International Journal of Mass Emergencies and Disasters
November 1991, Vol. 9, No. 3, pp. 339-353.

DESIGNING AN INTERACTIVE, INTELLIGENT, SPATIAL INFORMATION SYSTEM FOR INTERNATIONAL DISASTER ASSISTANCE

Louise K. Comfort
Graduate School of Public and International Affairs
University of Pittsburgh
Pittsburgh, Pennsylvania 15260

The complexity of disaster environments poses an extraordinary burden on human decision makers to take timely, appropriate action in uncertain conditions. The information load escalates beyond our limited cognitive capacity for processing information, yet timely action is critical when lives are at risk. The information burden increases with scope and complexity in disaster environments, impeding action despite available resources and committed personnel. The author argues that if individual and organizational learning processes can be increased in complex disaster environments, this knowledge may be shared with the wider international community to generate a stronger capacity to reduce the risk of, and losses from, disaster; and offers a design for an interactive, intelligent spatial information system which can provide decision-makers with flexible capacity to obtain an overview of the entire set of disaster response operations, while retaining the capacity for detailed examination of specific problems at any given time.

DISASTER: A GLOBAL PROBLEM

Over the last two decades, environmental disaster has emerged as a formidable international problem. Globally, disasters have cost three million lives, destroyed the homes of 820 million people and incurred $100 billion in property losses since 1970. Further, recent studies have shown recurring problems in communication, organization and efficiency in disaster environments that limit capacity for community response to reduce losses in lives and property (Turner 1978, Comfort 1989a, Comfort et al. 1989). These problems reflect the difficulty of designing strategies of action that enable communities vulnerable to seismic or other types of risk to plan for hazardous events, organize collective response when disaster does occur, and use available resources efficiently to reduce losses in lives and property.

The complexity of disaster environments poses an extraordinary burden on human decision makers to take timely, appropriate action in uncertain conditions. The information load escalates beyond our limited cognitive capacity for processing information (Simon 1981, Comfort 1988), yet timely action is critical when lives are at risk. The information burden increases with scope and complexity in disaster environments, impeding action despite available resources and committed personnel (Comfort et al. 1990). The urgent need for rapid response and the disruption of ordinary operating procedures compel responsible managers to invent means of individual and organizational learning to cope with the dynamic, interdependent events of disaster (Drabek et al. 1981, Rubin 1982, Perry and Mushkatel 1984).

There is evidence that the capacity for individual and organizational learning can be enhanced through structured information processes (Simon 1981, Comfort et al. 1990). The outcome of such learning processes, however, can be directly observed only in the crucible of actual disaster operations. Considering previous disaster operations as case studies, we may observe demonstrated improvement in individual and organizational learning in complex disaster environments as professional design, training and public awareness of risk increases. For example, data from three recent earthquake disasters of similar magnitude show strikingly different rates of loss. Table 1 presents data from the earthquakes of March 5, 1987 in Ecuador (6.9 Richter scale); December 7, 1988 in Armenia (6.9 Richter scale); and October 17, 1989 in Loma Prieta, California (7.1 Richter scale).

Table 1. Losses in Life and Property in Three Recent Earthquakes

Location	Date	Magnitude	# of Dead	Cost ($)
Ecuador	3/5/87	6.9 R[1]	over 1,000[2]	$1 billion
Armenia	12/7/88	6.9 R	over 25,000[3]	$16 billion
Loma Prieta, California	10/17/89	7.1 R	63[4]	$7.1 billion

[1]Richter scale of earthquake magnitude.
[2]Estimated figure, Ecuadorian Civil Defense.
[3]Official reports cite 24,542 dead; informed observers estimate 45,000 dead; actual figure may never be known.
[4]Initial reports cited 65 dead; this figure was later downgraded to 63 dead by the California Office of Emergency Services.

Sources: United Nations Economic Commission for Latin America and the Carribbean; Ecuadorian Civil Defense; Armenian Civil Defense; US Geological Survey; California Office of Emergency Services

Although the earthquakes differed in location and distance from populated areas, each engendered severe destruction, loss of life and required mobilization of disaster response. The relatively low loss of lives in the 1989 California earthquake demonstrates that buildings, bridges, power utilities and other lifeline facilities largely withstood the severe shaking in the San Francisco Metropolitan Region, an area of nearly six million people. Despite the ensuing trauma and economic losses of $7.1 billion, the event documents the technical claim that it is possible to design infrastructure for human communities that will withstand major earthquakes. After-action reports from emergency response organizations cite improved community response with prior training and an informed citizenry (Benuska 1990).

In any given location, a major disaster is likely to occur only once in a lifetime. Yet, across the world, these events occur with sobering regularity and stunning losses in lives and property. On a global scale, the problem of disaster can no longer be ignored or dismissed as a rare event. In order to reduce loss of life and property, it is imperative to share the sobering insights, hard-won experience and invaluable information gained from one disaster with communities in other areas of the world vulnerable to seismic or other types of risk. Without conscious learning, we invite recurring disaster.

THE PROBLEM OF EFFICIENCY IN INTERNATIONAL DISASTER ASSISTANCE

The problem of efficiency involves improving the uses of time, organization and coordination to achieve appropriate response to disaster. In a major disaster, complexity in response actions escalates geometrically with the numbers of people involved, the size of the affected area and the capacity to mobilize appropriate resources and technology. Complexity increases still more dramatically with differences in language, training, equipment, and experience when international disaster relief and rescue teams are involved (Comfort 1986a, 1989b, 1990).

Each disaster has unique characteristics, but common to all is the function of response. In a disaster, local resources are overwhelmed. Response necessarily involves the mobilization, organization and deployment of external resources to the stricken area. Improving the capacity for timely, appropriate response will increase the efficiency of disaster operations. In major disasters such as the Armenia earthquake of December 7, 1988, response comes voluntarily from international sources. Without planned organization prior to the disaster, the complexity of the process virtually guarantees inefficient operations. Disaster snarls the interdependent threads of communication and organization that facilitate collective action (Shrivastava 1987, Comfort et al. 1989). When response crosses disciplinary, organizational and jurisdictional boundaries to deliver external assistance to a stricken area, alternate forms of communication and organization that allow timely, flexible coordination over the entire span of disaster operations are essential.

The paradox of international disaster assistance has been discussed in detail in other research (Cuny 1983; Rosenthal and Charles 1990; Comfort 1986b, 1988). In general, international disaster assistance is characterized by enormous good will, quantities of donated goods and humanitarian concern for the victims. In practice, massive effort and generous contributions of time, personnel and equipment by many nations produce meager results in terms of lives saved or losses diminished. The discrepancy between effort expended and results achieved has been documented in most recent disasters (Cuny 1983, Comfort 1986b). This discrepancy indicates an ineffective use of resources and time.

Professional design improves the efficiency of international disaster response in three ways. First, professional design clarifies functions and responsibilities for action for major actors in the process (Mackenzie 1987). Second, it stimulates innovation and communication in meeting current needs by creating a knowledge base of shared information among the participants (Simon 1981). Third, it serves to integrate critical actors and resources in effective action (Benveniste 1989). In application to a problem as complex as international disaster assistance, professional design includes exploring the appropriate uses of information technology.

THE POTENTIAL FOR INFORMATION TECHNOLOGY IN DISASTERS

If individual and organizational learning processes can be increased in complex disaster environments, this knowledge may be shared with the wider international community to generate a stronger capacity to reduce the risk of, and losses from, disaster. The potential of information technology offers a systematic means of learning from recurring disasters on a global scale.

Information technology facilitates four critical functions in international disasters. First, it speeds communication across time and distance, making possible the instantaneous transmission and exchange of information from the disaster site to international centers of assistance and resources.

Second, information technology creates a shared knowledge base for all those participating in disaster response. Through careful design, it is possible to generate a disaster-specific database that provides a continuously updated record of events, actions, conditions, consequences, needs and available resources. This database may be accessed by multiple participants simultaneously and used to inform responsible action in disaster operations. It creates an "information-rich environment" (Simon 1981) in which disaster managers, in separate locations, can take informed action that contributes to the common goal of minimizing risk.

Third, information technology, well-designed, reduces the complexity of information flow to disaster managers. Information technology enables decision-makers to monitor the whole set of disaster operations more effectively, yet allows detailed consideration of specific problems at particular sites. It allows managers to identify critical areas of disaster operations and representthem graphically for simultaneous monitoring, to relate specific events to known characteristics of the community and region, and to sort incoming information in reference to pre-established priorities for action.

Finally, information technology enables local participation in an international network of assistance in disaster response and recovery. By facilitating the exchange of timely, accurate information, it allows local participants to take more appropriate action in response to needs reported from the disaster-affected area. These four functions create the potential for increasing organizational learning in disaster operations. As organizational learning from actual disaster events increases, efficiency in response operations is also likely to increase in the global arena.

A DESIGN FOR AN INTERACTIVE, INTELLIGENT, SPATIAL INFORMATION SYSTEM (IISIS) IN INTERNATIONAL DISASTER ASSISTANCE

Advances in information technology allow the design of an interactive, intelligent, spatial information system (IISIS) (Comfort et al. 1990, McCann et al. 1988) for use in international disaster assistance operations. The goal of such a system is to provide responsible decision-makers with flexible capacity to obtain an overview of the entire set of disaster response operations, while retaining the capacity for detailed examination of specific problems at any given time. The intent is to create a disaster-specific information system that allows practicing managers to draw relevant information from multiple sources in systematic ways.

An IISIS includes three components in a computerized information system that combines information search, processing, representation, storage and retrieval functions with electronic communication capabilities. These components include first, an interactive field status board that creates a disaster specific database to support decision making in international disaster operations; second, graphic mapping capability that allows the spatial representation of information from the field status board to multiple organizations and jurisdictional users; and third,

capacity for logical inference by the computer from information reported on the field status board to relevant knowledge bases included in the system (see Comfort et al. 1990). These components, operating interdependently, can improve the utility of information available to disaster managers engaged in separate but related functions vital to disaster operations. The field status board uses the concept of an electronic blackboard to enable disaster managers to report changing conditions from multiple field sites to a disaster coordinating center. This information is integrated by computers in a continuously evolving record of disaster events, conditions, actions, outcomes, resources and problems that can be accessed by authorized disaster managers from remote sites.

Using a graphic mapping capability, information from the field status board can be displayed graphically to remote sites, enabling managers at distant locations to visualize operating conditions in the disaster environment. Adding the capability of computerized logical inference routines, data from multiple sources can be entered into the computer to produce a calculated set of alternatives for action by disaster managers under specified conditions. Such routines can be used by disaster managers to explore alternative actions or to confirm possible choices against existing data from the knowledge base. The operations of these three components produce information that is stored in a layered, multijurisdictional database by function, discipline and time phase in disaster operations (see Comfort 1990).

In addition to these three components, an international information system would build on the experience of recent efforts such as the Telemedicine Project between the US and USSR following the Armenia earthquake and the Ufa train disaster. This project created an international medical consultation process between LDS Hospital in Salt Lake City, Utah and other US Telemedicine sites and hospitals in Yerevan and other USSR sites through a US satellite uplink and turnaround in Roaring Creek, Pennsylvania. Termed the US-USSR Spacebridge, it utilized the satellite communication facilities provided by the US National Aeronautics and

Space Administration. The project provided interactive diagnosis of medical injuries and treatment, and resulted in significant improvement in patient care and recovery (Ausseresses 1990).

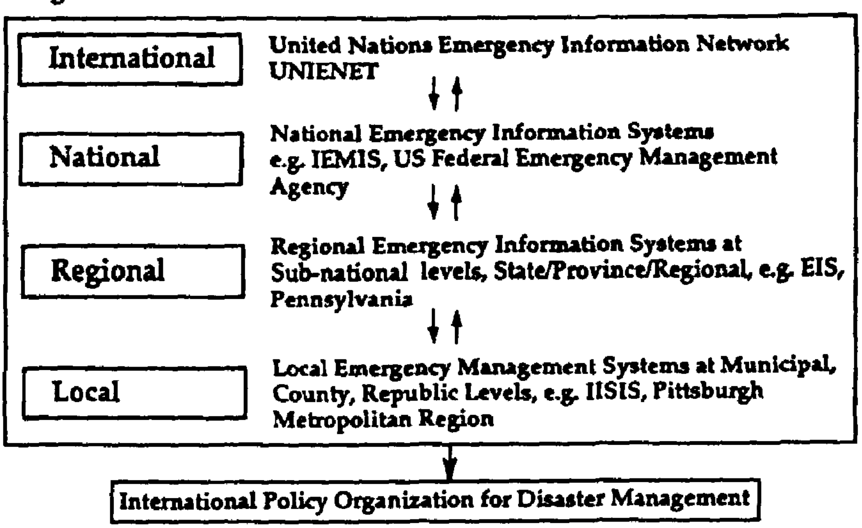
The design of an international information system, for use in the US or abroad, would rely on similar principles as those used by the National Communications System (Jaske 1989a, 1989b). These principles were first presented in reference to the development of a model IISIS for the Pittsburgh Metropolitan Region (Comfort et al. 1990). They may be adapted to create an international IISIS, extending the development over an estimated period of ten years. These principles include (1) an international geographic information system consisting of distributed, user-maintained segments coordinated by a single international agency; (2) maintenance of an international, multimedia communication system by a consortium of organizations that includes international, national, state, local and private entities with responsibilities for disaster response and assistance; (3) use of the same database systems that serve everyday operations for contributors to the information stream (these data bases, in turn, would be updated by IISIS participants worldwide as transactions evolve through the international information stream); (4) use of professional and universal standards of measurement and calibration in the development of models to estimate the effects of potential hazards or failure of vital systems affecting the public, and the testing of such models through field observations; (5) assurance of either redundant capability or surge capacity for all equipment involved in a potential role in the mitigation of disasters this capability would ensure the continued operation of information systems that may be damaged in disaster events; costs could be financed in the original capital investment on the basis of a specially defined risk assessment.

By improving the information available to support decision-making, an IISIS facilitates communication and coordination among participating agencies and thereby increases the efficiency of international disaster operations. It also allows the creation of a cumulative record of innovative performance and effective response to disaster events that may aid in forming global strategies for disaster response and recovery. Information technology, appropriately designed and used, serves as a vehicle through which responsible individual managers may activate broad organizational response to disaster. More importantly, it serves as a vehicle for continuing organizational learning in a global sequence of disasters.

REQUIREMENTS FOR AN IISIS IN INTERNATIONAL DISASTER ASSISTANCE

Four conditions are requisite for the development of an IISIS for international disaster assistance. First, disaster managers need to accept the concept of an IISIS as an element of their operating system. Second, an international, interdisciplinary advisory group needs to be formed to guide the development of the system and to ensure its application in actual disasters. Third, utilization of existing international information systems, such as UNIENET, UNDRONET and Red Cross networks, is necessary to avoid duplication and conflicts in outcomes. Figure 1 presents a graphic representation of existing information systems that may be linked together as a policy organization (Meltsner and Bellavita 1984) to form an international disaster information network. Such a disaster information network could support the formation of a model IISIS. Finally, it is important to develop a demonstration model for an IISIS to test its feasibility in actual international disaster operations.

Figure 1. Interactive International Disaster Information Network



AN INITIAL STRATEGY

In order to test the feasibility of an IISIS for international disaster assistance, the concept needs to be translated into a working model. While the construction of a full, interdisciplinary IISIS requires a major commitment of resources and time, a practical means of testing the concept is to build a demonstration model based on actual experience gained in disaster operations. Such a model would include a computerized knowledge base containing data identifying critical aspects of operations from an actual disaster, such as magnitude of an earthquake, its geological epicenter, time of day, weather conditions, physical characteristics of the affected area, population, building types and numbers, transportation routes, available resources in terms of trained personnel, medical facilities, water and power facilities and other vital elements of a community's vulnerability and capacity to respond to disaster.

The demonstration model would operate via a network of computers and electronic means of communication through which authorized managers could access the community knowledge base. Authorization would be granted to disaster managers on the basis of previously specified responsibilities and skills in disaster operations. Access to the network would allow disaster managers from different organizations to interact with an evolving knowledge base in transmitting and receiving information in simulated replay of events and conditions from an actual disaster. These interactions would include the ability to communicate with key jurisdictional personnel, generate maps of the disaster-affected area and check possible decisions against known characteristics of the community. While a model is not a complete characterization of a given disaster, it would allow responsible participants to simulate different solutions to selected problems from an actual event in retrospective analysis. Insights gained from this interactive learning process could be used to anticipate and minimize likely problems in future events.

The Armenian earthquake disaster offers an appropriate case for the study of medical services in disaster. Response to this disaster demonstrated significant international cooperation and coordination in providing medical assistance to victims of the earthquakes (Klain et al. 1989). Operations reports documented the number and types of medical teams from 14 nations that responded to the massive medical needs generated by the disaster (Ausseresses 1990). This extensive response allows a rich basis for study. It is possible to draw on the Armenian experience, focusing on the commonality of response from participating organizations and jurisdictions, to design a demonstration model to provide decision support for the organization and delivery of medical services in disaster environments.

Such a model would serve three goals important to organizational learning in the disaster management community. First, it would acknowledge time as a measure of efficiency. Second, it would accept the humanitarian commitment to saving lives as the basis for action at the international level. Finally, it would begin a cumulative record of medical response to disaster that may aid in forming global strategies in disaster response and recovery.

Strong leadership in humanitarian response to disaster has already been demonstrated by physicians. Examples include the bold work of the International Physicians for Peace against Nuclear War, Medecins sans Frontiere, Doctors without Borders and members of the Armenia Ministry of Health in the organization of the 1990 Yerevan conference. It is fitting that a medical model be the first segment of an interactive information system to support decision making in international disaster assistance.

In terms of design, it is important to clarify the relationship of the medical module to the whole information system. The design for the knowledge base of the whole information system will be layered by jurisdiction: local, regional, national and international (Figure 2). Within each jurisdictional layer will be a modular knowledge base, organized by disciplinary perspective, function and time phase in disaster operations. For each jurisdiction, disciplinary perspectives may include technical, organizational, medical, political and cultural types of knowledge required for appropriate response to disaster (Figure 3). Other perspectives, such as economic or psychological, may be added as appropriate for specific areas. Within each disciplinary perspective, further sub-categories of knowledge and skills needed for response may be specified (Comfort 1989b).

Figure 2. A Model of Multijurisdictional Response in Disaster Management

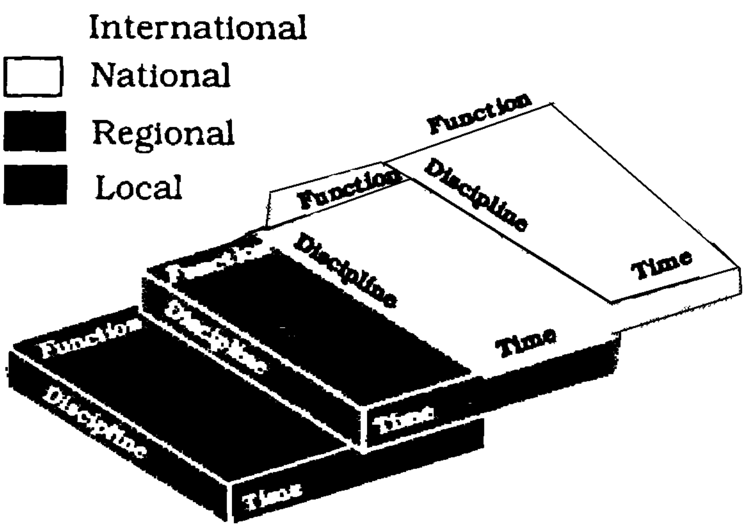
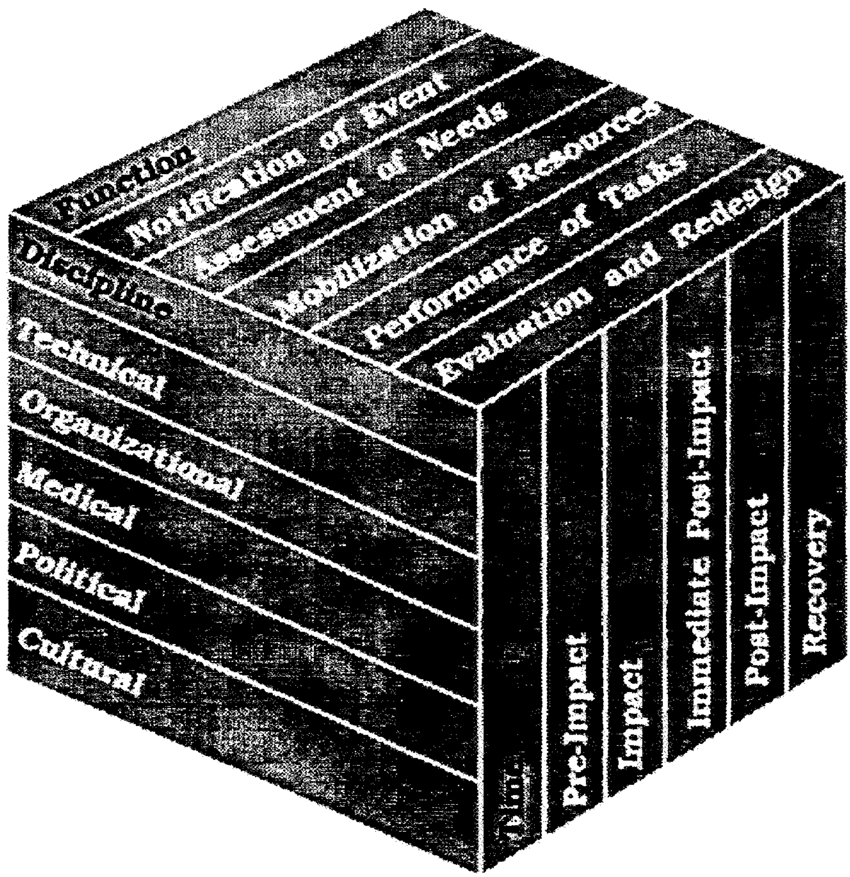
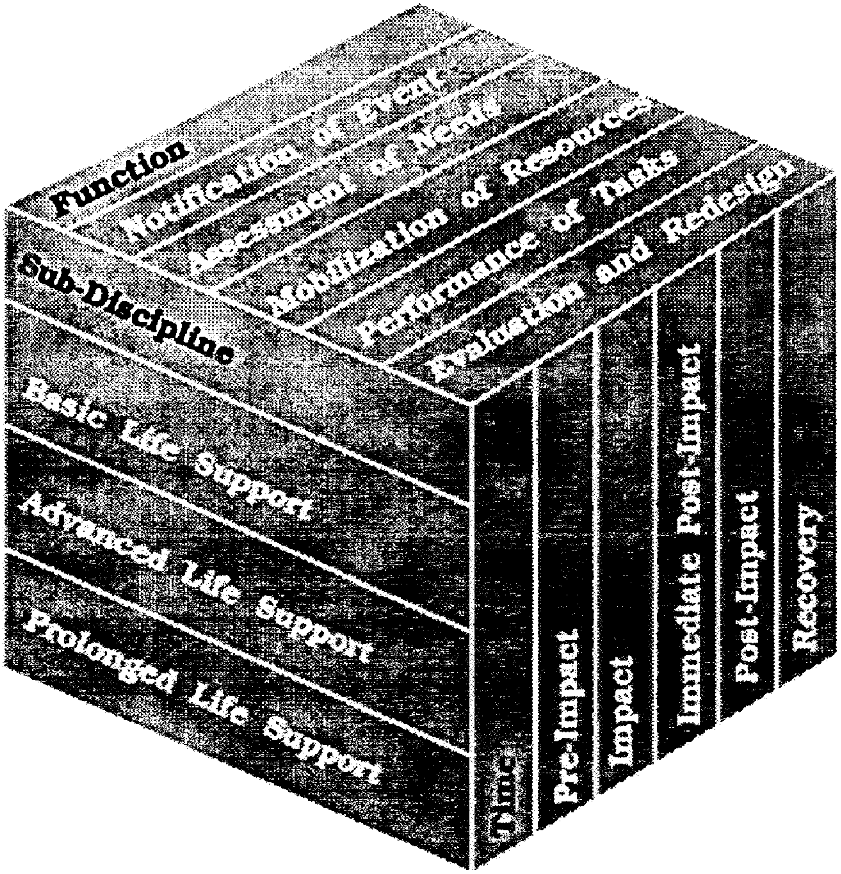


Figure 3. A Model of Local Jurisdictional Response in Disaster Management



For example, in the medical module, sub-categories of information on basic life support, advanced life support and prolonged life support (see for example, Safar et al. 1988) may be organized by time phase in the disaster (Figure 4). These sub-categories could be accessed by authorized disaster managers in other disciplines and at other locations who are responsible for logistics, communication, transportation and shelter in the disaster operations process. Timely access to medical information would assist these managers in providing the appropriate support essential to effective coordination in the complex disaster operations process. The objective is to design a working knowledge base to support decision-making across the range of participating organizations, disciplines, time phases and jurisdictions involved in disaster operations in order to mobilize, organize and deliver medical care in disaster environments more efficiently.

Figure 4. A Model of Medical Response in Disaster Management



Figures 2 - 4 illustrate relationships among the layers of the knowledge base and organizational components that may be included in a larger, interdisciplinary IISIS.

A PROPOSAL FOR ACTION

An IISIS forms the core of a plan to minimize losses in lives and property in recurring international disasters. This plan includes four steps:

1. Design of an initial model to support the organization and delivery of medical services in international disasters, using the IISIS concept
2. Demonstration of this model in an international setting

3. Evaluation of the model by an international, interdisciplinary advisory group
4. Request for international funding and participation in the development of such a model for international disaster assistance, with cooperation from national and international organizations engaged in disaster response and recovery.

Taken now, at the beginning of the International Decade for Natural Hazard Reduction, these steps would represent a substantial contribution to increasing the timeliness and validity of information available to international managers responsible for disaster assistance operations. Working together, it is possible to achieve a significant increase in the efficiency of international disaster assistance over the ten-year period of the Decade, or by the year 2000. Such a project would serve as a living memorial to the victims of the Armenia earthquake of December 7, 1988. It would translate the lessons learned from the Armenia earthquake into a form that would enable other communities at seismic risk to prepare more effectively for earthquakes that recur in geological sequence. Such a network may serve as the first step toward the development of a global IISIS, or inquiring system (Churchman 1971), directed toward solving problems of seismic risk.

REFERENCES

Ausseresses, A.D. 1990. *Telemedicine: Technology in Practice*. Paper presented at the International Symposium on Medical Aspects of Earthquake Consequences in Armenia, Yerevan, Armenia, October 9-11.

Benuska, L. 1990. "Loma Prieta Earthquake Report." *Earthquake Spectra* 6 (Supplement).

Benveniste, G. 1989. *Mastering the Politics of Planning*. San Francisco, California: Jossey Bass Publishers.

Churchman, C.W. 1971. *The Design of Inquiring Systems: Basic Concepts of Systems and Organization*. New York: Basic Books.

Comfort, L.K. 1986a. "Improving Organizational Decision Making Capacity: A Design for an Interactive Emergency Information System." Pp. 181-193 in *Terminal Disasters: Computer Applications in Emergency Management*, edited by Sallie Marston. Monograph No. 39, Institute of Behavioral Science. Boulder, Colorado: University of Colorado.

________. 1986b. "International Disaster Assistance in the Mexico City Earthquake." *New World* 1: 12 - 43.

________. 1988. "Designing Policy for Action." Pp. 3-29 in *Managing Disaster* edited by L.K. Comfort. Durham, North Carolina: Duke University Press.

________. 1989a. "The San Salvador Earthquake." Pp. 323-339 in *Coping With Crisis*, edited by M.T. Charles. Springfield, Illinois: Charles C. Thomas Publishers.

________. 1989b. "Learning From Risk: Organizational Interaction Following the Armenia Earthquakes." Working Paper 89-23 Institute of Governmental Studies. Berkeley, California: University of California. [With the Disaster Reanimatology Study Group.]

________. 1990. "Turning Conflict into Cooperation: Organizational Designs for Community Response to Disaster." *International Journal of Mental Health* 19: 89-108.

Comfort, L.K., J.I. Abrams, J.C. Camillu and E. M. Riccie. 1989. "From Crisis to Community: The Pittsburgh Oil Spill." *Industrial Crisis Quarterly* 3: 17-39.

Comfort, L.K., T.R. Woods and J.E. Nesbitt. 1990. "Designing an Emergency Information System: The Pittsburgh Experience." Pp. 31-49 in *Crisis Management and Information Systems*, edited by Tom Housel. Greenwich, Connecticut: JAI Press.

Cuny, F.C. 1983. *Disasters and Development*. Oxford: Oxford University Press.

Drabek, T.E., H. Tamminga and T. Kilijanek. 1981. *Managing Multiorganizational Emergency Responses*. Boulder, Colorado: University of Colorado.

Jaske, R.T. 1989a. "Some Considerations of Data Management Standards in Achieving a National Distributed Data Processing System." Paper presented at the Geographic Information Systems Conference. Washington, D.C. (March).

________. 1989b. "The Geographic Information System as the Ultimate Data Management System." Paper presented at the International Geographic Information System Symposium, Baltimore, Maryland. (March).

Klain, M., E. Ricci. P. Safar, V. Semenov, E. Pretto, S. Tisherman, J. Abrams, and L. Comfort. 1989. "Disaster Reanimatology Potentials: A Structured Interview Study in Armenia." *Prehospital and Disaster Medicine* 4: 135-157.

Mackenzie, K. 1987. *Organizational Design: Organizational Audit and Analysis Technology*. Norwood, New Jersey: Ablex Publishing.

McCann, C.A., M.M. Taylor, and M.I. Tuori. 1988. "ISIS: The Interactive Spatial Information System." *International Journal of Man-Made Machine Studies* 28: 101-138.

Meltsner, A. and C. Bellavita. 1984. *The Policy Organization*. Beverly Hills, California: Sage Publications.

Perry, R.W. and A.W. Mushkatel. 1984. *Disaster Management: Warning, Response and Community Relocation*. Westport, Connecticut: Quorum Books.

Rosenthal, U. and M. Charles. 1990. *Coping With Crisis: The Management of Disasters, Riots and Terrorism*. Springfield, Illinois: Charles C. Thomas Publishers.

Rubin, Claire B. 1982. *Long Term Recovery from Natural Disasters*. Washington, D.C.: Academy for State and Local Government.

Safar, P., E. Pretto and N. Bircher. 1988. "Disaster Resuscitology Including Management of Severe Trauma." Pp. 36-86 in *Medicine for Disasters*, edited by P. Baskett and R. Weller. London: Wright-Butterworth Publishers.

Shrivastava, P. 1987. *Bhopal: Anatomy of a Crisis*. Cambridge, Massachusetts: Ballinger Publishing Company.

Simon, H.A. 1981. *The Science of the Artificial*. Cambridge, Massachusetts: MIT Press.

Turner, B. 1978. *Man Made Disasters*. London: Wykeman Publishers.