Title
Complexity, information technology, and crisis management

Author
Comfort, Louise K.

Publication Date
1995

Complexity, Information Technology, and Crisis Management

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

Working Paper 95-1

IGS
INSTITUTE OF GOVERNMENTAL STUDIES
UNIVERSITY OF CALIFORNIA AT BERKELEY

m- 5/24/95

Complexity, Information Technology, and Crisis Management

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

Working Paper 95-1

COMPLEXITY, INFORMATION TECHNOLOGY, AND CRISIS MANAGEMENT

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

Prepared for presentation at the Conference on "Evolving Complexity" at the University of Texas at Dallas, November 18-19, 1994.

Complexity, Information Technology, and Crisis Management

Louise K. Comfort
University of Pittsburgh

Complexity and Change

The intersection between complexity and change increasingly characterizes our social environment. As measures on these two axes of social structure and process increase simultaneously, the systems that we have designed to order our environment for accomplishing goals of physical security, economic stability, and creative expression become increasingly vulnerable and unpredictable. Left unattended, these conditions lead to crisis.

In this paper, I examine the intersection of complexity and change in social systems and the effect of this dynamic relationship upon social action. I draw upon concepts from complexity theory to offer some preliminary hypotheses about transition in complex systems, and examine some current advances in information technology that may facilitate human reasoning in rapidly changing, complex environments. I present observations and data from an actual case in crisis management, disaster response operations following the Northridge Earthquake, January 17, 1994, in reference to the task of generating constructive transition in complex systems. Finally, I offer a set of conclusions that link improved performance in complex systems to appropriate uses of information technology, especially under the urgent time constraints of crisis.

The classic linear model of cause and effect in social action assumes that change is the product of individual effort.

That is, individuals are considered primarily responsible for the outcomes they are or are not able to achieve. In complex, changing times, this assumption becomes less reliable for many people. Too many factors operate outside their control; too many events occur to invalidate their reasoned plans. The social environment appears increasingly chaotic, incomprehensible, and resistant to individual efforts made in good faith. Individuals blame "the system" for their failures, which they do not understand.

Ilya Prigogine, Nobel Laureate in chemistry, asserts that the problem lies less with the social world itself than with our understanding of its dynamics and potential creative force. In Prigogine's (1987:102) terms, the "basic message of the second law of thermodynamics [is that] we are living in a world of unstable dynamical systems." In a dynamical model of human society, there is an internal structure to social patterns of interaction, but this system is "firmly embedded in an environment with which it exchanges matter, energy, and information" (Nicolis and Prigogine, 1989:230). The continual exchange of energy, information, and material conditions with the environment drives the internal dynamics of human social systems and leads to the spontaneous reorganization of roles and behavior among the actors in the system.

The possible loss of stability at one level of operation in a social system need not be viewed as destructive. Rather, it may create the opportunity for a transition to a new and more appropriately ordered pattern of interaction between the system and its environment (Nicolis and Prigogine, 1987:71). Understanding this process of transition to more effective levels of system organization and performance within the flux of the environment and learning how to produce effective transitions in a timely, efficient manner are critical skills that we need to develop in both research and practice.

The capacity to make 'transitions' between different states, an essential feature of complex behavior (Nicolis and Prigogine, 1987:36), appears to be a distinguishing characteristic between linear and nonlinear social systems. With linear models of policy analysis, econometrics, or trend analysis, we are able to chart the performance of established systems within prescribed parameters over time. However, these models do not allow us to anticipate future states in dynamic systems or to predict with any degree of certainty what outcomes would follow from alternative courses of action. These models assume that existing conditions are likely to remain stable over time, and that conditions operating in the future will function very much as they did in the past. In a rapidly changing, complex environment, these models are very often invalid or misleading.

In nonlinear systems, differences in initial conditions precipitate variations in performance that increase exponentially in processes iterated over time (Prigogine and Stengers, 1984; Ruelle, 1991; Nicolis and Prigogine, 1987.) Two primary characteristics of nonlinear systems are stochasticity and irreversibility in time (Prigogine, 1987; Gell-Mann, 1994). That is, random events set in motion sequences of reasoning and action that differ from previous behavior in the system, generate different dynamics of selection and evolution in performance (Kauffman, 1993), and create memories and interpretations of that experience that produce a unique combination of choices, actions, and reasoning that could not be predicted. Similarly, these action and reasoning processes, once generated and instantiated in experience and practice, cannot be reversed.

Understanding the processes of social change and learning how to bring it about successfully, within schedule and under budget, are urgent needs in our present society. The 1994 mid-term elections illustrated the dissatisfaction of those who perceived that change, although initiated in reference to public programs such as health care and employment generation, had not been achieved as promised in the 1992 presidential campaign. In complex environments, there are multiple variables interacting to influence or obstruct a given course of action, generating instead a different dynamic than the anticipated plan.

Devising means of measurement for nonlinear, dynamic systems requires thoughtful exploration and innovative application. The dimensions of nonlinear systems are dynamic and multiple. At least three dimensions intersect to influence action in complex systems. They are: 1) the degree of urgency, or time pressure, for decision; 2) the degree of uncertainty of outcomes; and 3) the number of actors participating in the system. As conditions increase or decrease on any given dimension, that change directly affects performance on the other two dimensions. The result is a set of environmental conditions and adaptive actors operating in a continually evolving process of dynamic change. To understand this process and to use it constructively in designing social action, we need methods of measurement and analysis that allow us to assess each dimension in reference to simultaneous change in the others.

<u>The Characteristics and Constraints of Complex, Adaptive Systems</u>

At least five conditions serve to constrain the evolution of dynamic social systems. The first, and most powerful constraint, is our limited cognitive capacity. If human problem solving capacity derives from short-term memory and that memory is restricted to seven items at a time, plus or minus two (Newell and Simon, 1972; H.A. Simon, 1969, 1981), we quickly lose track of events or conditions in which there are tens, hundreds, or thousands of interacting variables. Our long term memory, in contrast, is virtually unlimited (Simon, 1969, 1981) and serves as a corrective factor in human judgment, when we have time to reflect on the issues before us and search for corroboration in evidence or alternative explanations.

While each of us can carefully develop a partial view of a given slice of our environment, no one of us, alone, can comprehend a set of measures for the whole society. Further, human problem solving capacity tends to decrease under the stress of urgent time pressure. In complex, interdependent systems operating under tight time constraints, individual judgment is subject to error. The urgency of time, intersecting with limited cognitive capacity, is a defining dimension for complex social systems.

Second, given our cognitive constraints, the design and maintenance of social systems depends upon collaborative human action. Since collaboration is essentially a voluntary act, this condition acknowledges the uncertainty, a second defining dimension of complex behavior, involved in initiating any course of action. The system itself needs to include mechanisms for detecting and correcting error, sure to emerge from an eclectic set of partial views. Ironically, while we often cannot see error in our own reasoning, we can easily identify error in the reasoning of others (Argyris, 1982, 1990, 1993). Designing means of error detection and correction, without threatening or embarrassing the participants in the system, requires building a normative commitment to discovery of the "truth," or at least to agree upon standards of evidence and reasoning that will allow others, when presented with the same evidence, to draw similar conclusions. A well-developed process of professional social inquiry serves this function of detection and correction of error in the judgments used for policy making (Lindblom and Cohen; 1979; Lindblom, 1991).

Third, in acknowledging the role of selection and chance in the evolution of change (Kauffman, 1993:10, 24-25), we shift the dynamic from a deterministic to a more complex process that includes the possibility of informed guidance and self organization in the system. Gell-Mann (1993:316) states that:

> ...chance plus selection pressures can lead from a simple initial condition to highly complex forms and to complex ecological communities comprising such forms.

The challenge is not only to recognize and describe this process of transition between action states that produces complex systems, but to understand better how it occurs so that change which is consistent with the articulated goals of the system can be more easily achieved and processes that negate the goals of the system can be avoided or interrupted. Change becomes a continuing process of discovering the "best fit" in the system's recurring interactions with its environment (Piaget, 1980), rather than a single, dramatic event. Further, upper and lower constraints on action are articulated by participating system members in this on-going process. Consequently, understanding and designing mechanisms by which system participants engage voluntarily in timely, constructive transition to a more efficient interaction with their environment is as important as diagnosing the substantive problem prompting the inquiry. While improved mechanisms for self evaluation of performance will not remove uncertainty from the change process, such mechanisms are likely to facilitate patterns of inquiry, reflection, and review among system participants that will enable them to make transitions more easily and lead to more effective outcomes.

Fourth, system performance depends upon the mix of resources in time, materials, attention, and information available to the participants. As the number of participants and the number of interactions among those participants increases the number of demands placed upon a given system, the performance of the whole tends to drop. As vividly illustrated by Garrett Hardin (1968) in his essay, "The Tragedy of the Commons," a given system is able to achieve only ever poorer resolutions to shared problems (Kauffman, 1993:51), given the constraints of time, uncertainty, and a declining number of opportunities for choice. Poor performance, in turn, creates the necessity and/or opportunity for transition to a new state.

Finally, in a dynamic world, stasis is not a viable choice. If we are not seeking better means of understanding, functioning, and coping with the environment in which we live, we diminish our chances for reaching our goals through system performance. Unless we are able to manage change successfully, we waste scarce resources, especially human resources, in our efforts to create a humane world with respect for individual dignity, creativity, and stewardship of the environment.

Toward a Theory of Transition in Complex Systems

Drawing upon concepts from complexity theory and field observation of complex systems in action, I offer the following set of preliminary hypotheses regarding the process of transition in complex systems. This set does not yet constitute a theory, but rather represents a set of preliminary hypotheses presented for review, disconfirmation, and further observation in actual practice. The set includes:

1. Early detection of differences in the initial conditions of a system's operation allows early identification of possible variations in performance in action iterated over time (Prigogine and Stengers, 1984)

2. Differences in initial conditions may require different types of information distributed at different rates of absorption to different sub-groups operating within the system (Cohen and Levinthal, 1990)

3. A sensitive balance between structure and flexibility within the system allows the adaptation of existing structure to changes in information, energy, and materials from the environment and the formation of sub-groups to perform different tasks needed to achieve the system's goal in response to different clientele needs (Kauffman, 1993)

4. Each sub-group develops its own dynamic of learning and action to achieve the larger system's goal (Ditto and Pecora, 1993), while maintaining the system's focus through information exchange

5. Without continual feedback and focus, the energy and direction of the various sub-groups may conflict and compete for attention and resources within the larger system, decreasing performance (Hardin, 1969)

6. Declining performance in the system tends to dealign attention, energy, and resources from prior commitments and create opportunities for reallocation of system resources in new directions (Cohen, March, and Olsen, 1971)

7. A cumulative shift in energy, action, and understanding of the larger goal generates a refocusing of attention among the set of sub-groups, shifting their separate cycles of feedback on performance toward a dominant cycle of feedback and reformulation of a common goal for the entire system (Ditto and Pecora, 1993)

8. This dominant shift in resources, action, and attention constitutes a redefinition of the state of the system and produces substantive change in performance (Kauffman, 1993; Gell-Mann, 1994), or transition to a new state

This set of preliminary hypotheses proposes a beginning model of transition in complex systems. In order to test these hypotheses in practice, we need to develop a set of nonlinear measures and supporting concepts that capture the dynamic exchange of information, attention, and action both within the system and between the system and its environment. An important concept borrowed from the study of nonlinear dynamics in physical systems is "state space" (Ditto and Pecora, 1993:78-80). William Ditto and Louis Pecora (1993:78), physicists who have explored methods of exploiting chaos in mechanical systems, define state space as:

> ...essentially a graph in which each axis is associated with one dynamic variable. A point in state space represents the state of the system at a given time. As the system changes, it moves from point to point in state space, defining a trajectory...which represents the history of the dynamic system.

Using this concept of state space, it is possible to map the dynamic movements of a system and to identify its concentrations and gaps in energy and action (Burt, 1992). These graphic representations of dynamics within the system may reveal sub-systems in operation that are functioning in a stable way, independent of the rest of the system. These sub-systems represent sources of energy, which if oriented in the same direction, can provide a powerful impetus to the redirection of the entire system. By mapping the state space, or trajectory of the dynamic movements in an actual social system, analysts can identify where to allocate system resources of time, energy, and attention to enable the sub-systems to focus on the same goals simultaneously. The resulting dynamics may shift the entire system into a newly realigned and more effective state.

Similarly, the concept of an N-K system (Kauffman, 1993: 175-209) describes the characteristics of self organizing systems where N equals the number of actors in the system, K equals the number of interactions among these actors, and P equals the 'bias for choice' among the actors, or the goal of the actors that drives action. These three measures allow the identification of a fourth measure -- the boundaries of the system -- operating in response to specific events, times, conditions, and locations in the wider environment. Defining the boundaries helps to identify the relationships between types of complex systems and especially to distinguish sub-systems within larger systems. A final measure, D, equals the duration of the interactions among actors in the system, acknowledging that some interactions may be intense but brief, while others may continue over long periods of time. Other characteristics regarding the content of transactions, sources of support, and conditions of the environment may be identified and mapped, but this set of measures provides an initial assessment of the operating characteristics of a complex system.

This set of characteristics may be summarized as follows (Comfort, 1994:306-307):

1) N = number of organizations participating in disaster response
2) K = estimated number of interactions among participating organizations
3) P = shared goal of organizations, or 'bias for choice' in actions
4) B = boundaries of the system
5) D = duration of interactions among organizations
6) T = types of transactions performed by organizations

While these measures identify the types of information that allow us to track the dynamic characteristics of system performance, they also exceed the cognitive capacity of individual managers to monitor their operating systems, using ordinary methods of data collection, analysis, and static representation. Using advanced information technology, however, it is possible to establish monitoring and mapping techniques that allow managers to track these characteristics of dynamic system performance and to incorporate this information into their management processes. The next section will present a brief summary of a selected set of advanced information technologies that can be used to extend human reasoning capacity in reference to complex systems.

<u>Information Technology as Decision Support in Complex Systems</u>

The rapid expansion and proliferation of information technology and its creative application to social policy issues marks a sea-change in organizational design and performance. The technical capacity of computers to order, store, retrieve, and transmit information over long distances through telecommunications, as well as to perform complex calculations with this information quickly and accurately, transforms human problem solving capacity. No longer limited to seven items at a time (plus or minus two), human managers can now address complex problems in practical terms which they could only imagine before.

While many applications of advanced information technology have been designed, developed, and put into practice, at least three represent important advances for policy making. These are: 1) an electronic status board, coupled with interactive communications and a layered knowledge base; 2) geographic information systems, coupled with active indexing of dynamic information; and 3) intelligent reasoning for recurring subsets of problems.[1] Each application addresses at least one if not more of the dimensions defining information processes in complex systems, and the integrated set represents an increased technical capacity to manage the intersecting dimensions of complex systems.

An Electronic Status Board.

Central to creative response in complex systems is sufficient structure to hold and exchange information (Kauffman, 1993: 208-227). An electronic status board provides technical support to practicing managers to do exactly that. Using the design concept of an 'electronic blackboard' (Nii, 1984), this concept has been adapted to serve the information needs of practicing managers in hazardous materials management.[2] The electronic status board integrates incoming information from multiple sources regarding dynamic changes in the state of hazardous materials with stored knowledge regarding the parameters of the community to provide a current assessment of a threatening situation. Designed to assist practicing managers in crisis situations, the electronic status board creates a disaster-

---

[1]These three applications are currently being integrated in a prototype interactive, intelligent, spatial information system (IISIS) to facilitate the management of hazardous materials in Allegheny County, Pennsylvania. The prototype is in its second year of development at the University Center of Social and Urban Research, University of Pittsburgh, in collaboration with the Center for Parallel, Distributed, and Intelligent Systems, and is funded by Allegheny County Emergency Management Agency, Pittsburgh, PA.

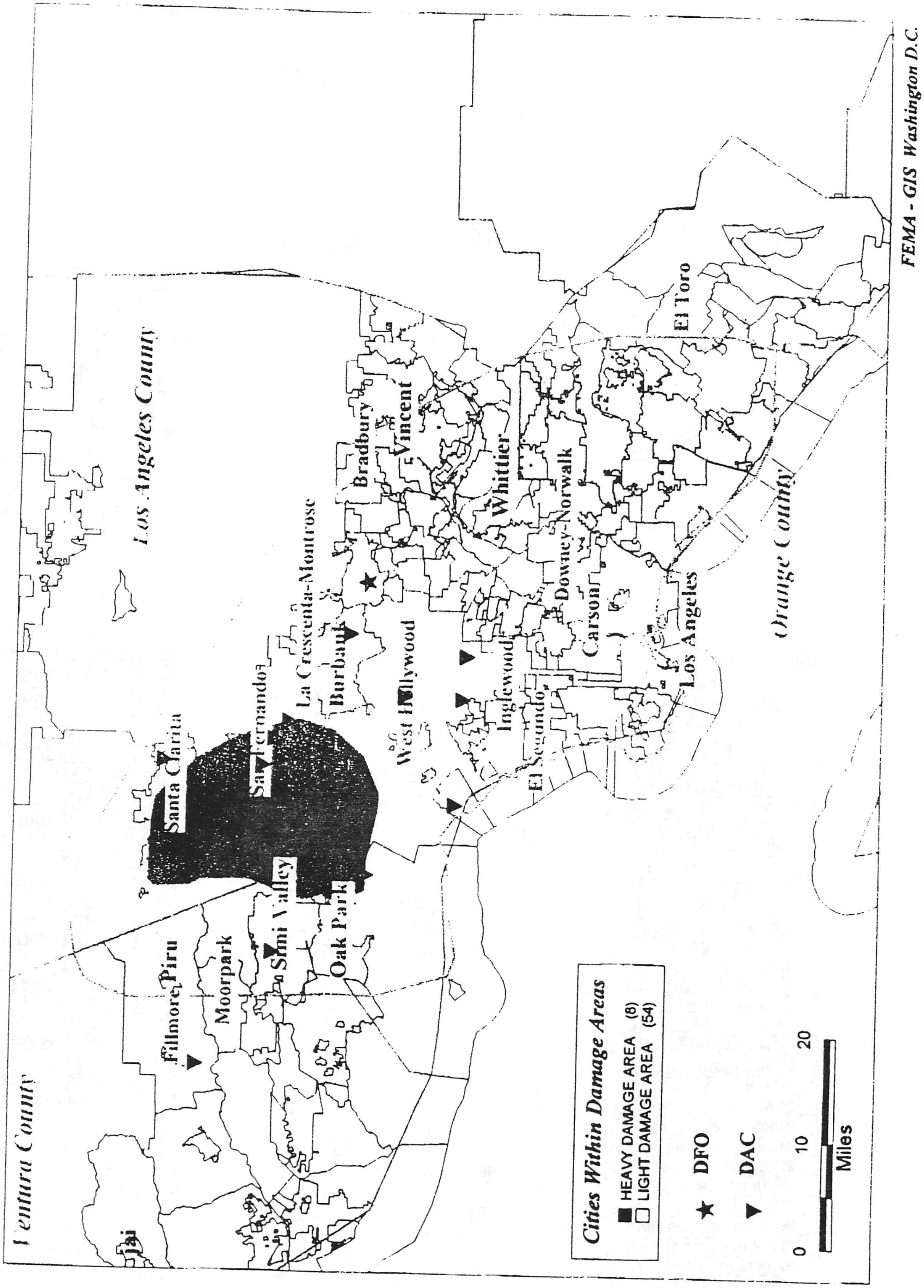
[2]This design is incorporated into the IISIS prototype, and its implementation has benefited from the advice and counsel of Bruce Buchanan, Department of Computer Science, University of Pittsburgh.

specific knowledge base that provides timely, valid information under conditions that require urgent response. The electronic status board also serves to focus the attention of multiple participants in disaster response operations on the critical sequence of tasks in a rapidly evolving emergency.

Geographic Information System.

A rapidly developing technology, GIS combines stored knowledge regarding the parameters of a system with graphic representation of data to policy makers. This technology, widely recognized as a powerful tool for planning and policy design, is increasingly being adapted for rapid response operations when practicing managers need to convey critical information regarding changed conditions to many people simultaneously. When combined with the electronic status board, incoming information can be integrated with existing knowledge of a specific geographic area, and the newly created map can be transmitted via telecommunications to multiple managers simultaneously. For example, Map 1 identifies the degree of damage caused by the Northridge Earthquake in the Tri-County Area of Los Angeles, Ventura, and Orange Counties in Southern California, and Map 2 shows the location of Red Cross and Salvation Army shelters in this area. This visual representation of information reduces the uncertainty regarding alternatives for action that managers confront when they are faced with vague or conflicting information from different

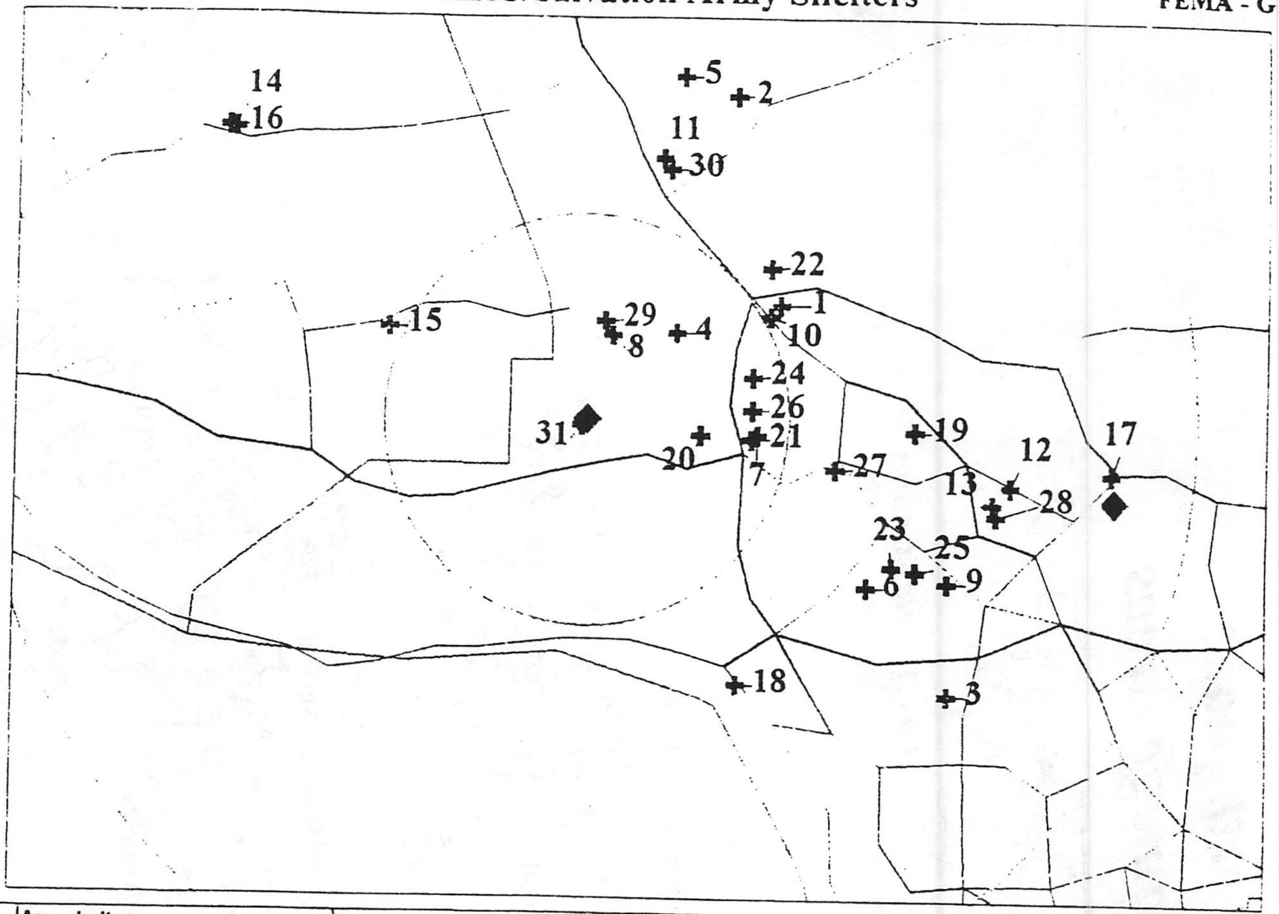
Northridge Earthquake
Tri - County Damage Areas



MAP 1

Northridge Earthquake
ARC/Salvation Army Shelters

FEMA - GIS



ID	Arc_shelte	Address	City	St	Open	Arc_chapte
1	SAN FERNANDO REC. CTR	208 PARK AV	SAN FERNANDO	CA	Y	LOS ANGELES
2	CANYON HIGH SCHOOL	19300 W. NADAL ST	SANTA CLARITA	CA	Y	LOS ANGELES
3	MANUAL ARTS SCHOOL	4131 S. VERMONT	LOS ANGELES	CA	Y	LOS ANGELES
4	GRANADA HILLS HIGH SCHOO	10535 ZELZAH AV	GRANADA HILLS	CA	Y	LOS ANGELES
5	SAUGUS HIGH SCHOOL	21900 W. CENTURION WY	SAUGUS	CA	Y	LOS ANGELES
6	FAIRFAX HIGH SCHOOL	7850 MELROSE AV	LOS ANGELES	CA	Y	LOS ANGELES
7	VAN NUYS HIGH SCHOOL	6525 CEDROS	VAN NUYS	CA	Y	LOS ANGELES
8	MASON REC. CTR	10400 MASON AV	CHATSWORTH	CA	Y	LOS ANGELES
9	L.A. COMMUNITY COLLEGE	855 N. VERMONT	LOS ANGELES	CA	Y	LOS ANGELES
10	SAN FERNANDO HIGH SCHOO	11113 O'MELVENY AV	SAN FERNANDO	CA	Y	LOS ANGELES
11	BOYS AND GIRLS CLUB	24825 N. NEWHALL	SANTA CLARITA	CA	Y	LOS ANGELES
12	WILSON JR. HIGH SCHOOL	1220 MONTEREY RD	GLENDALE	CA	Y	GLENDALE-LACRESENTA
13	GLENDALE ARMORY	100 COLORADO BLVD	GLENDALE	CA	Y	GLENDALE-LACRESENTA
14	SAN CAYETANO MID SCHOOL	514 MOUNTAIN VIEW	FILLMORE	CA	Y	VENTURA COUNTY
15	ROYAL HIGH SCHOOL	1402 ROYAL AV	SIMI VALLEY	CA	Y	VENTURA COUNTY
16	VETERANS MEMORIAL BLDG.	511 2ND ST	FILLMORE	CA	Y	VENTURA COUNTY
17	JACKIE ROBINSON PARK	1081 N. FAIR OAKS	PASADENA	CA	Y	SAN GABRIEL VALLEY
18	SANTA MONICA COMM. COLLE	17TH ST & PEARL ST	SANTA MONICA	CA	Y	SANTA MONICA
19	MCCAMBRIDGE PARK & REC C	1500 GLEN OAKS	BURBANK	CA	Y	BURBANK
20	BIRMINGHAM H. S.	17000 HAYES ST	VAN NUYS	CA	Y	LOS ANGELES
21	VAN NUYS CTR	14917 VICTORY BLVD	VAN NUYS	CA	Y	SALVATION ARMY
22	SYLMAR HIGH SCHOOL	13050 BORDON AVE.	SYLMAR	CA	Y	
23	HOLLYWOOD HIGHSCHOOL	1521 NORTH HIGHLAND AV	HOLLYWOOD	CA	Y	
24	SEPULVEDA RECREATION CE	8801 KESTER AVE.	SEPULVEDA	CA	Y	
25	LE CONTE JR HIGH SCHOOL	1316 N. BRONSON AVE.	LOS ANGELOS	CA	Y	
26	FULTON JR. HIGH SCHOOL	7477 KESTER AVE	VAN NUYS	CA	Y	
27	N. HOLLYWOOD HIGH SCHOO	5231 COLFAX AVE	N. HOLLYWOOD	CA	Y	
28	ROOSEVELT JR HIGH SCHOOL	1017 S. GLENDALE AVE	GLENDALE	CA	Y	
29	SHEPERD OF THE HILLS	19700 RINALDI	CHATSWORTH	CA	Y	
30	NEWHALL SENIOR CENTER	22900 MARKET ST	VAN NUYS	CA	Y	
31	CANOGA PARK HIGH SCHOOL	6850 TOPANGA CANYON R	CANOGA PARK	CA	Y	
32	PIRU SCHOOL .	802 ORCHARD ST.	PIRU	CA	Y	

MAP 2

sources. Active indexing, a developing technique for representing dynamic information, incorporates evolving information from a changing environment into the map and creates an "intelligent" map, in which the information previously stored on the map is integrated with incoming information to provide an updated assessment of the situation.[3] This technology addresses all three dimensions affecting action in complex systems by facilitating the representation of timely, accurate information to multiple managers simultaneously, and thereby reducing the uncertainty of collaborative action.

Intelligent Reasoning.

Intelligent reasoning uses the capacity of the computer to extend a logical sequence of steps for a given set of conditions to calculate probable outcomes.[4] Combined with incoming information from the electronic status board and visual representation of this information to multiple managers, this capacity of the computer allows managers to explore the probable outcomes of different alternatives for action and to calculate the consequences associated with each. It contributes to reducing the uncertainty involved in dynamic conditions, especially important in crisis situations when a large number of managers with differ-

---

[3] Development of this technique for active indexing is currently underway at the Center for Parallel, Distributed, and Intelligent Systems, University of Pittsburgh under the supervision of S.K. Chang, Director.

[4] This component of the IISIS prototype owes much to the thoughtful supervision and work of Bruce Buchanan, Department of Computer Science, University of Pittsburgh.

ent backgrounds and experience may be involved.

These three applications illustrate the substantial assistance that information technology can provide to practicing managers as they cope with threatening situations. It enables them to share critical information widely, while still providing a monitoring and feedback process to each participant to keep the system's response current and in focus. The critical test is whether these applications can be implemented in actual practice.

Crisis Management: A Laboratory for Complex Systems.

While we do not yet have a case in which an integrated interactive, intelligent, spatial information system has been fully implemented in an actual crisis, there is sufficient evidence from disaster operations following the Northridge, California Earthquake, January 17, 1994 to show the potential for using advanced information technology to facilitate the transition from crisis to recovery in the rapidly evolving interjurisdictional disaster response system.

At 4:31 a.m. on January 17, 1994, an earthquake measuring 6.7 on the Richter scale struck the communities of Northridge, Reseda, and Granada Hills in the San Fernando Valley, a section of the City of Los Angeles. It is the largest earthquake to occur in a heavily-populated urban area in California, affecting directly or indirectly approximately three million people in parts of Los Angeles and adjacent cities. The timing of the event, early in the morning on a holiday weekend, contributed to a low death toll and minimized the damage that would likely have occurred in this area under normal daytime activities. Sixty people died in earthquake-related circumstances, which included 19 deaths from heart attacks. Approximately 33 deaths were the direct result of collapsed buildings. Thousands of persons reported injuries, ranging from cuts and bruises to serious trauma requiring hospitalization. Area hospitals reported treating over 2,800 injured persons within 72 hours following the earthquake, admitting 530 patients for hospital treatment.[5] Less traumatic, but equally urgent were the shelter and welfare needs of nearly 33,000 people who suffered damage to their homes. The massive scale of this disaster was mitigated only by the knowledge that it could have been much worse, but for the fortuitous timing of the event.

Response operations were activated immediately by the earthquake, and carried out largely by experienced, well-trained local organizations. State and federal organizations responded promptly to requests for assistance, and immediately mobilized back-up resources to support the local efforts. The first response, including urban search and rescue teams engaged in life-saving activities, and emergency response teams engaged in identifying and stabilizing life-threatening conditions, was completed within 36 hours. From that point, the needs of the community turned to restoring basic services and meeting the basic human needs generated by the significant loss of housing,

---

[5]Earthquake Engineering Research Institute. 1994. Northridge Earthquake, January 17, 1994, Preliminary Reconnaissance Report, Chapter 9, Social Impacts and Emergency Response:86-89.

property, jobs, transportation, and access to other services such as medical care and nutrition.[6] The costs of this disaster, in terms of lost public infrastructure, damage to housing, businesses, schools, hospitals, and the costs of services provided to those rendered homeless and jobless are estimated to be between $13 and 20 billion dollars, close to the losses suffered in the massively destructive Hurricane Andrew in South Florida and Louisiana in August, 1992. With economic losses of this magnitude, the Northridge Earthquake was clearly a national disaster, as reserves and resources from the entire nation were directed toward re-establishing the economic, social, and infrastructure systems of the Los Angeles Basin.

The use of advanced information technology in disaster response and recovery operations following the Northridge Earthquake is unprecedented. These technologies include: Caltech USGS Broadcast of Earthquakes/Rapid Earthquake Data Integration (CUBE/REDI) system; Operational Area Satellite Information System (OASIS); Emergency Digital Information System (EDIS); Geographic Information System (GIS); Recovery Channel, and a major shift to

---

[6] Detailed accounts of damage resulting from the earthquake and the numbers of individuals, households, and businesses affected are presented in a number of sources. These include the daily coverage of the event in the Los Angeles Times, the situation reports prepared by the Federal Emergency Management Agency and the California Office of Emergency Services, the transcript of the California Seismic Safety Commission's hearings on the response to the earthquake, and reports of professional organizations such as the Earthquake Engineering Research Institute, the Earthquake Engineering Research Center of the University of California, Berkeley, and EQE International, an engineering firm with offices in San Francisco and Irvine, California.

cellular telephones for intra-agency communication. Although these technologies were operating largely through separate entities, they had a significant cumulative effect upon disaster reponse.

Through a combination of planning, preparedness, interactive communication, shared commitment, and chance -- or structure and process -- an interorganizational, interjurisdictional disaster response system evolved very rapidly following the Northridge Earthquake. Within nine days, approximately 9,000 personnel, representing hundreds of organizations -- city, county, state, and federal, as well as private and voluntary -- were actively working together in a coordinated effort to address the community needs generated by the earthquake.[7] On February 2, 1994, federal and state agencies reported over 6,000 employees serving 300,000 clients in disaster response and recovery activities.[8] The North-ridge case provides an extraordinary laboratory to observe the dynamics of complex, adaptive systems in action.[9]

---

[7] Situation reports, FEMA and California Office of Emergency Services, January 27-28, 1994; Interview, Viki Doty, Federal Emergency Management Agency, Region IX, Pasadena, CA, January 28, 1994.

[8] Director's Meeting, Federal Emergency Management Agency, Disaster Field Office, Pasadena, CA, February 2, 1994.

[9] This section draws heavily upon a previous account of the Northridge Earthquake in L. Comfort. 1994. "Risk and Resilience: Interorganizational Learning Following the Northrdige Earthquake of January 17, 1994." Journal of Contingencies and Crisis Management, Vol.2, No. 3 (September):174-188.

While the processes to monitor accurately the number of organizations and the interactions among those organizations were not in place for disaster operations, it is possible to obtain a rough approximation of organizational engagement in disaster operations by jurisdiction and type of transaction from a content analysis of newspaper reports. Table 1 presents the distribution of mentions of disaster response activities reported for public, private, and nonprofit organizations for the first three weeks following the earthquake (Los Angeles Times, January 18, 1994 - February 8, 1994). Not surprisingly, public organizations which have legal responsibility for first response in disaster received the large majority (70%) of mentions. Nonprofit organizations were second, with 19.9% of the mentions, and private organizations received one-tenth of the mentions, 10.1%. Figure 1 represents the distribution of mentions graphically, with reported activities increasing from the first week of response to the second, but declining during the third week.

Table 2 presents the distribution of reported activities by organizations engaged in disaster response by type of jurisdiction and type of transaction. Figure 2 represents graphically this distribution of reported mentions of organizational response activities by type of transaction. Interestingly, over one-third (35.6%) of the reported activities were carried out by organizations at the municipal level. Adding the reported activities for county organizations, the combined city/county total is 42.3%, demonstrating a very strong capacity for disaster response at the

Table 1

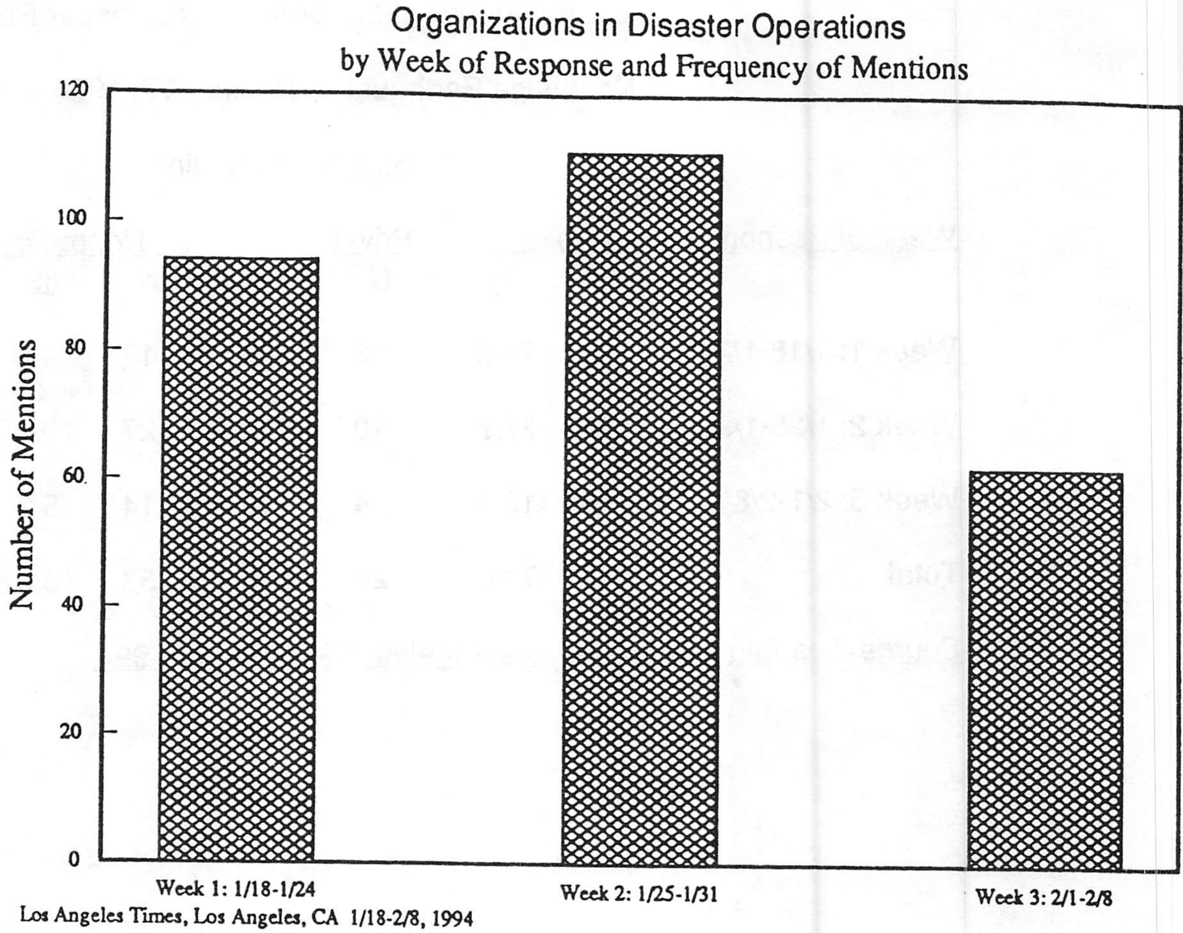
Organizations Participating in Disaster Response by Source of Funding, Week of Response, and Frequency of Mentions in Newspaper Reports

Northridge Earthquake, January 17, 1994

Week of Response	Source of Funding: Public		Private		Nonprofit		Total	
	N	%	N	%	N	%	N	%
Week 1: 1/18-1/24	69	25.8	13	4.9	12	4.5	94	35.2
Week 2: 1/25-1/31	74	27.7	10	3.7	27	10.1	111	41.6
Week 3: 2/1-2/8	44	16.5	4	1.5	14	5.2	62	23.2
Total	187	70.0	27	10.1	53	19.9	267	100.0

Source: Los Angeles Times, Los Angeles, CA 1/18-2/8, 1994

Figure 1



Organizations in Disaster Operations
by Week of Response and Frequency of Mentions
120
100
80
60
40
20
0
Number of Mentions
Week 1: 1/18-1/24
Week 2: 1/25-1/31
Week 3: 2/1-2/8
Los Angeles Times, Los Angeles, CA 1/18-2/8, 1994

Table 2

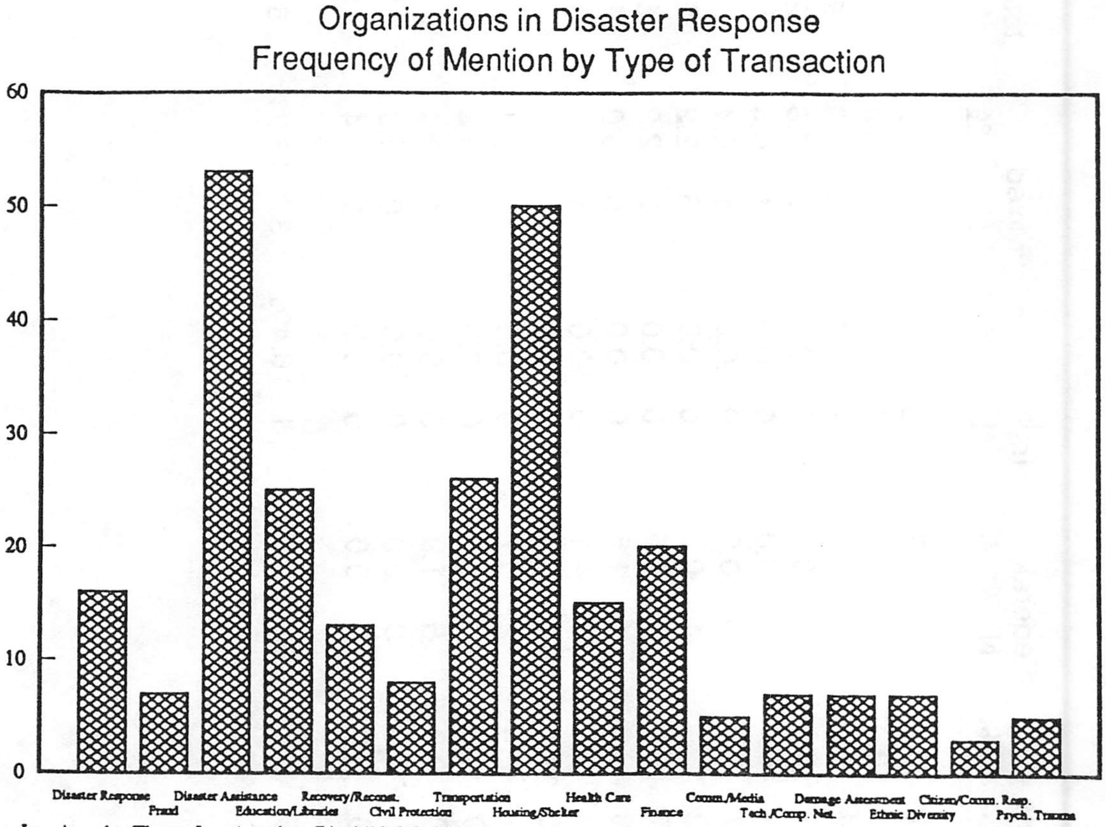
Organizations Participating in Disaster Response by
Type of Jurisdiction, Type of Transaction and Frequency of Mention in Newspaper Reports

Northridge Earthquake, January 17, 1994

Type	City N	City %	County N	County %	Region N	Region %	State N	State %	Federal N	Federal %	Int'l N	Int'l %	Mixed N	Mixed %	total N	total %
Disaster Response	5	1.9	3	1.1	0	0.0	2	0.7	2	0.7	0	0.0	4	1.5	16	6.0
Fraud	2	0.7	1	0.4	0	0.0	1	0.4	2	0.7	0	0.0	1	0.4	7	2.6
Disaster Assistance	19	7.1	1	0.4	8	3.0	4	1.5	15	5.6	1	0.4	5	1.9	53	19.9
Education/Libraries	16	6.0	0	0.0	0	0.0	2	0.7	0	0.0	0	0.0	7	2.6	25	9.4
Recovery/Reconst.	9	3.4	1	0.4	1	0.4	1	0.4	0	0.0	0	0.0	1	0.4	13	4.9
Civil Protection	5	1.9	1	0.4	0	0.0	1	0.4	0	0.0	0	0.0	1	0.4	8	3.0
Transportation	5	1.9	0	0.0	11	4.1	3	1.1	1	0.4	0	0.0	6	2.2	26	9.7
Housing/Shelter	11	4.1	4	1.5	10	3.7	7	2.6	12	4.5	0	0.0	6	2.2	50	18.7
Health Care	5	1.9	4	1.5	2	0.7	0	0.0	4	1.5	0	0.0	0	0.0	15	5.6
Finance	4	1.5	1	0.4	0	0.0	3	1.1	11	4.1	0	0.0	1	0.4	20	7.5
Comm./Media	3	1.1	0	0.0	0	0.0	0	0.0	1	0.4	0	0.0	1	0.4	5	1.9
Tech./Computer Net.	3	1.1	0	0.0	0	0.0	1	0.4	2	0.7	0	0.0	1	0.4	7	2.6
Damage Assessment	4	1.5	0	0.0	2	0.7	0	0.0	0	0.0	0	0.0	1	0.4	7	2.6
Ethnic Diversity	0	0.0	0	0.0	1	0.4	0	0.0	5	1.9	0	0.0	1	0.4	7	2.6
Citizen/Comm. Resp.	3	1.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	1.1
Psych. Trauma	1	0.4	2	0.7	1	0.4	0	0.0	0	0.0	0	0.0	1	0.4	5	1.9
Total	95	35.6%	18	6.7%	36	13.5%	25	9.4%	55	20.6%	1	0.4%	37	13.9%	267	100.0%

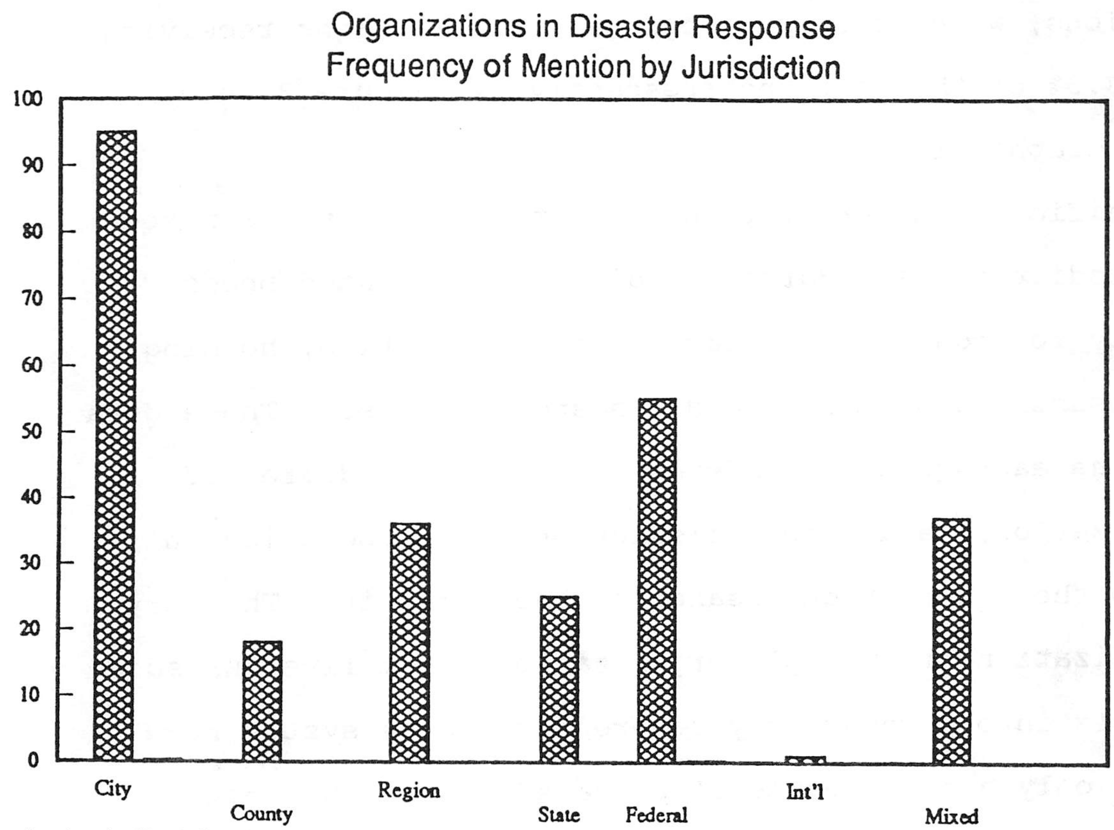
Source: Los Angeles Times, Los Angeles, CA 1/18-2/8, 1994

Figure 2



Los Angeles Times, Los Angeles, CA 1/18-2/8, 1994

Figure 3



Los Angeles Times, Los Angeles, CA 1/18-2/8, 1994

local level. Federal organizations accounted for 20.7% of the total mentions, with state and regional organizations receiving 9.4% and 13.5% of the mentions, respectively. Figure 3 shows these data graphically.

A significant number of response actions involved a mixed set of jurisdictions in addressing disaster-generated needs, particularly for education/libraries, transportation, housing/shelter, disaster assistance, and disaster response. These data show that the earthquake engendered a substantial degree of interorganizational and interjurisdictional collaboration in response to the destruction wreaked on the community. The very rapid mobilization of multiple organizations from five jurisdictional levels into a remarkably coherent response system reflected not only a high degree of preparedness at the local level, but also an unprecedented use of information technology to facilitate interactive communications and response in this disaster.

The use of information technology during the Northridge disaster response operations was, in many respects, ad hoc, with individual groups piecing together components in order to serve immediate needs. Nonetheless, it was sufficient to demonstrate the significant potential for using information technology to facilitate action in complex environments such as disaster response.

Further, the Northridge disaster operations illustrates the process of self organization through which subsets of organizations formed of interjurisdictional and interorganizational task forces around specific issues, such as housing. The Housing Task Force, made up of representatives from city, county, public, private, and nonprofit organizations, operating directly from the Disaster Assistance Centers, proved far more effective in assisting applicants find appropriate housing than if this function had been assigned to a single organization or jurisdiction as in previous disaster operations.

Recent technical advances using satellite and other systems already available in California allowed the use of organizational communication and information processes that enabled multiple organizations and individuals to participate effectively in disaster response and recovery activities. Improved communication and information processes, in turn, enabled a more rapid activation of response capacity within and among organizations. In a spiral of organizational learning, this capacity increased the demand for focus and integration of new information into existing strategies and practice. The State of California is currently engaged in a major program of integrating information technology into its disaster mitigation, preparedness, response, and recovery activities.

Conclusion

In management theory, we are truly at a "bifurcation point." We can continue to pursue means of control in social systems and seek to perfect them against unlikely odds, or we can invest scarce resources in designing learning environments which allow individuals discover new ways of engaging in collaborative action to build constructive communities. Understanding the dynamics of change in complex social systems represents a major challenge to policy studies involving public, private, and/or nonprofit organizations. It means recognizing the essentially voluntary nature of social action, and the constraints imposed by limited cognitive capacity in an increasingly interdependent world.

Sociotechnical systems that use information technology to extend human reasoning capacities offer an important means to enable individuals to move more easily between micro and macro levels of conceptualization and action in problem solving, enabling groups of actors to form and reform around emerging issues in a dynamic environment. We need a theory of transition that guides our efforts to generate change in complex social systems more effectively. It will likely utilize advanced information technology as an aid to human reasoning in complex, adaptive environments.

REFERENCES

Argyris, C. 1982. Reasoning, Learning and Action. San Francisco: Jossey-Bass Publishers.

Argyris, C. 1990. Overcoming Organizational Defenses. Boston: Allyn and Bacon.

Argyris, C. 1993. Knowledge for Action: A Guide to Overcoming Barriers to Organizational Change. San Francisco: Jossey-Bass.

Cohen, M., J.G. March, and J.P. Olsen. 1972. "A Garbage Can Model of Organizational Choice," Administrative Science Quarterly, 17:1-25.

Cohen, Wesley M. and David A. Levinthal 1990 "Absorptive Capacity: A New Perspective on Learning and Innovation". Administrative Science Quarterly, 35: 128-152.

Comfort, L.K. 1994. "Self Organization in Complex Systems." Journal of Public Administration Research and Theory, Vol. 4, No. 3 (July):393-410.

Burt, Ronald. 1992. Structural Holes: The Social Structure of Competition. Cambridge, MA: Harvard University Press.

Ditto, William L., and Pecora, Louis M., "Mastering Chaos," Scientific American, Vol. 269, No. 2 (August):78-84.

Gell-Mann, Murray. 1994. The Quark and the Jaguar: Adventures in the Simple and the Complex. New York: W.H. Freeman & Co.

Hardin, G. 1968. "The Tragedy of the Commons," Science, 162:1243-1248.

Kauffman, Stuart A. 1993. The Origins of Order: Self-Organization and Selection in Evolution. New York: Oxford University Press.

Kiel, L. Douglas. 1994. Managing Chaos and Complexity in Govern ment. San Francisco: Jossey-Bass Publishers.

Lindblom, C.E. 1990. Inquiry and Change. New York: Yale University Press.

Lindblom, C.E. and D. Cohen. 1979. Usable Knowledge. New Haven: Yale University Press.

Newell, A. and H. A. Simon. 1972. Human Problem-Solving. Englewood Cliffs, NJ: Prentice-Hall.

Nicolis, G. and I. Prigogine. 1989. Exploring Complexity: An Introduction. New York: W.H. Freeman and Co.

Nii, P. check reference in 1985 article, Terminal Disasters.

Piaget, J. 1980. Adaptation and Intelligence. Chicago: University of Chicago Press.

Prigogine, I. 1987. "Exploring Complexity." European Journal of Operational Research. Vol. 30, No. 2 (June):97-103.

Prigogine, I. and I. Stengers. 1977, 1984. Order Out of Chaos. New York: Bantam Press.

Ruelle, D. 1991. Chance and Chaos. Princeton, NJ: Princeton University Press.

Simon, H.A. 1969, 1981. The Sciences of the Artificial. Cambridge, MA: MIT Press.