AN INTERACTIVE INTELLIGENT SPATIAL INFORMATON SYSTEM (IISIS) FOR DISASTER MANAGEMENT: A COMMUNITY MODEL

University of Pittsburgh
University Center for Social and Urban Research
May 29, 1998

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Working Paper 98-9

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Problem Statement

The startling increase in costs of disaster in the U.S. over the last decade has compelled the emergency management community to shift its focus from response and recovery to mitigation of damaging events. These costs have been estimated at $50 billion per year[1], creating a cumulative impact on the nation's capacity to manage continuing risks to communities exposed to natural and technical hazards. Mitigation practices that have relied either primarily on technical solutions, or organizational training and response, have historically failed.[2] In most instances, these failures resulted not from lack of effort, money, or awareness of risk. They resulted from lack of adequate knowledge about the likely consequences of a disaster in an interdependent, urban environment, and lack of timely, accurate information available to responsible organizations to enable them to take effective action under the stress of an actual event.[3] As disaster losses escalate in interdependent environments, the search for improved methods of risk reduction and response intensifies.

This problem involves three broad sets of issues. The first set is practical: how can a community increase its capacity to mitigate and respond to disaster in its environment? The second set is social, cognitive, and organizational: what are the cognitive processes that occur among experienced personnel engaged in interactive disaster response operations; how do these processes change to meet the dynamic demands of an evolving situation; and what kinds of information are needed to support decision making within and among organizations in reference to that event? The third set is technical: how can an information system support the dynamically changing roles of individuals and organizations as they adapt to shifting needs, without overwhelming the personnel in complexity; and how can the system provide distributed intelligent support in response to changing local conditions to assure that actions taken conform to the established guidelines of emergency management?

IISIS Approach

The prototype interactive, intelligent, spatial information system (IISIS) offers an approach to mitigation and response that links information technology with organizational design and learning to create an information system that provides decision support to practicing agencies. It utilizes aspects of advanced computational techniques including intelligent reasoning, graphical information system techniques, and flexible computer human interface design to support communication, coordination, feedback and learning processes identified by social science analysis. The prototype IISIS facilitates coordination of the multiple aspects of disaster response, provides real-time information as the disaster evolves, and provides intelligent guidance to decision makers confronting complex situations requiring urgent action.

The IISIS prototype is designed to provide interorganizational decision support to multiple organizations seeking to achieve the common goal of reducing risk, and to support appropriate action at multiple levels -- households, private businesses, public agencies, and nonprofit organizations -- when threats occur. This approach produces a `sociotechnical' system of interacting computers, organizations, and individuals working toward a common goal. The term, sociotechnical, indicates the interdependent relations among the built environment, machines and people who use them in the dynamic environment of a modern urban community. Computers become active components of the response system, enabling a diverse set of human decision-makers to process complex information simultaneously with sufficient accuracy and timeliness to support coordinated action.

The IISIS design supports a dual use system for improved management of disaster at both organizational and community levels. That is, managers may use the system in their respective public, private, and nonprofit organizations for daily, routine operations in monitoring and mitigating seismic risk. When disaster occurs, the IISIS activates a community-wide response network that creates an event-specific knowledge base by drawing relevant information from multiple data bases and many organizations to support interorganizational and interjurisdictional decision making in reference to that event. Dual use ensures that users are familiar with the system and the information is current when a disaster occurs.

Figure 1: Sociotechnical System, IISIS Prototype

The long-term goal of this project is to increase the capacity of communities to mitigate and respond effectively to disasters. This need is especially critical at the local level, where the initial actions taken can affect the subsequent course of decisions and actions dramatically -- positively or negatively -- over the course of disaster operations. The IISIS design specifically incorporates information needs acknowledged by practicing emergency managers and recognizes the importance of organizational design, training, development and learning as central to the effective utilization of information technology in disaster hazard reduction. This project would mark a vital step toward the realization of a global information infrastructure to reduce disaster hazards.

The transition from routine to disaster operations presents a stubborn problem in disaster response. The inability of personnel to grasp the magnitude of changes occurring in disaster environments may be due to missing data, but it may also be due to a cognitive lag behind the pace of rapid change. An information system that simply reported all of the events occurring in a disaster may not provide management personnel with a coherent, comprehensible interpretation of the whole situation. Assessing the rates of change in the frequency of demands for assistance, and the degree of complexity in interactions among the components of the evolving response system may be summarized, analyzed, and presented by the system to the set of professional disaster managers simultaneously. Such measures would provide crucial assessments of the `state of the community' that would enable professional managers to adjust their actions in the crisis effectively and efficiently.

System Design

The current IISIS prototype consists of three basic components: 1) interactive communication among distributed knowledge bases; 2) dynamic representation of graphical information as the event unfolds, using GIS; and 3) intelligent reasoning by the computer to integrate incoming information from the environment with stored information about the community, its infrastructure and population to assess the likely consequences of the event for the community. Figure 2 illustrates how observations of a threatening event are transmitted via a Web page interface to an information system that provides a continuous assessment of the 'state of the community'. The intelligent reasoning component will calculate the probabilities of risk from specific events for designated community systems, and, when completed, will calculate the cumulative probability of risk for the whole community. As information from the environment enters the information system, it is passed to the intelligent system, which first compares the change in new information about the community with stored information from the knowledge base to assess the degree of discrepancy. The intelligent system draws upon multiple sources of knowledge concerning stored data about the geographic and physical characteristics of the environment, social and economic characteristics of the population, legal and organizational requirements for action. Based upon discrepancies between incoming and stored information, the intelligent system will calculate probabilities of risk, and return this information to the user, via the Web interface. As events change, new information triggers a continuing reassessment of the state of the community, providing practicing managers with current assessments of the probability of risk at specific locations, as well as an overall assessment of risk for the whole community.

Figure 2: System Design, IISIS Prototype

The IISIS prototype supports decision-making at multiple levels of jurisdiction and action. The human-computer interface is a set of Web pages that receive input from the user, transmit it to the information system, and return new information, processed through the system, to the user. The screens are designed to keep the manager's focus for his/her particular level of operations, but to allow movement to other jurisdictional levels of operation and other phases of disaster management as the event evolves. For example, if the user designates response as the phase of disaster operations, all subsequent screens will capture information regarding response operations. The designation of jurisdictional level has the same function. The user may, however, shift the stage or level of operations by changing the selection to a different phase or jurisdiction. The system is designed to be flexible and allows adaptation to meet specific needs.

The set of functions for the IISIS prototype is organized in three basic subsets of functionality. The first identifies the initial conditions of the community as the basic knowledge base for coordinated action. The second subset reports the event and assesses its impact upon the community dynamically. The third subset provides a continuous record of disaster operations for the specific disaster event.

Figure 3 shows the field status screen, which allows the user to enter the initial report of a damaging incident. This screen displays the initial information characterizing the incident: time, location, type of hazard, estimated severity, environmental conditions such as temperature and wind direction. Figures 4 - 7 show aspects of the process of dynamic assessment of the event. The intelligent reasoning component will provide further assessment of these events as they evolve. It will identify the area of geographic impact, and within this area, estimate the consequences of this event for the population of the community, its built environment, its lifelines and existing resources for response.

This information is posted on the `electronic blackboard' which is monitored by the knowledge sources for the separate organizations that have legal responsibilities for response in disaster fire, police, emergency medical services, public works, and others. The organizational knowledge sources contain the standard operating procedures for each organization in event of emergency. If any one of these procedures is triggered for action by the incoming information, that action is reported to all other emergency response organizations via the electronic blackboard. The intelligent component uses this information to calculate the probability of risk to individual sectors of the community, as well as the cumulative level of risk for the whole community. This information is returned to the user (practicing manager) by the computer via the Web page.

Figure 3: Field Status Screen

Figure 4: Disaster Site, Community Scale

Figure 5: Disaster Site, Block Scale

Figure 6: Disaster Site, Building Scale

Figure 7: Damage Assessment

The third set of general functions provides record of disaster operations for the current disaster event. It includes needs reported from the community and actions mobilized in response by the set of public, private and nonprofit organizations engaged in disaster operations, transmitted simultaneously to relevant personnel. The prototype IISIS tracks the pattern of interactions among participating organizations, creating a common base of knowledge for the event and enabling the organizations to adjust their actions mutually in order to achieve the shared goal of protecting the community. Computer screens representing these functions are designed to capture the dynamic flow of information and action that occurs in the disaster management process and to facilitate coordinated action among the range of organizations and jurisdictions participating in this process. Figures 8 and 9 illustrate the exchange of information among the notification directory, jurisdictional plan governing the incident, the logistics and strategies involved in conducting operations, the current status of operations and the complete log of actions taken during the event. It represents this dynamic flow of information from different sources, actors and organizations through the system and back to the decision makers in an enhanced, updated form.

Figure 8: Current Status of Operations

Figure 9: Log of Actions

IISIS poses four fundamental system design issues that set this project apart from current practice in building information systems for organizational use. First, this research addresses information needs for decision-makers operating in the dynamic, urgent environment of disaster operations following a major disaster. Most information systems are designed for well-understood tasks and relatively static situations, demonstrated in practice in fields as diverse as software engineering and expert system development. The full consequences of a major disaster in a complex urban environment, however, cannot be predicted reliably in advance. A multi-agent decision support system for such an environment must necessarily be dynamic, incorporating a continuous stream of new information into the system and adapting performance of different subsystems accordingly (O'Hare and Jennings, 1996:67-75).

Second, in this dynamic operating environment, participating personnel often take on new roles, or create novel relationships which did not exist prior to the disaster. An adaptive information system needs to be more flexible than a typical information system in order to offer personnel a range of views regarding the evolving situation as needs and available resources change (Hoschka, 1996).

Third, disaster environments place a large cognitive and emotional burden upon participating personnel. The proposed prototype will provide not only a knowledge base of relevant information and a dynamic description of unfolding events, but also an intelligent guidance system to support individual reasoning and cooperative decision making processes in that event. Rather than the narrowly focused architecture of traditional expert systems and decision support systems, this system will provide a robust and broad base of support for human reasoning. It will offer: 1) local advice for strategic situations; 2) a general implementation of the standard operating procedures for disaster response (based on the qualitative inputs provided by human users); and 3) a broad based assessment of the overall situation regarding aspects such as rates of change of activity and levels of risk (Metzler and Martincic, 1998).

Fourth, given the dynamic, urgent environment of disaster operations, the information system needs to be both robust and sustainable. The dual-use design of this system will serve to increase both qualities, as managers would use it in their daily operations for single-organizational tasks and update the knowledge base on a continuing basis. Dual use ensures that users are familiar with the system and the information is current when a disaster occurs. This design overcomes the twin weaknesses of single-use emergency information systems: lack of familiarity with the system among personnel when the disaster actually occurs, and obsolete data in the knowledge base. If organizations use the system to support their daily activities, their personnel will not only maintain the currency of the knowledge base, but make the transition to community-wide use more easily.

Conclusion and Expected Results

The IISIS prototype offers a mechanism for the development of a sociotechnical system for managing risks in a complex urban environment. By adapting and integrating appropriate information technologies to support interorganizational decision making and providing real time information to practicing managers, IISIS will contribute to advances in both technical and organizational functions at two levels of performance: professional and public. At the professional level, it will enable public, private and nonprofit organizations to adapt their resources and energy constructively to reduce risk and respond effectively when disaster occurs. At the public level, it will enable ordinary citizens to gain timely access to relevant information. The use of the IISIS prototype for both professional and public communication of information regarding risk will contribute to that community's capacity to adapt and respond to demands from its environment in a more timely, appropriate, and efficient manner.

END NOTES

1. James Lee Witt, Director, Federal Emergency Management Agency, estimated the cost at $50 billion per week in the years of heaviest losses from 1992-1996, Address, National Flood Insurers Conference, Pittsburgh, PA, April, 1997. These events include the costs of major disasters such as Hurricane Andrew, 1992; $28 billion; the Mississippi Floods, June-July, 1993, over $10 billion with continuing costs; the Northridge Earthquake, $26.7 billion, as well as the continuing costs of recurring tornadoes, floods, winter storms, heat emergencies, and the terrorist incidents of the World Trade Center and the Oklahoma City bombing.

2. In Hurricane Andrew, August 1992, for example, a major source of failure in the loss of housing was due to shoddy construction practices. This occurred despite the fact that Florida has a rigorous building code enacted to guard against exactly this type of failure, due to the recurring risk of hurricanes. K. Carley and J. Harrald, 1997. "Organizational Learning under Fire." In L.K. Comfort, Ed. Special Issue: Initiating Change: Theory and Practice. *American Behavioral Scientist.* Vol.40, No.3:310-332.

3. L. K. Comfort, 1997. "Shared Risk: A Dynamic Model of Organizational Learning and Action." In J. Garnett and A. Kouzmin, *Handbook of Administrative Communication.* NY: Marcel Dekker, Inc.:395-411.

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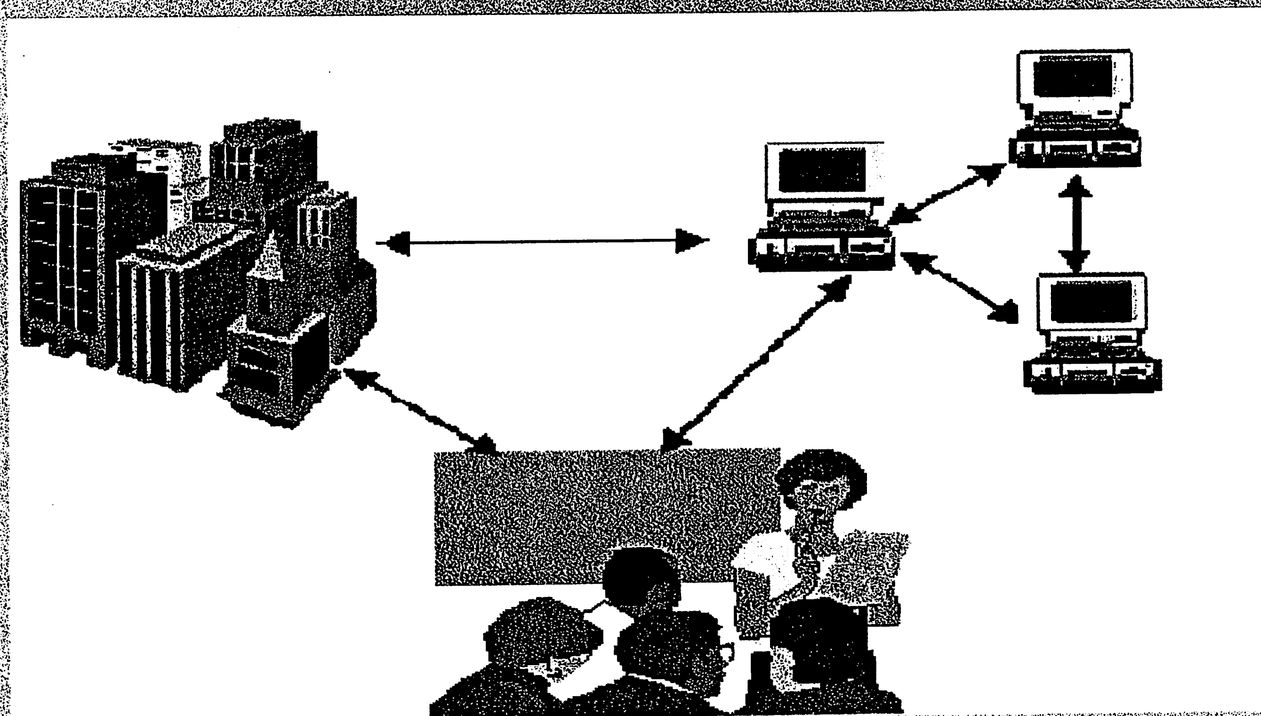
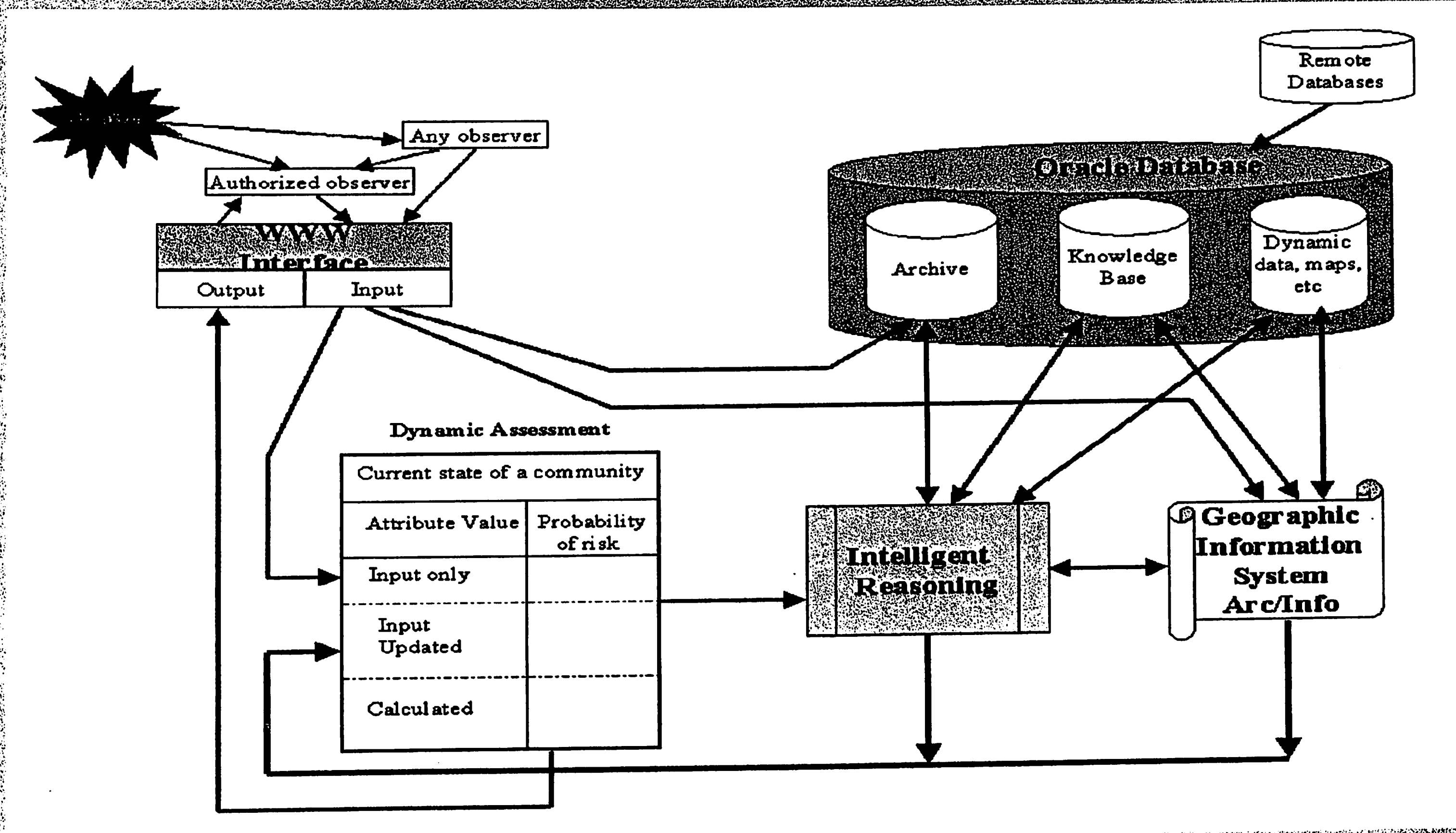
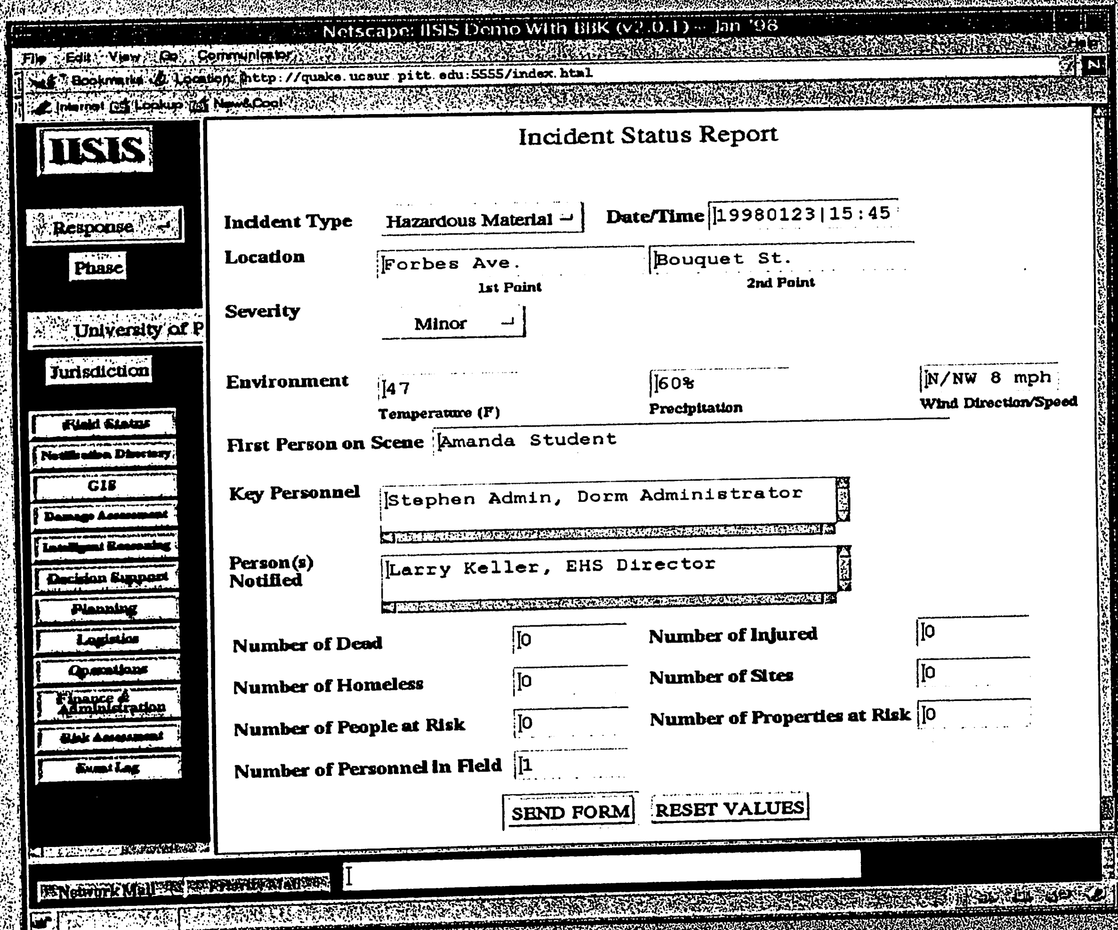
Figure 1: IISIS, Sociotechnical system



System Design



IISIS Prototype, Three Basic Subsets



1. Existing conditions in the community as the basic knowledge base for coordinated actions

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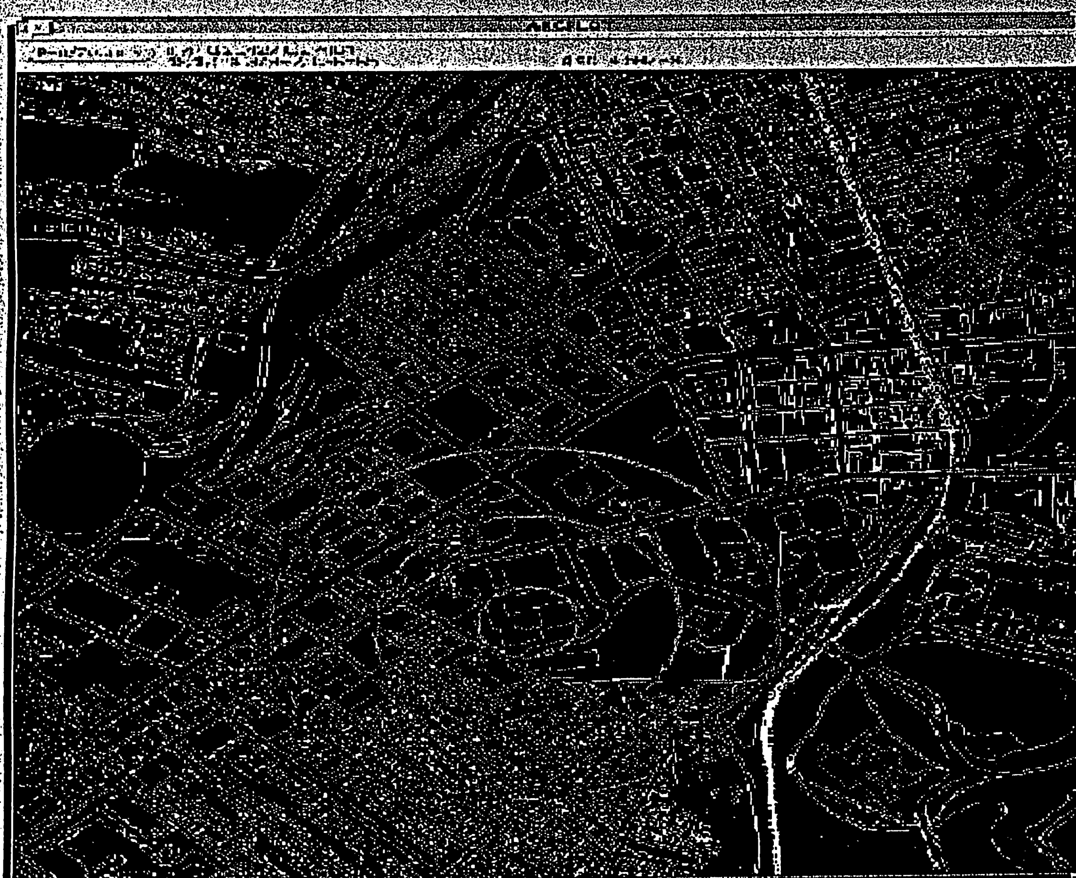
IISIS Prototype, Three Basic Subsets

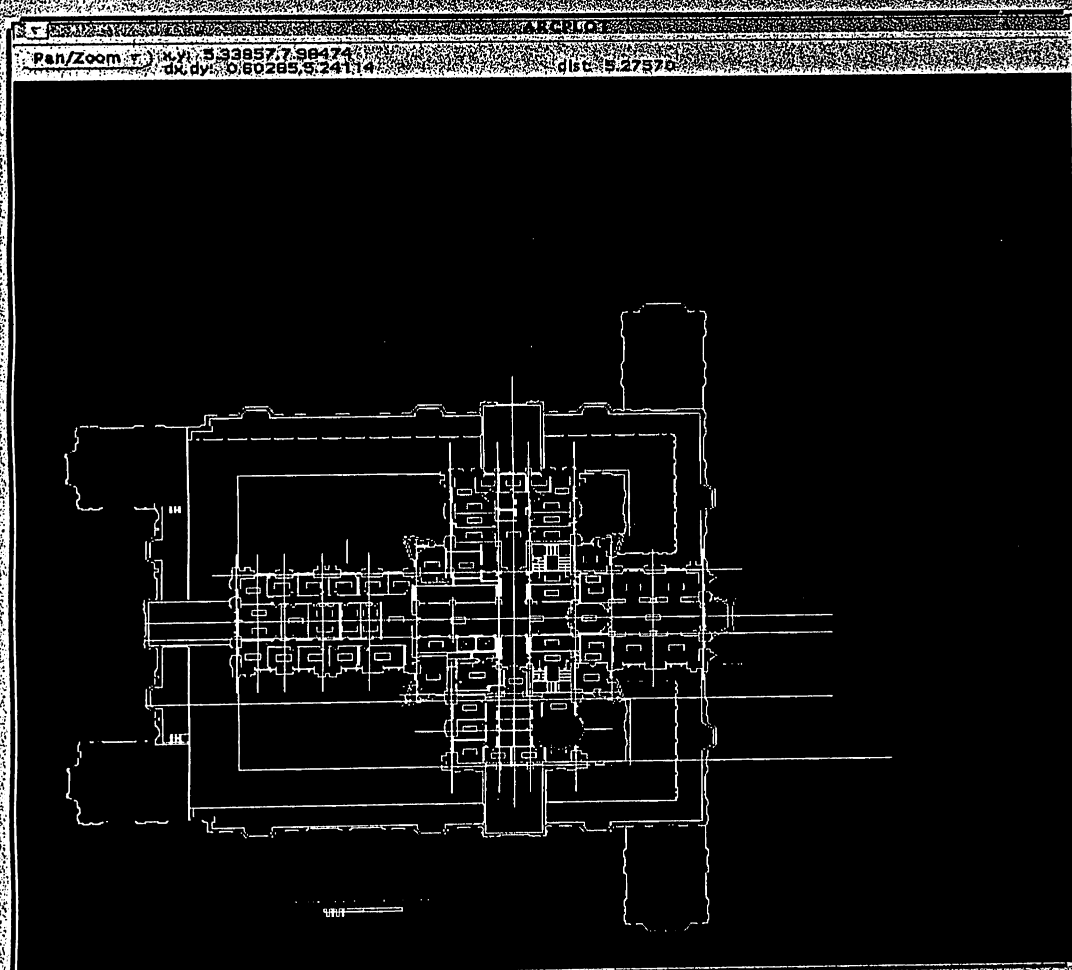


2. Event and its impact upon the community dynamically

⇦ Community Scale

⇦

IISIS Prototype, Three Basic Subsets

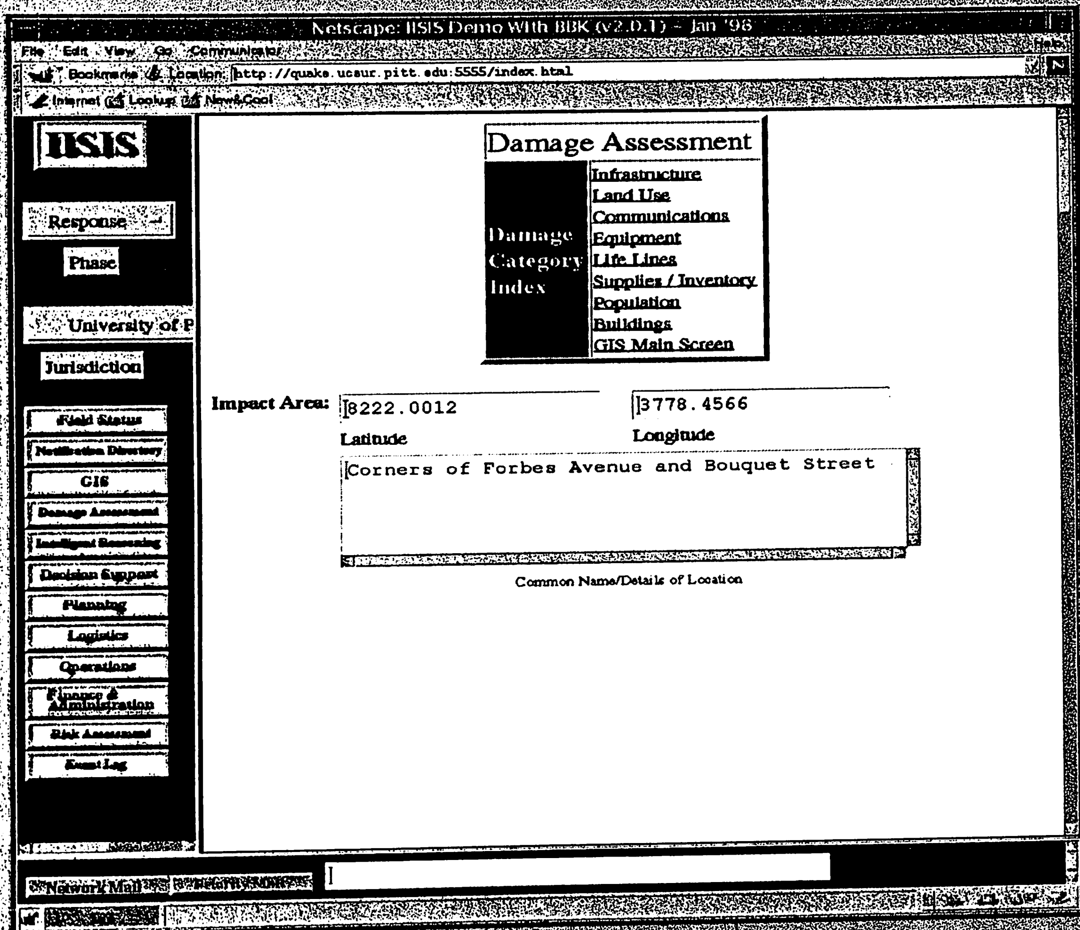


2. Event and its impact upon the community dynamically

⇦ Building Scale

⇦

IISIS Prototype, Three Basic Subsets

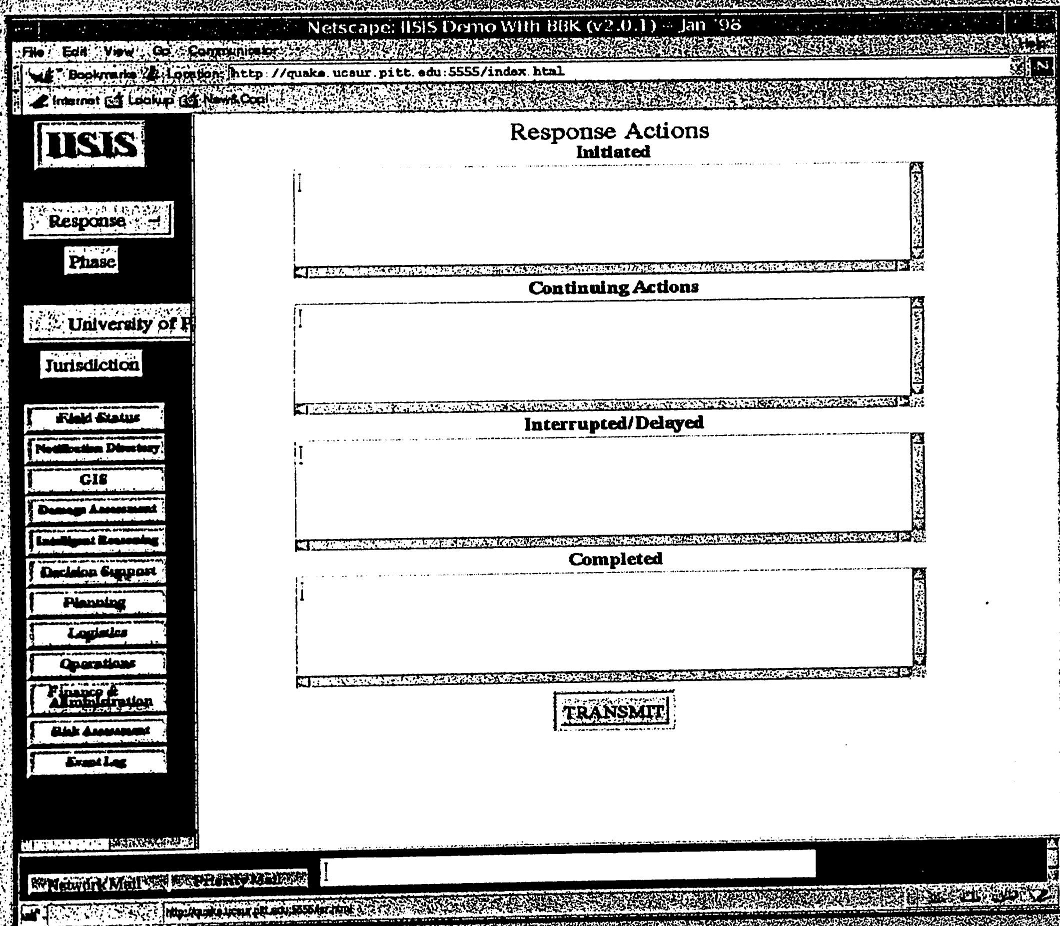


2. Event and its impact upon the community dynamically

⇦ Damage Assessment

⇦

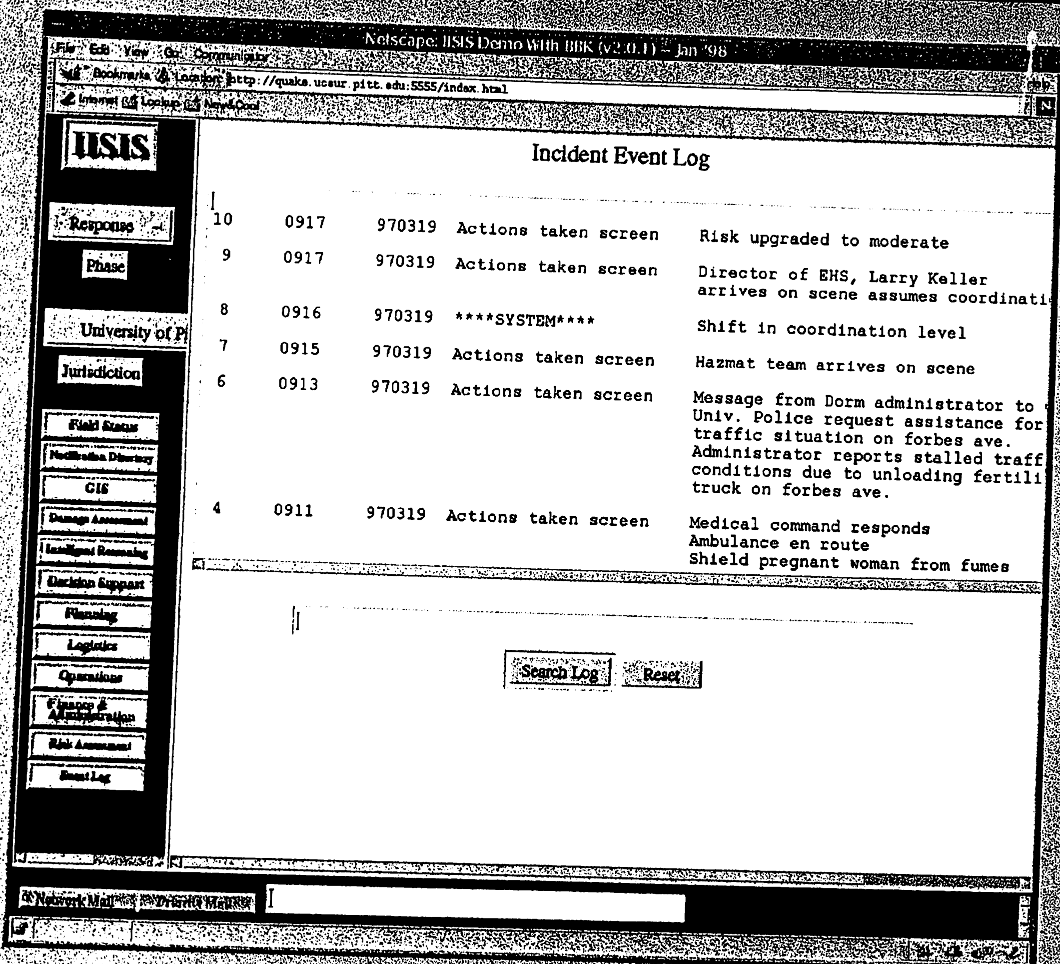
IISIS Prototype, Three Basic Subsets



3. A continuous record of disaster operations for the specific disaster event.

⇦ Current Status of Operations

IISIS Prototype, Three Basic Subsets



3. A continuous record of disaster operations for the specific disaster event.

⇦ Log of Actions

⇦