful in evaluating both the performance of the emergency information system and the action strategies developed by the emergency service personnel.

Again, the data structures for storing knowledge in the computer will have to be specified technically and in detail. Figures 1 and 2 represent only the kinds of knowledge that are needed in a comprehensive emergency information system.

Knowledge Utilization

In artificial intelligence, 'knowledge utilization' defines the set of inference processes used within the information system. In 'expert' systems, the intent is to model the information search and synthesis processes of the computer after the reasoning processes of experienced professionals in the field (Hayes-Roth, Waterman and Lenat, 1983). The primary task for decision makers operating in emergencies is the management of complexity under rapidly changing conditions. However, that complexity and the stress of the operating environment tends to overwhelm the decision making processes of public service personnel trained to perform under more normal conditions. In these circumstances, an emergency information system makes interorganizational decision making feasible—a process heretofore elusive due to the previously mentioned bounded rationality of human decision makers (Simon, 1969, 1981). The capacity of the computer to process simultaneously and systematically large amounts of information makes it possible for humans to base their decisions on more complete and comprehensive evidence than previously considered.

The research findings of Michael Cohen (1981, 1984) indicate that at least two strategies contribute significantly to increased effectiveness in decision making under conditions of complexity. First, information search processes conducted in parallel resulted in more timely, accurate, and effective decisions (Cohen, 1981); identification of error occurred earlier, and modifications in actions taken, based on the correction of discovered error, tended to produce more substantive results. Cohen (1984) also found that decisions made by multiple centers with shared authority resulted in more appropriate decisions than those made by a single center with global authority. While these findings were produced by a computer simulation and have not yet been replicated in human decision making environments, they suggest that the use of these two strategies--parallel information searching and sending and receiving information from multiple centers simultaneously while adjusting the global base of information accordingly--may greatly enhance the capacity of human decision makers to function in complex environments. Both of these strategies are incorporated in the blackboard architecture for the computer outlined above.

The appropriate set of inference processes for an emergency information system will likely include a mixed strategy of heuristics and decision rules (Buchanan and Duda, 1982). This strategy will need to fit the operational dynamics of emergency conditions as closely as possible. The specifications for these inference processes will have to be carefully formulated; the capacity of the computer will have to be matched to the demands of the emergency operating environment, and the system will have to incorporate the known reasoning strategies developed by experienced professionals in the field.

Towards a Working Emergency Information System

Other issues, such as system implementation, monitoring, and maintenance, need to be carefully considered in the development of a fully functioning, effective emergency information system. The steps proposed in this paper represent only the initial stages in the design, development, implementation, and evaluation of such a system. The next stage involves identifying a jurisdiction and a group of practicing public service personnel with emergency responsibilities who are willing to engage in the simulated emergency operations exercise and the data collection activities needed to create the knowledge base for their jurisdiction. The technology is currently available to extend the organizational memory of a given city or jurisdiction in ways that can significantly improve the performance of emergency operations. Deciding to develop such a system, however, is a significant personal and professional commitment.

Summary

In practical terms, the design and implementation of an interactive emergency information system offers great promise for the practicing community of emergency service personnel. With relatively little expenditure of time and money, the development of a working system is likely to result in a substantial improvement in emergency operations. As multiple jurisdictions adopt and develop compatible emergency information systems, a constructive and beneficial integrated emergency management network can be formed. The cumulative effect of such an interactive network will be to increase the relevant information and professional knowledge available to participating public service personnel, and thus to reduce uncertainty in emergency operations. While emergency information systems are clearly subject to some human error, they offer a significant opportunity for increasing the capacity of organizations and governments to make decisions during emergencies.

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The simulation will use the scenario of a catastrophic earthquake in

California. A similar event could be used in different geographic, social, and economic settings to investigate different kinds of problems which, nonetheless, would still involve the primary goals of emergency response: protection of life and property and the prompt restoration of civil order and public services. During the simulation, the number, order, and complexity of problems introduced into the collective emergency decision making process will be monitored closely in order to track the strategies developed by the participants and to assess the favorableness of decisions actually taken.

After the simulation exercise, in a post-operations review, all participants will be given the results of their performance. Each participant will be asked to review systematically the kinds of information that decision makers needed, what sources they wanted to consult, what formats they wanted and when they wanted them. These findings will then be used to modify and correct the initial knowledge base for use in a second simulation.

Knowledge Representation

Knowledge representation in the design of this emergency information system is critical from two perspectives. For the users, it is important that the knowledge be organized in a form that can be easily understood by them and quickly accessed to meet their needs in emergency operations. For the computer, to ensure ease, efficiency, and speed in computation, it is important that the data structures fit the problem solving tasks involved as appropriately as possible (Feigenbaum, 1980, p. 2). An initial schema for organizing the knowledge required for an emergency information system for a city jurisdiction is presented in Figure 1. The technical computer specifications of the data structures are beyond the scope of this essay. Figure 1 presents, rather, the kinds of knowledge needed and the search processes defined by standard emergency operations procedures. It serves as a preliminary plan for ordering the data and identifying the processing tasks, from which a set of technical procedures for representing the data within the computer can be specified. It assumes a 'blackboard' architecture (Nii, 1980; Hayes-Roth, B., 1983; Hayes-Roth, Waterman and Lenat, 1983), that permits separate knowledge sources to interact with the global database as the the emergency progresses temporally.

The knowledge to be stored in the computer is organized in separate units corresponding to the organizations which have responsibilities under the jurisdiction's emergency plan. These organizations all have information regarding

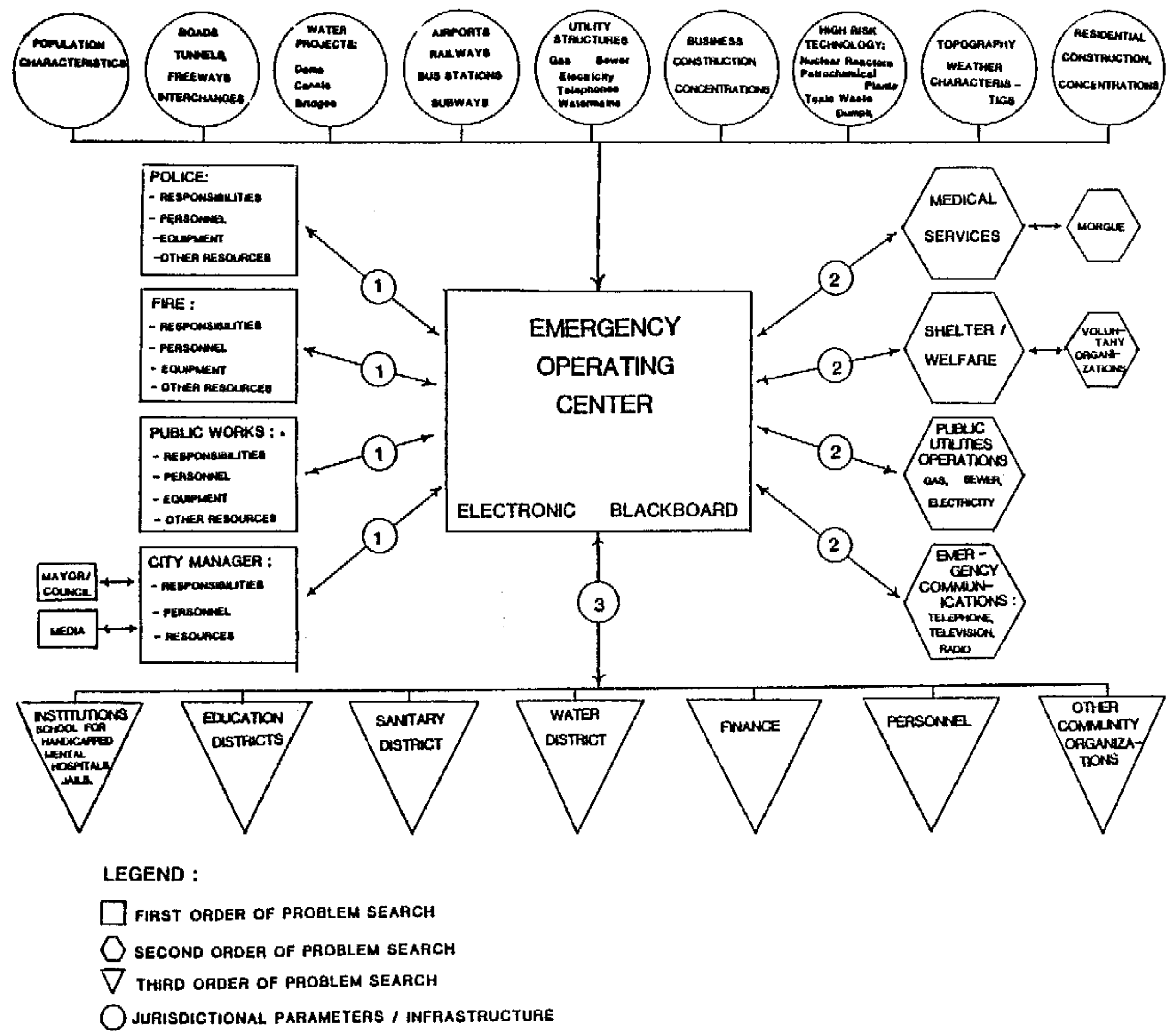

Figure 1
Emergency Information System Schema

their specific responsibilities, personnel, equipment, and other resources which can be stored in the computer. Three orders of priority for problem search and identification are specified to be followed in the event of an actual emergency. These priorities are shown in Figure 1, with the first order listing of organizations at the left of the diagram, the second order listing at the right of the diagram, and the third order listing across the bottom of the diagram. All organizations will have members participating actively during the simulation exercise and interacting with the 'blackboard' or global data base to request information, enter new information, or initiate search strategies for problem solutions.

Across the top of the diagram are types of information about the population and infrastructure of the jurisdiction which serve as limiting parameters for the kinds of solutions to emergency problems that can be designed for that specific jurisdiction. Included in this information will be hazard assessment data which estimate the vulnerability of the jurisdiction's infrastructure to varying severities of earthquake.

The 'blackboard' is shown in detail in Figure 2. It will correspond, in emergency management terms, to the Emergency Operating Center (EOC). That is, all critical information regarding the progress of the emergency will be reported to the EOC and entered into the emergency information system to be recorded on the 'blackboard'. The blackboard will serve as the global data base for the system. It will record, search for, and identify possible strategies for action in response to problems posed, given the existing parameters of the jurisdiction. It will also monitor the status of actions taken and record the problems that have been solved or stabilized. The 'blackboard' will be organized into five distinct units. First, the 'plan', will represent the emergency plan for the given jurisdiction, its goals, objectives, operating procedures, and assigned responsibilities. Second, the 'agenda for action' will list the specific incidents, arranged according to the emergency plan priorities, requiring response. Third, 'decisions taken' for allocation of resources, personnel, and equipment in response to emergency requests will be recorded, with provision for updating the status of these actions as new information is reported from the field. Fourth, all problems which have been reported 'solved or stabilized' will be recorded and removed from the agenda or record of actions in process. Fifth, and very important to the functioning of

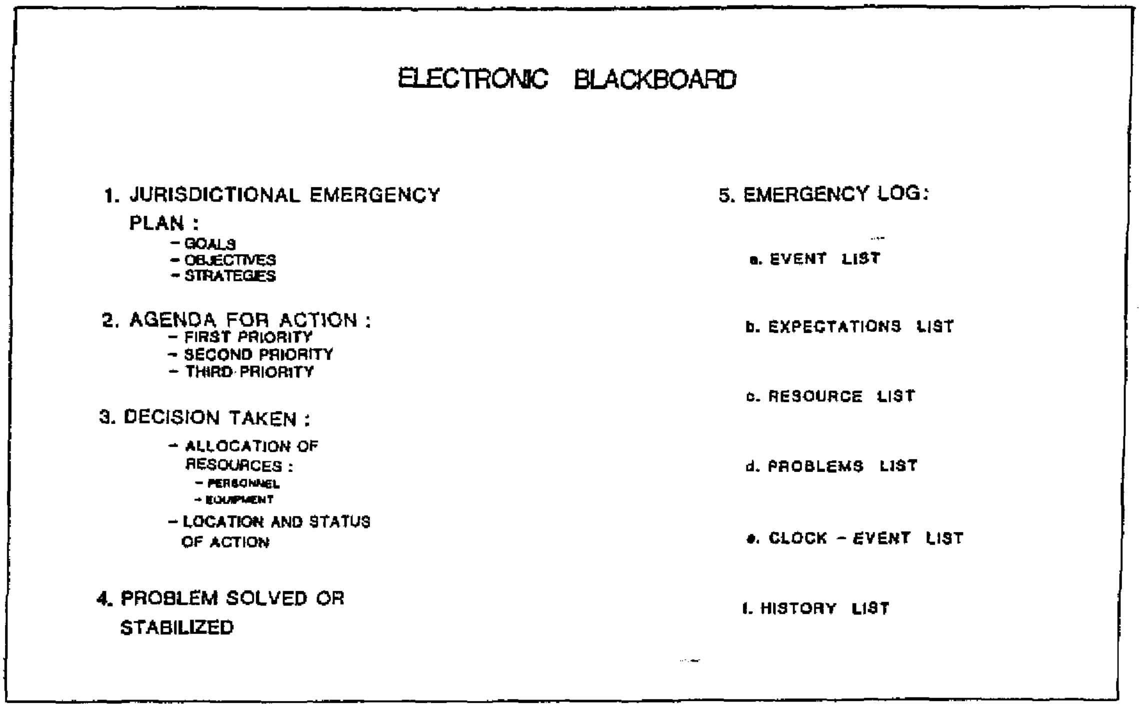

Figure 2
Emergency Information System Electronic Blackboard

the blackboard, is the continuous 'log' of emergency events and developments. This log will contain six separate lists[2], all vital in monitoring the progress of the emergency. They include:

- Event List: This list will record all events reported to the Emergency Operating Center during the emergency. The agenda for action will be set from this continually changing list.

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[2] This log is adapted from a similar set of lists that H. Penny Nii (1980, pp. 16-17) included in her discussion of the blackboard model. Ms. Nii's model focused on information about the system needed for computer processing. This set of lists specifies information needed for monitoring the progress of the emergency as well as the operation of the system.

- **Expectations List:** This list will combine information entered during the emergency with data regarding the jurisdiction's parameters in order to generate expectations about possible hazards to be detected and confirmed.

- **Resource List:** During the emergency, multiple decision makers allocate resources from their respective agencies to multiple locations. This list will monitor which resources are allocated to which locations and report the remaining available resources for the entire jurisdiction.

- **Problems List:** This list will contain a description of the various problems encountered by the stored information units or "knowledge sources" in responding to search requests and will list information needed from the user in order to complete the search.

- **Clock-Events List:** Because emergency events may change rapidly with time, this list will post check lists, for specific knowledge sources or organizational units, to be reviewed periodically against incoming information. The postings will serve as a timely reminder for operating emergency personnel to check the status of their immediate responsibilities.

- **History List:** This list will record all processing actions performed by the computer during the course of the emergency. It will serve both as a record of emergency events and of the strategies undertaken to meet the demands made upon the emergency system. It will be very useful in evaluating both the performance of the emergency information system and the action strategies developed by the emergency service personnel.

Again, the data structures for storing knowledge in the computer will have to be specified technically and in detail. Figures 1 and 2 represent only the kinds of knowledge that are needed in a comprehensive emergency information system.

Knowledge Utilization

In artificial intelligence, 'knowledge utilization' defines the set of inference processes used within the information system. In 'expert' systems, the intent is to model the information search and synthesis processes of the computer after the reasoning processes of experienced professionals in the field (Hayes-Roth, Waterman and Lenat, 1983). The primary task for decision makers operating in emergencies is the management of complexity under rapidly changing conditions. However, that complexity and the stress of the operating environment tends to overwhelm the decision making processes of public service personnel trained to perform under more normal conditions. In these circumstances, an emergency information system makes interorganizational decision making feasible—a process heretofore elusive due to the previously mentioned bounded rationality of human decision makers (Simon, 1969, 1981). The capacity of the computer to process simultaneously and systematically large amounts of information makes it possible for humans to base their decisions on more complete and comprehensive evidence than previously considered.

The research findings of Michael Cohen (1981, 1984) indicate that at least two strategies contribute significantly to increased effectiveness in decision making under conditions of complexity. First, information search processes conducted in parallel resulted in more timely, accurate, and effective decisions (Cohen, 1981); identification of error occurred earlier, and modifications in actions taken, based on the correction of discovered error, tended to produce more substantive results. Cohen (1984) also found that decisions made by multiple centers with shared authority resulted in more appropriate decisions than those made by a single center with global authority. While these findings were produced by a computer simulation and have not yet been replicated in human decision making environments, they suggest that the use of these two strategies--parallel information searching and sending and receiving information from multiple centers simultaneously while adjusting the global base of information accordingly--may greatly enhance the capacity of human decision makers to function in complex environments. Both of these strategies are incorporated in the blackboard architecture for the computer outlined above.

The appropriate set of inference processes for an emergency information system will likely include a mixed strategy of heuristics and decision rules (Buchanan and Duda, 1982). This strategy will need to fit the operational dynamics of emergency conditions as closely as possible. The specifications for these inference processes will have to be carefully formulated; the capacity of the computer will have to be matched to the demands of the emergency operating environment, and the system will have to incorporate the known reasoning strategies developed by experienced professionals in the field.

Towards a Working Emergency Information System

Other issues, such as system implementation, monitoring, and maintenance, need to be carefully considered in the development of a fully functioning, effective emergency information system. The steps proposed in this paper represent only the initial stages in the design, development, implementation, and evaluation of such a system. The next stage involves identifying a jurisdiction and a group of practicing public service personnel with emergency responsibilities who are willing to engage in the simulated emergency operations exercise and the data collection activities needed to create the knowledge base for their jurisdiction. The technology is currently available to extend the organizational memory of a given city or jurisdiction in ways that can significantly improve the performance of emergency operations. Deciding to develop such a system, however, is a significant personal and professional commitment.

Summary

In practical terms, the design and implementation of an interactive emergency information system offers great promise for the practicing community of emergency service personnel. With relatively little expenditure of time and money, the development of a working system is likely to result in a substantial improvement in emergency operations. As multiple jurisdictions adopt and develop compatible emergency information systems, a constructive and beneficial integrated emergency management network can be formed. The cumulative effect of such an interactive network will be to increase the relevant information and professional knowledge available to participating public service personnel, and thus to reduce uncertainty in emergency operations. While emergency information systems are clearly subject to some human error, they offer a significant opportunity for increasing the capacity of organizations and governments to make decisions during emergencies.

Acknowledgements

The author wishes to acknowledge with warm thanks, the thoughtful comments of my colleague, Michael Gold, on the draft manuscript of this essay. I also wish to thank Lotfi Zadeh and John McDermott for guidance on the current literature on expert systems; Nicholas Caruso and Lucy Thomas, librarians at GSPIA for their assistance in obtaining the relevant materials, and Gary Roberts for his diligent assistance in the research for this paper.

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EXPERT SYSTEMS AS DECISION AIDS FOR DISASTER MANAGEMENT[1]

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Introduction

The capabilities of computer technologies to provide aid in disaster response are now well recognized. Effective response requires managing information flow prior to, during, and after potentially catastrophic events. Information technology can play a vital role in this process (McNally and Morentz, 1984).

The purpose of this report is to discuss a relatively new facet of information technology--artificial intelligence (AI). Because of the newness of the technology, we will illustrate AI's possible usefulness by describing a system that we have implemented for demonstration and research purposes.

Artificial Intelligence

Though the commercial successes of artificial intelligence programs have been relatively recent, the theoretical origins of AI date back several decades. AI has its roots in the mathematical logic systems of Frege, Whitehead, Russell, and Tarski, and in the theories of computation developed by Church and Turing, among others. The logic theorists demystified thinking by showing that some aspects of reasoning could be formalized in a relatively simple framework. New ideas about the nature of computation provided the link between these formal systems of logic and early computers. The crucial advance was the recognition that computation was abstract symbol processing, breaking away from the notion that computers were inherently numerical.

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[1] This paper is presented with the kind permission of the editors of Disasters: The International Journal of Disaster Studies and Practice in which it appeared in a slightly different form.

The introduction of symbol processing opened the door for attempts to mimic the human mind. By studying the way humans solve problems, AI researchers have developed techniques to represent human decision making. Knowledge representation, efficient searching of possibilities, and learning processes are all essential to AI programming.

The area of expert systems has recently emerged as the leading practical application of AI research. An expert system's user interacts with the computer in a "consultation dialogue," much like he or she would approach a human expert on the same problem. The user explains the problem, perhaps performing some tests, and then asks questions about the computer's proposed solution. Excellent results have been achieved in many consultation environments (Barr and Feigenbaum, 1979).

The Principles of Expert Systems

The Problem Area

Expert systems are designed to manipulate and solve symbolically expressed problems that are difficult for human researchers to solve. Many problems are characterized by an exponential growth in complexity when the problem size is linearly increased. The explosion in the solution search space is often more than human researchers are capable of handling (Barr and Feigenbaum, 1979).

Such problems are typically dealt with by "experts" of the human variety--persons equipped with a vast amount of task-specific knowledge acquired from previous training and experience in the field. These professionals often possess more than a sheer volume of facts. Many problems are solved by humans who simply "see" things about the problem that are unclear to the layman. A grand master in chess is a classic example of someone possessing this kind of "reasoning."

Representing Expertise

Representing the various types of knowledge that characterize expertise constitutes one of the main directions of expert systems research. Expert systems are often designed with knowledge concerning:

1) Facts about the domain,
2) Hard rules or procedures,
3) Problem situations and potential solutions,
4) General strategies, and
5) Conceptual models of the domain.

Much of this information must be stored in the expert system program by utilizing special techniques for knowledge representation. Many systems use production rules of the form "If A then B" to store information types (2), (3), and (4). Domain information is often stored in tables or matrices, while the designers' conceptual model of the problem is usually built into the program logic.

The clearest distinction between expert systems and conventional computer programs (often models or simulations), is the flexibility of the artificial intelligence design. Much of the knowledge that is used by human experts does not constitute definite decision sequences, rather it is "hunch-like." Using inexact reasoning, expert systems are able to focus on what would otherwise be an impossible problem and provide analysis and solutions with human-level ability.

Transfer Expertise

The primary bottleneck to the development of expert systems is the acquisition and implementation of expert knowledge. Typically, one or several "experts" will consult with the system designers for long periods of time during the development stages. This process is often arduous and inexact, leading to long delays in producing a working expert system.

System Processing

Expert systems attack problems by feeding all the available information concerning the problem into the knowledge base that makes up the heart of the system. Often this information will consist of production rules that will generate possible hypotheses or solutions to the problem. Once initial possibilities have been determined, the process of confirming or narrowing the solution begins. In systems involved in diagnostic problems, the program will usually use its conceptual model to suggest tests to be performed or questions to be answered. These will narrow the solution range until the system is confident that it has reached a valid conclusion.

Dynamic data analyzers, such as the Pentagon battlefield systems, will await more incoming data to confirm or deny existing hypotheses or even generate new potential solutions. Again, when the system is confident of a solution or hypothesis, it will suggest it to the user. Often the measure of confidence is expressed as a numeric weight which begins as a measure of the incoming data reliability and is propagated through the system to measure the strength of the rules being applied. Unfortunately, the strength of the rules is usually an arbitrary assignment given by the human "experts" during the system design and is therefore subject to error.

Explanation of Knowledge

A key feature of many expert systems is their ability to explain their reasoning in understandable terms. This capability is one of the distinguishing features of human expert consulting and is implemented on computer systems to improve the user's confidence in the system's judgement. When the exact reasoning process that the system followed is available, it is easier to convince users that the solutions are valid and can be relied upon. However, there are differing philosophies on whether the system should actually use the same reasoning processes as the expert. Several systems use techniques far more elaborate than any used by humans but then attempt to explain their solution in conventional ways.

Knowledge Acquisition

System's designers are interested in knowledge acquisition for two reasons. The first is the practical consideration that it is often impossible to guarantee that the human "experts" have taken everything into account during the system design. The second is a more theoretical interest in having the system progress through self-learning. The former consideration is merely a safeguard against project deadlines; the latter may open the door for expert systems that can outperform even the best of human minds.

Expert Systems as a Component of Decision Aids

Various frameworks have been proposed which identify the specific components of a decision aid. We have developed a paradigm specifically for disaster response decision aids (Belardo et al., 1984); Figure 1 displays the components of a decision support system and identifies the role of expert systems. The five components include:

- A data bank,
- A data analysis capability,
- Normative models,
- Expert systems, and
- Technology for display and interactive use of data and models.

This "system" ideally interacts heavily with two external elements; 1) the disaster manager and 2) the disaster response environment.

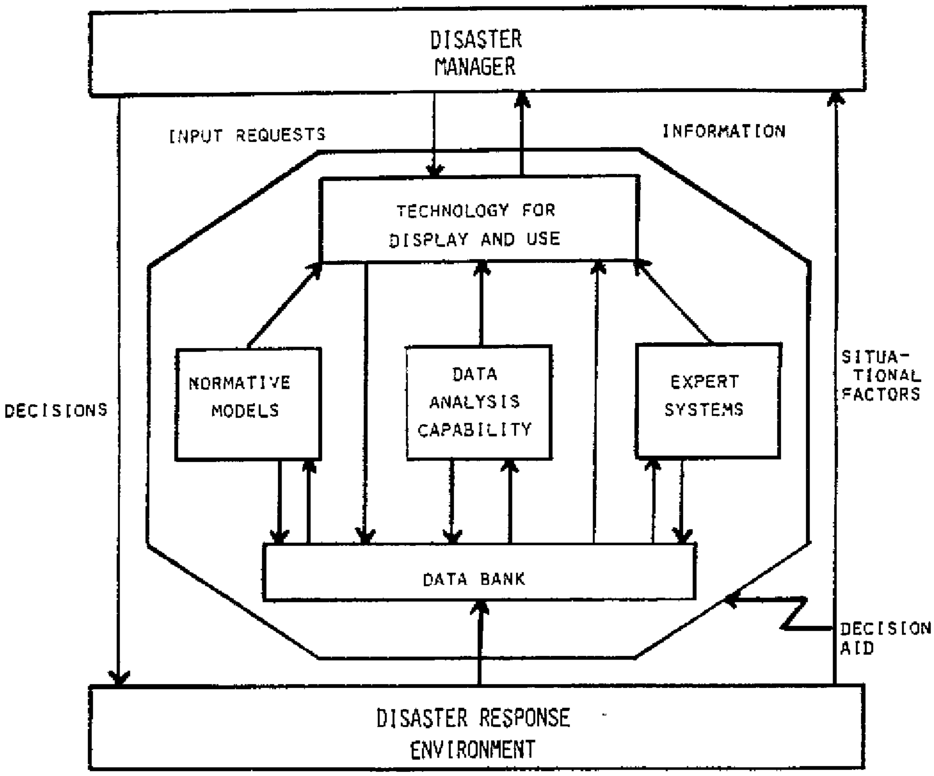

Figure 1
Components of a Disaster Response Decision Aid

The data bank stores information from the environment. Some of this (e.g., data concerning response resources) is obtained prior to an actual disaster, while other data is gathered concerning current conditions (e.g., theweather). This data may be presented to the decision maker in raw or transformed format.

In many cases, the data may be processed or analyzed using statistics or formulas to provide specific types of information that are useful in decision making. For example, data regarding the nature of the disaster and the prevailing weather can be combined to forecast the potential effects of the incident.

Normative models can help to provide response solutions that are not readily apparent, to evaluate the tradeoffs between alternative solutions, and (sometimes) to provide recommendations on actions to be taken. These models interact with both the data bank and the analysis functions.

The expert system component uses a rule-based view that captures the expertise of disaster managers. The system, as discussed in the previous section, takes data from the data bank and assesses its plausibility or worth. Using the data, production rules result in recommendations to the disaster manager.

The final system component, the technology for display and interactive use, is the part of the system that links the disaster manager and other components of the computerized decision support system. It can be argued that this component is the key element in determining the success of the system. If the manager cannot receive the information in an appropriate format (tabular, graphical, or whatever), the system may well go unused. Although research is somewhat inconclusive on our ability to design decision aids that are congruent with a person's particular cognitive style (Zmud, 1979), providing decision makers with a variety of display and data retrieval capabilities does enhance use of the decision aid in disaster response (Belardo et al., 1984).

A Demonstration System

A small demonstration system designed to handle fire control in the event of a petroleum pipeline break caused by an earthquake well illustrates the potential of expert systems. Such a system would be employed by Emergency Operating Center (EOC) personnel to quickly allocate emergency vehicles in a situation where a few minutes delay could result in millions of dollars in property loss. The system's key data inputs would be helicopter or ground reports of fire damage. Correlating these timed reports, the system would recommend in a matter of seconds the best procedure for combating the fire. As new data comes in from field reports, the system is capable of altering its recommendations and planning the best fire control alternative.

Scenario

The system is customized for an imaginary city in southern California, through which runs a six inch petroleum pipeline. The precipitating disaster is an earthquake with a magnitude of 8.3 on the Richter scale. Such a quake would have devastating effects on the entire southern part of California, leaving millions homeless and causing almost incalculable amounts of damage. It is presumed that in the imaginary city many structures topple and major roads become unusable. All of these special circumstances are assumed in the program design. A properly developed system could be made more flexible so that it could adapt to situations in other locations.

After the actual shock waves have ceased, the primary danger for this city is fire. It is presumed that somewhere along the length of the pipeline that is close to ground, there will be a break. There is no question that such a break would cause instant ignition of an intense, uncontrollable fire. The fire would burn in two different directions, making emergency operations exceptionally difficult. Structures close to the break would ignite, and winds would drive the flame front to the west. Meanwhile the liquid petroleum, still aflame, would pour down the streets of the city seeking the lowest ground. As it moves on, there could conceivably be additional structure fires touched off by the flowing flames.

The task of the expert system is to assess the fire threat and recommend precise emergency actions to limit losses to a minimum. The program accepts timed damage reports to assess the progress and seriousness of the fire. When sufficient reports have been received, the system recommends fire control strategies and the optimum locations to implement them. The capability to assess available emergency vehicles has been added to the program in an effort to approximate real-world conditions, and an additional feature has been included that posts warning messages to indicate that the fire is endangering critical locations such as schools and hospitals and that evacuations should be ordered if they have not already been carried out.

The Program

Written in the Pascal computer language, the demonstration system contains many of the features available in full-scale expert systems. We will attempt to explain some of the information that is contained in the system and the method in which the system processes that data.

Much of the specific domain knowledge is represented in data tables or files. For instance, a grid map of the city for determining street locations is contained in the matrix called CITY. Blocks are represented by 0 value entries, while streets are given numbers that are in turn entered in the street listing table, STREETS:

Street #	Street Name
1	First Avenue
2	Second Avenue
3	Main Street
.	.
.	.
.	.

While the internal processing uses street numbers (because they are consistent with the matrix map representation), the user is presented with the full street name. Similar tables exist for emergency vehicle locations and critical citizen locations. Reference tables allow the system to calculate the changes in damage caused by increased wind velocity and different oil flow rates.

Incoming data is of several types: variables that are primarily external, like wind speed, weather forecast, and oil flow rate; and program variables—mainly damage reports and vehicle availability. The external variables can be entered into the program immediately and require no specific system knowledge; the program variables require a brief interval for field reports to be accumulated and processed. In many cases, the EOC manager responsible for managing the situation will not arrive at the EOC center for up to thirty minutes after the precipitating disaster. In this time, field reports can be compiled for quick access and data entry. Input data is controlled by an input menu from which the user selects the input he or she is ready to enter. The user then types the information in using the specified format. The procedure is simple and fast.

The program's knowledge base is stored in a large file of production rules that follow a rough "If A then B" format. A sample of the production rule file looks like this:

Antecedent	Consequent
BLOCK 1 = BURNED	CONTAIN EAST (BLOCK 3 + WIND FACTOR)
FLOW 1.2	ALLOCATE 3 VEHICLES SOUTH BLOCK 67
STREET 17 = BLOCKED	ADD STREET 17 BAD LIST
STREET 35 = BURNED	WARN #2
.	.
.	.
.	.

The rules file is relatively large, a necessity in any complicated expert system. The system processes the rules file into understandable conditions (the file is written to be discernable to a user), and then applies the conditions to the available data. Whatever actions indicated in the rules list are performed and communicated to the user. The rules list must be processed several times before the program (or the user) can be sure that all of the potential recommendations have been found: because one rule may produce a result that another rule is waiting to see. Thus, the system must process the rules a second time so that the latter rule has all of its necessary input.

The output of the system consists of recommended fire fighting strategy and recommended allocation of available emergency equipment. The user is free to accept the recommendations or alter them as he or she likes. Several interactive features allow one to quiz the system about its recommendations. A menu choice will display all of the rules used by the system in generating its latest results. This amounts to a listing of those rules in the rule file that were found to be true on the last pass of the rule processor. Another menu item allows the user to alter a system variable to any value chosen and rerun the rule processor. This flexibility is especially valuable when the EOC manager has doubts about the validity of the data. To assist the manager in evaluating the outputs, a recommendation weight is attached to each major strategic decision. The weight is an evaluation of the sensitivity of the system, given its current inputs. For example, when winds are high and there is a large probability of rain, the chance of the system making a less than optimum decision is greater.

Conclusion

The primary use of a demonstration program like the one described here is to enable understanding of expert systems. While it is of some practical value, the system is of such a small scale that it does not distinguish itself greatly in performance over mathematical models or trained human experts. It should be stressed that this is merely a function of the small size of the problem that we have used in this example. As we noted earlier, the strength of expert systems lies in their ability to comprehend extremely large problem areas, particularly those which involve the integration of different solution techniques. An expert system designed to handle emergency decisions in all areas of disaster management would be capable of outperforming human personnel. Furthermore, it would be difficult, if not impossible, to apply a mathematical model to such a situation, because of the difficulty in obtaining accurate statistics describing similar events.

Clearly the implementation of some automated decision aid system is particularly appropriate for managing the conditions following any disaster (Belardo et al., 1983). The goal of this paper has been to demonstrate that expert systems are capable of filling that role and doing so admirably.

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ILLUSIONS AND REALITIES: USING INFORMATION TECHNOLOGY IN EMERGENCY MANAGEMENT[1]

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Introduction

> All of our equipment, software, tends to be organized around national decisions. Crises, by their very nature, are irrational processes. People who are good at managing crises tend to be people who have gotten very, very good at making decisions in almost the total absence of information, making gut decisions based on who they could trust and couldn't trust.
>
> Dr. Jacques F. Vallee (1981)

The immense disparities that exist today between the often illusory sophistication engendered by technological achievement (limited to relatively few clusters within the civilized world) and the reality of humankind existing marginally throughout most of the globe mirror our varying capacity for dealing with the range of crises that beset humankind. Although an array of ingenious technology has been developed to help prevent, ameliorate, or at the very least respond to various kinds of disasters, the adaptation of such advanced tools and techniques has been very uneven within the emergency management (EM) community.

This is not to gainsay the impressive move toward better trained EM personnel at every level of government and within the private sector. Both through the National Emergency Management Institute and an array of training and orientation programs undertaken at the state and local level, the men and women who comprise this 12,000-person cadre are daily increasing the technical skills needed for this demanding profession. Yet, in performing their jobs, these professionals must ask themselves certain questions: how much preparation for coping with various types of emergencies is possible? how much is useful? how much can be learned from prior experience, either first- or

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[1] The views expressed are those of the author and are not necessarily those of the Congressional Research Service or the Library of Congress.

second-hand, with a given disaster? what investment in data relevant to a possible crisis can be justified? how is it possible to maintain a high level of motivation when actual emergencies occur infrequently?

To deal with these unscheduled events, those charged with EM tasks must be able to improvise as well as use their training and knowledge of the resources at hand; they must be able to communicate concisely and well in order to provide the maximum possible warning and response; and they must be able to learn from and communicate their experiences.

Another dimension to the problem of developing the best possible EM system is that plans must consider multiple disasters and interactive conditions, such as may be found in an urban area. For example, a tornado could damage a chemical plant in a midwestern city, causing a toxic release, and also damage the warning system, impeding evacuation directives and procedures.

Benefits and Problems in Using Information Technology

Our nation prides itself on being able to systematically analyze situations and marshall the requisite resources—human, technical, financial—to plan for or cope with emergencies. Yet, there is a growing sense within both the public and private sectors that our nation is inadequately prepared to cope with the natural and technological crises of these complex times. Our society and government are increasingly hard-pressed to anticipate, much less respond effectively to, many of the hazards that threaten lives and property. The devastation wrought by the Mount St. Helens' eruption or the tornadoes that ravaged the Carolinas in early 1984 indicate that some of the priorities and processes involved in managing emergencies need to be rethought.

"Information technology" may be one tool for coping with these kinds of problems. Most experts now recognize that their own senses and analytical abilities may be insufficient to handle a given problem and that only a computer can effectively manage all the relevant information. Therefore, one critical facet of strengthening the emergency management capability in the United States—whether the focus is on mitigation, prevention, response, or recovery—is the development of advanced information systems for collecting, storing, processing, retrieving, and sharing essential data and information that may be used by emergency managers. In particular, at a time when officials are overburdened with information, it is imperative that systems be selective and capable of filtering out unimportant information.

The introduction of advanced technology into any information handling environment, such as the emergency management community, poses problems. Decision makers at all levels of the emergency management system have to understand the benefits and limitations of using information technology. Their questions include: What can technology do to better manage vital information? Can technology enhance the determination of information validity, and thus help to deal with misinformation or "disinformation"? Should small-scale experiments and practical case studies be undertaken to better understand the man/machine interfaces involved in advanced systems? In addition, it is not clear how the technology can be best used to improve vertical or horizontal communication among emergency managers. Nonetheless, some innovations have already proved beneficial. The growing use of sensors (aloft and aground), processors, and disseminators allow those responsible for developing appropriate strategies to make decisions within a more well-informed context.

Included among the organizations in the United States with recognized roles and responsibilities in emergency management who share concerns about the use of this emerging technology are (Chartrand, 1984):

- Federal agencies, such as FEMA, USGS, NWS, NOAA, DOD, and many more
- State and local governments (including task forces)
- Regional commissions
- Private sector consultants and information services
- Information "clearinghouses"
- Organizational "watch centers"
- National coordinating groups
- Private sector contractors—corporate, university, nonprofit.

Emergency management was once primarily a volunteer activity, but now there are hundreds of full- and part-time professionals involved in every aspect. These people have learned that James Michener (1982, p. 622) was correct when he pointed out that:

> [our] balance in life consists of handling in real time those problems which cannot be delayed, then recalling more significant data during periods of reflection, when long-term decisions can be developed.

Congressional Insight and Initiatives

Congressional interest in the potential impacts of information technology is increasing, and not surprisingly encompasses all four phases of emergency management. Among the many questions coming under legislative scrutiny are:

- Is there a current, valid, long-range plan addressing the role of communications networks in emergency situations?
- Has the optimum use of advanced information technologies in various disaster scenarios been studied, and plans for their operational utilization developed?
- Have priorities been determined for the creation, maintenance, and use of those essential information files that may be available to decision makers during emergencies?
- Will secure communications be available in contingency situations?
- Are the advantages and disadvantages of various technologies employed in anticipating or responding to natural or human-caused disasters understood by managers or operators?
- Is there a need to review present emergency management concepts and plans, particularly those concerning the roles of "watch centers," networks, and key human resources? (U.S. Library of Congress, 1983)

During the 97th and 98th Congresses, the Subcommittee on Investigations and Oversight, under the leadership of Representative Albert Gore, Jr., of the House Committee on Science and Technology, undertook a multifaceted exploration of the role of information technology in emergency management. Early on, Gore noted:

> The subject of disasters is not one that many of us care to dwell on. Earthquakes, fires, assassinations, terrorist attacks and nuclear melt-downs are the stuff of Hollywood and we like to keep it that way. As a result of this "out of sight, out of mind" ethic, our society is often ill-equipped to deal with emergencies when they do arise. (U.S. Congress, 1984, p.123).

Present and potential uses of computers and telecommunications received primary attention in the 97th Congress, as the Subcommittee considered their value in preventing or coping with technological or natural disasters. Following a roundtable discussion led by Chairman Gore and Dr. Richard Beal of the White House, two days of hearings were held on September 29 and 30, 1981, with expert testimony by acknowledged governmental and private sector leaders in the field. Subsequently, a technical forum was sponsored by the Subcommittee on November 23, 1981, featuring participation by 17 senior individuals who engaged in structured discussions and witnessed demonstrations of technology-supported information systems.

The second phase of the Subcommittee's activity in this area occurred in the first session of the 98th Congress, with the convening of a combined two-day hearing and workshop, on November 16 and 17, 1983. The highlights of these various Subcommittee initiatives along with interpretive commentary and summary recommendations are contained in a committee print entitled Information Technology in Emergency Management, prepared by the U.S. Library of Congress, Congressional Research Service (1984). In summary, the thematic goals established and pursued by the Gore Subcommittee throughout its investigation were to:

1) Establish the full range of natural and technological disasters;
2) Identify what technology can and cannot do;
3) Recognize the overt and subtle interaction between human beings and their innovations; and
4) Ascertain the value of incremental improvements, when sweeping policy and program revamping is not possible. (Chartrand, 1984)

(In addition to the major report that highlighted the initiatives taken by the Gore Subcommittee, a few other important studies have been conducted in recent years that analyze this complex topic (Strauch, 1980; Janicik, 1979; National Research Council, 1982; Tenopir and Williams, 1982; Carroll, 1983; U.S. Office of Technology Assessment,1984).

Retaining the Critical Dominance of the Human Role

Most will agree that order and change need to be better synthesized within the emergency management environment; however, there is less agreement on how that can be achieved. Dr. Robert F. Kahn of the Defense Advanced Research Project Agency (DARPA), reminds us that "technology for emergency management should be usable. . . a natural part of the working environment. . . dependable. . . ubiquitous. . . [and] interoperable with other systems (U.S. Congress, 1981, p. 180)." This is a large order and may be seen by many at the local level, where there are limited resources, as unattainable. Yet, much can be done with a little ingenuity. (See, for example, the description of the activities in Vermillion County, Illinois cited in U.S. Congress, 1984, pp. 345-346, 383-384.)

There is a great deal that may be learned by civil sector authorities from their defense establishment and intelligence community counterparts. Time and again during the recent congressional hearings and workshops, participants referred to tools and techniques developed by these emergency-oriented groups.

In many instances, it has been imperative to involve both military and civilian forces in responding to certain types of emergencies, and hazard managers have learned that not only is the sharing of resources during a disaster often required, but prior joint planning of such resource allocation can be very beneficial.

Another resource for civilian authorities dealing with crises is the National Voluntary Organizations Active in Disaster (NVOAD) comprised of key private sector groups.

Collaborative effort among these groups is often impeded by obstacles posed by bureaucracies or individuals, but the overriding need to develop interjurisdictional emergency response mechanisms has resulted in increasingly concerted action. Maximum communication between authorities at various levels must be achieved to ensure protection of life and property. Moreover, as Alexander M. Hunter has pointed out, not only is this a matter of saving lives and property but a question of civil liability as well (U.S. Congress, 1984, p. 358).

Thus, with all of the incredible advances gained as a result of the inventiveness of man, the human factor remains paramount. The nation's leaders must keep this in mind as they try to increase our country's preparedness for emergencies. They must balance the natural human desire for stability with the changes necessary to ensure sufficient emergency preparedness and "continuity in government" under unsought crisis conditions. Those changes effect financial, commercial, and social services, as well as emergency preparedness systems. Robert F. Littlejohn was emphasizing this broader view of the human role in crisis management when he said:

> Crisis management. . . is actually the antithesis of mismanagement and it is something that has to be really fine tuned: identifying crisis issues; forecasting what an impact would be on a company politically, socially, and economically; and looking at what is the probability of the crisis taking place (Littlejohn, 1984).

Issues and Opportunities

Human industry and ingenuity have combined to provide an ever-broadening array of technology that supports emergency management. Some specific examples include (U.S. Congress, 1984, p. 5):

- 800 minicomputer warning systems in use throughout the country;

- A variety of airborne platforms such as the NASA U-2 and NOAA Flying Laboratories, along with sophisticated satellites featuring multi-sensor collection systems;

- Large masses of data stored in computerized or microfilm files (e.g., those at the National Hurricane Center);

- The rapid retrieval of key data utilizing on-line access systems available to users located in emergency operations centers (EOCs), mobile units, or other remote sites; and

- The varied communications conduits—land, air, and satellite systems (e.g., Inmarsat)—for transmitting key data. (An example of an innovative on-line system now in operational use is NOTEPAD, the communication network used at the Diablo Canyon nuclear power plant (see Figure 1).

In the case of aerial data collection (infrared, radar, conventional photography), the possibilities for use in advanced crisis condition detection are many. Arthur C. Lundahl and Dino A. Brugioni, pioneers in this field, suggest:

> The future portends even greater opportunities because the imagery can now be digitized, and the combining of imagery interpretation expertise with computer technology. . . provides us with numerous innovative applications. The enormous volume of imagery-derived data now under computer control provides untold opportunities for utilization by analysts in Emergency Operation Centers (Lundahl and Brugioni, 1985).

One valuable resource for many emergency managers is geographical data that can help in the determination and analysis of potential impact areas, transportation routes, and evacuation sites. Dr. Jerome E. Dobson of the Oak Ridge National Laboratory Ridge comments that the primary effect of this system would

> not be to supplant human intelligence and decision making, but rather to speed up many calculations and judgments that are already being made in emergency situations. The greatest advantage would be a better understanding of where the impacts can be expected to occur . . . this understanding would be shared through a common set of information among planners and decision makers at all levels of authority (U.S. Congress, 1984, p. 320).

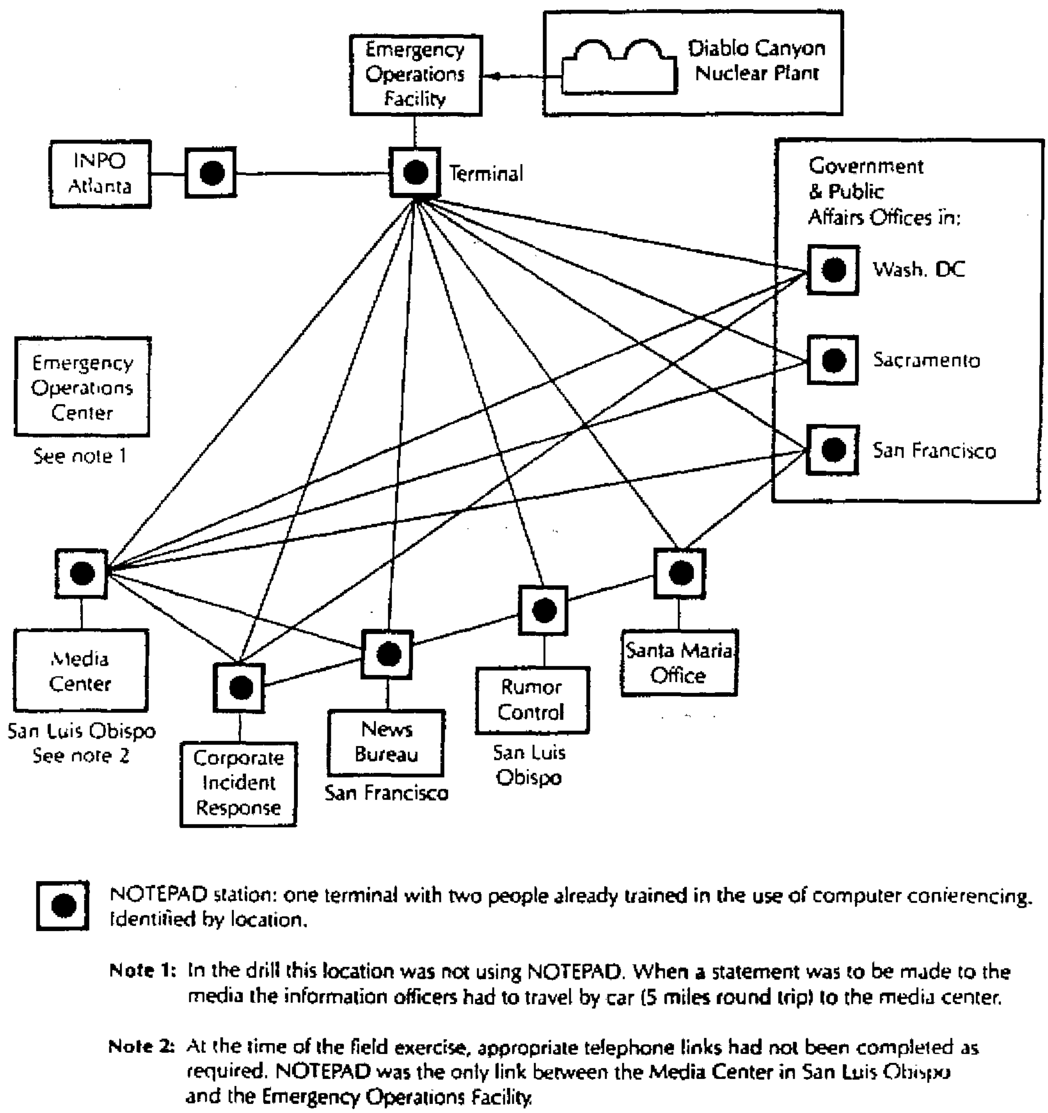

Figure 1
Flow Diagram—Diablo Canyon Emergency Drill
(Source: Jacque F. Vallee, INFOMEDIA Corporation)

Another notable application of information technology, observes Dr. Marilyn C. Bracken, is that associated with hazardous waste management. She emphasizes the "enormous potential" of its use:

> Obtaining the best information possible—being able to assess the uncertainty and limitations surrounding the data, in a critical time frame—is the objective of all. . . involved in emergency management (Bracken, 1984).

These comments indicate the breadth of this topic. As the investigation by the Gore Subcommittee progressed, a number of identifiable issues and action opportunities emerged (U.S. Congress, 1984, pp. xv-xvi). First, the Federal Emergency Management Agency (FEMA) was urged to consider such actions as:

- Creation of a uniform disaster reporting system,
- Establishment of a National Assistance Program Index,
- Expansion of present orientation and training capabilities and programs, including multisensor work,
- Development of a permanent simulation capability, including models capable of using a wide variety of data, and
- Preparation of a five-year plan, featuring interagency information handling capabilities.

Secondly, other federal agencies, either in collaboration with FEMA or through unilateral action should:

- Create a "core crisis management mechanism," preferably within the Executive Office of the President,
- Reexamine the present role of the Federal Communications Commission in emergency communications,
- Establish a focal point in a designated agency to study the application of technology to non-DOD problems,
- Direct Federal technology providers to review new information technologies for possible EM use, and
- Undertake the establishment of a civil sector communications network with qualities of flexibility and durability.

Thirdly, state and local emergency authorities were encouraged to:

- Establish or upgrade mutual aid assistance agreements, with particular attention to technological interactive support,
- Standardize communications frequencies at least within an identifiable potential disaster area,
- Develop "liability" ground rules to clarify decision-making protocols and priorities,
- Optimize their EM capabilities in the interest of "self-sufficiency"—a prerequisite for certain types of disasters, and

- Begin to prepare that "secondary layer" of EM statutes and regulations, to augment or serve in the absence of federal laws.

Fourthly, the Congress through its committee structure was asked to contemplate:

- Further revision of the Communications Act of 1934,
- Intensified oversight regarding a range of emergency management activity areas, both pre- and post-disaster,
- Creation of a "national emergency communications network,"
- Establishment of a requirement for the "dual use of technology" in funding new procurements, and
- Delineation of a new "clearinghouse" activity which would collect, store, and make available prioritized EM data.

These overarching concerns, along with many others articulated by witnesses and workshop participants, reveal the complex decisions regarding policy that must be made by those charged with determining the future of emergency management.

The attitude of the many participants in the Subcommittee hearings was decidedly favorable toward the greater utilization of information technology. Understandably, they also recognized obstacles to be overcome as well as commitments that needed to be made by those in authority. A selection of comments is presented here regarding six specific areas cited by those involved in emergency management as being particularly critical (U.S. Congress, 1984, pp. 22-24). First is an observation regarding the role of information technology in the emergency management environment and the way in which humans must interact with that technology:

> If the technology cannot be used by [emergency managers] and dozens of other people with whom I work, it is going to be of little value . . . . Every 2 or 3 years the membership on our committee changes, and if we are not getting people thoroughly familiar with the utilization of this technology, it is going to be more harmful than helpful. I would keep my communications simple. (Charles F. Allen, city EM manager)

The role of human beings in advanced EM systems drew this comment:

> The essential point that humans provide in an operational center, to paraphrase Tom Belden, is to act as a corporate memory. They have to know who the people are, who knows what, at what point in time. . . . No amount of technology can make up for the inadequacies of training, quality, motivation, and energized leadership. (Vincent J. Heyman, Planning Research Corporation, senior associate)

Other comments also focused on the role of human resources and means of linking individuals using advanced electronic technology:

> Every time there is a crisis which is unique, you scurry around to find who is smart about this. . . how do you put them together. . . wire them together. . . . It is taking advantage of what all of these various communications systems are, and taking advantage of people who know people. (Dr. Thomas G. Belden, consultant)

The creation of "knowledge bases" for decision makers in emergency management elicited this statement about those actually working in the field:

> In any large-scale civil emergency. . . we do not call it intelligence, but there are vast information requirements. . . . If they need, for example, information on the distribution of population or the availability of other assets in and near Mount St. Helens, that is intelligence. That includes damage assessment, which is commonly an intelligence responsibility in the military. . . the data base problem may be no worse on the civil side but has been given less focused attention in the past and is less unified in terms of the capacity to communicate among the data bases. (Francis P. Hoeber, consultant)

Concern about the nature and reliability of networks, both under normal and contingency conditions was also voiced:

> You should have alternate routes to every path that you are going to take. . . . You should have two gateways between every network at alternate sites. . . . Analysts use the files but they usually have backup methods for getting data, too. . . . As time goes on and they get more experience with the system, they will begin to rely upon it more and more. . . . The further you get from the Washington area the more the people rely on the information since it is the only source they have. (George M. Hicken, government system manager)

And finally, the discussants often cited their belief that further research and development must be carried out in order to maximize the utility of computerized files, and make them accessible to as many potential users as possible.

> [in addition to] research and development needs. . . we need mostly an awareness of what technology is available. We need research on the data integration, particularly from the software, because the present database management systems are not adequate. We need display integration of sensory information from multi-sources. (Curtis L. Fritz, consultant)

Effective Crisis Management: An Unflagging Need

It is difficult to foresee when this nation will not have to confront and manage emergencies, so every attempt must be made to prepare for these crises and to respond to them utilizing all possible resources. If a "systems approach" is a viable means to that end, then the lessons learned within the aerospace, military, and intelligence establishments must be heeded. The importance of this strategy was heralded as early as 1966 during the deliberations of the National Commission on Technology, Automation, and Economic Progress. The commission's report (1966, p. 100) states that:

> In short, what a systems approach implies is comprehensive planning so that we can trace out the effects, progressive and regressive, of any set of choices and decisions upon all other relevant decisions.

Although all these meetings emphasized the ways in which officials collect, process, and use information, the needs of the public for enlightenment and education—whether through television, radio, written publications, or lectures and seminars—also must be considered and met.

Summary

Both government and society are learning that the durability and flexibility of emergency management systems are critical parameters determining functional effectiveness. There is an increase in both simulations and actual exercises utilizing crisis-handling systems in order to test their operation under stress. To many, if not most, emergency managers, the criterion in these tests is the delivery of needed information that is accurate, timely, comprehensive (where possible), and relevant to the challenge at hand. The technology is incidental; if its performance is unreliable—whether in linking individuals, organizations, or networks or in simply retrieving essential pieces of key data—then the emergency management office may opt to return to a simpler, more trustworthy system.

The acquisition, verification, and transmittal of information has always been critical in meeting a variety of crises ranging from small-scale localized disasters to larger emergency situations affecting a wide geographic area. Thus, information technology more and more offers a wide range of potentials for enhancing the effectiveness of crisis organizations—both governmental and private—responsible for emergency warning and notification, situation assessment, decision making during crises, and dissemination of information necessary for responsible action. Those who shape key policies and direct the resultant programs must continue to seek out all potential resources to meet the increasing needs posed by an evermore complex and hazardous society. Implicit in these difficult challenges are many opportunities for the optimum utilization of those innovative technologies that, when combined with intelligent human direction, can ensure our survival and well-being as a nation.

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