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# RISK AND RESILIENCE: INTERORGANIZATIONAL LEARNING FOLLOWING THE NORTHRIDGE EARTHQUAKE OF JANUARY 17, 1994

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## ABSTRACT

This article examines the tension between anticipation and resilience as a means to reduce risk. I argue that information drives the processes of order and entropy within a complex, adaptive system, altering both the internal relationships between the parts and the whole and the external relationships between the system and its environment. I examine a set of four theoretical measures of complex, adaptive systems in a case study of the inter-organizational disaster response system that evolved following the Northridge, California Earthquake of January 17, 1994, and assess the extent to which these measures explain the dynamics of the ensuing disaster response system. Striking the balance between anticipation and resilience, order and chaos requires a process of continual learning. If the "secret of safety lies in danger," structuring a process for continuous learning is a primary requirement for maintaining creativity and adaptation in practice.

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**Strategies for Uncertain Environments**

Designing policy for future events depends crucially on the degree of certainty or uncertainty that characterizes the arena of action.[1] Strategies for coping with risk of future adverse events vary from efforts to ignore the possibility of collective harm to detailed efforts to prevent such harm from occurring. The effectiveness of either strategy depends upon the accuracy of our estimates of future events, our capacity to reorganize existing resources, skills, and knowledge to meet unexpected demands, and most importantly, our ability to fashion systems of action that cross and recross organizational and jurisdictional lines.

Theorists in public policy and administration hold competing perspectives (t'Hart, Rosenthal, and Kouzmin, 1993; Dror, 1985; Kartez and Kelley, 1988; Sutphen and Bott, 1990) on the classic problem of how organizations should respond to the special category of low probability, high consequence events. Such events include earthquakes, hurricanes, tornadoes, explosions, or other hazards that potentially may cause collective harm. These theories have consistently focused on the tension between processes of command and control (Perrow, 1984; March and Weissinger-Baylon, 1988; Hirschhorn, 1993; Sagan, 1993) and processes of innovation and discovery (Cohen, 1988; Wildavsky, 1988; Comfort, 1990; 1994) as means to reduce potential collective harm. Theories of reduction of risk through redundancy (Simon, 1969, 1981; Landau, 1991) have been rejected in practice as too costly for low probability events in given locations (Rossi, Wright, and Burden, 1982). Risk reduction through incremental 'trial and error' is equally unacceptable, given the potential for catastrophe if the event, for example, a major earthquake, does occur (Laporte and Consolini, 1991).

In his wide-ranging study of societal risk, Aaron Wildavsky (1988) addressed the problem of how to devise effective courses of public action to cope with uncertain, destructive, collective events. He contrasted a strategy of anticipation, which assumes a capacity to prevent harm before it occurs, with a strategy of resilience, which assumes a capacity to reorganize resources and action to respond to actual danger, after it occurs. Anticipation, to Wildavsky (1988:77), meant "a mode of control by a central mind...efforts...made to predict and prevent potential dangers before damage is done." Resilience, in contrast, was defined as "the capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back." In characterizing the two strategies, Wildavsky (1988:224) viewed resilience as developed by "trial and error, general capacities, and decentralization." Anticipation, in contrast, involved "predicting hazards, specialized protections, centralization, and detailed standards." Wildavsky concluded that seeking a balance between anticipation and resilience is the most beneficial strategy of coping with risk.

Wildavsky insightfully laid out the problem of risk, but his analysis gave little specification regarding the design of a process that could consistently reduce risk in action. He offered no clear delineation of an organizational structure that would maintain the process of learning across time, space, and jurisdictions that is essential to improving societal action in contexts of future danger. We visualize the problem of risk more clearly from his writings, but we are left to specify more completely designs to assist organizations in functioning more effectively in uncertain environments.

The emerging literature on complex systems (Prigogine and Nikolis, 1977; Prigogine and Stengers, 1984; Ruelle, 1991; Kauffman, 1993; Gell-Mann, 1994) provides fresh insight on how organizations actually cope with uncertainty in dynamic environments. In this article, I first re-examine Wildavsky's concepts of risk, anticipation, and resilience in the light of recent literature on complex systems and identify a set of basic characteristics that are common to both. Second, I examine this set of common theoretical characteristics against the interorganizational disaster response system that evolved in the dynamic environment following the Northridge, California Earthquake of January 17, 1994. Third, I inquire whether strategies of anticipation, resilience, and organizational learning can be identified in the performance of complex systems evolving in the California context of recurring seismic risk. Finally, I assess what conditions contribute to, or inhibit, effective performance among a set of interdependent organizations seeking to achieve a common goal of protection of life and property in an environment of recurring danger.

**Theoretical Background**

The study of complex systems involves a study of organizations in process, engaging in change. Structure is needed for organizations to function in this process, but it is continually modified through action as the organizations, operating interdependently, interact with their dynamic environment. Four characteristics are critical to understanding this creative interaction between structure and process. Each was identified by Wildavsky in his book, Searching for Safety, but he focused chiefly on the process of search as a strategy for coping with uncertain environments. His work largely omits the role of structure in generating the search and maintaining the process of continuous inquiry and learning.

Coupling elements of the search process identified by Wildavsky with insights regarding structure in motion from the complex systems literature provides a more complete understanding of the critical interaction between structure and process that fosters organizational learning and adaptation in dynamic environments. Complex, adaptive systems, in operation, may be capable of sustaining the balance of anticipation and resilience that Wildavsky envisioned, but it is rare in practice. Four characteristics appear essential to achieve this balance. They are: 1) a capacity for creative innovation among organizational units that interact as a system to achieve a common goal; 2) flexibility in relationships between the parts of the system and the whole; 3) interactive exchange between the system and its environment; and 4) a crucial role for information in increasing either order or chaos, regularity or random behavior within the system. The particular configuration of this set of four characteristics defines a given operating system, or structure in process, which continues to transform itself through action toward a system-wide goal. Each characteristic will be discussed briefly below.

A capacity for creative innovation.

Innovation is recognized both by Wildavsky and researchers studying complex systems as a major strategy for coping with risk. Wildavsky identifies innovation as a primary characteristic of resilience. He (1988:71) states:

> The organism or social system that can, from its supply of basic resources, synthesize what it needs whenever new dangers arise is...in a much stronger position to cope with unexpected consequences or with hazards that only occasionally manifest themselves.....Such responsive systems are capable of converting available generalized resources, such as wealth, knowledge and technical skill, into appropriately tailored solutions if, as, and when required.

The balance between anticipation and resilience that Wildavsky (1988:186) sought corresponds roughly to the concept of the "edge of chaos" identified by Kauffman (1993), Gell-Mann (1994), and others writing about complex systems.

Stuart Kauffman (1993), a biologist studying processes of change, identified a narrow region, the 'edge of chaos,'[2] as that most conducive to creative performance in living systems. He observed that living systems vary in their behavior on a continuum between order and chaos, with the extremes of either state moving toward the center. He held that systems develop most productively when there is sufficient order to hold and exchange information among their component parts, but sufficient flexibility to adapt to changing conditions, both internally and externally. Kauffman views the "edge of chaos," like the balance between "anticipation" and "resilience" proposed by Wildavsky, as the context that is most likely to generate innovative strategies in response to unexpected demands.

Murray Gell-Mann (1994:50), a physicist studying change in complex, adaptive systems, defines the ratio between regularity and randomness, or order and chaos, as the critical factor in determining the capacity of the system to adapt successfully to unexpected disturbances. Gell-Mann rephrases the tension between order and chaos in organizational performance as one that represents different constructs of simplicity and complexity, focusing, in contrast to Wildavsky, more on structure than on process. As the list of regularities characterizing a given system's operation increases, that system becomes more complex (Gell-Mann, 1993:50-53). Exceptions or special interventions may be necessary for the system to function successfully under dynamic conditions, which include random events. Gell-Mann notes especially the interactive, continuously evolving relationship between a system and its operating environment. He further acknowledges the environment as a continual source of potential order or entropy for the system.

In summary, innovation in rapidly changing environments occurs most frequently when the operating system has the technical skill, organizational flexibility, relevant knowledge, and goal-oriented focus to incorporate incoming environmental information into appropriate adaptations in performance to meet its defined goals.

Flexibility in relationships between the parts and the whole

The relationship of the parts to the whole is critical in any system, but in dynamic environments, it is precisely this factor which allows the system to either adjust and adapt to changing conditions or causes it to fail. Wildavsky (1988:112) proposed a 'rule of risk;' that is, "no system can remain stable, unless the parts are able to vary in order to protect the whole."[3] Such a rule, however, implies unequal levels of risk and safety for individual members or components, which then must be shared by the larger system or else it will fail.

Gell-Mann (1994:112) counters the threat of unequal risk to system performance by the axiom of connectedness. In his terms (Gell-Mann, 1994:20-21), everything truly is connected to everything else, at some level of interaction within some time frame. Gell-Mann also recognizes the intricate web of interacting layers and sub-systems that make up this complex, global system. To Gell-Mann, the task of science is to discover what those connections are, and by making these relationships more explicit and understandable to members of our global system, enable them to act in ways that allow the system to function more effectively. Consequently, discovering weakness in one part of the system enables other parts to respond in ways that either reinforce the weak areas or adjust their performance to dissipate the weakness throughout the larger system. The overall performance of the system improves through the interaction of its parts, even though individual components remain weak.

Conversely, if the parts of the system seek first to stabilize themselves, the whole, when faced with disturbances, will become more unstable (Wildavsky, 1988:216). Consequently, the safety of individual members of the system is inextricably bound with the safety of the whole. To improve the safety of both members and whole, risks must be shared throughout the system.

Interactive exchange between the system and its environment

The process of continuous, reciprocal exchange between a system and its environment provides a third defining characteristic for complex, adaptive systems. This exchange produces both the energy for, and resistance to, mutual adaptation. Wildavsky (1988:166) considered this process to be evolution, "resilient, not anticipatory ..., allowing stability through change," implying that it is only the system that adapts. Others recognize that the system's ability to adapt successfully to changing requirements from the environment depends upon both the rate of change occurring in the environment (Gell-Mann, 1994:303) and the system's capacity for absorption of new information (Cohen and Levinthal, 1990:131-133). The broader view of complex systems holds that the actions of the system also change the environment as it reorganizes its actions and resources in response to newly perceived needs (Kauffman, 1993:174, 208-227). Consequently, the combination of chance and choice may lead to widely varying adaptations to similar conditions (Ruelle, 1991; Gell-Mann, 1994:316).

This process of interactive exchange produces a set of forms of evolving complexity, as each adaptation creates the opportunity for the system to address a still more difficult problem. In turn, each new phase of adaptation builds upon earlier forms, which become modified by attrition or transformation.[4] Most important, this adaptive process generates a transformation in knowledge and in the dissemination of that knowledge throughout the wider society (Gell-Mann, 1994:362). This new level of shared knowledge and broad societal understanding, reciprocally, reshapes the relationships between system and environment, which become manifest in modified structural forms.

<u>A crucial role for information in evolving complexity</u>

In crucial ways, information constitutes the energy that drives a complex system in its processes of both internal adaptation among its constituent parts and external exchange with the broader environment. Wildavsky (1988:121) recognized this role as essential to developing resilience:

> Resilience depends upon numerous participants interacting at great speed, sending out and receiving different signals along a variety of channels.

But Gell-Mann (1994:58) acknowledges that it is the product of this exchange, or "mutual information" among the constituent parts of the system, that enables the system to alter its patterns of behavior to produce substantive structural change.

Information and its means of collection, integration, and dissemination become a constant factor in either transforming patterns of organizational behavior to reduce risk of future threat or in increasing the danger of catastrophe in environments of recurring societal risk. If information constitutes the energy that drives the system and produces order, ignorance -- or the absence of relevant information -- represents the opposing process of entropy, or disintegration into disorder within the system (Gell-Mann, 1994:219, 236).

Consequently, how a system designs its information flow and exchange, both among its constituent parts and between the whole system and its external environment, serves as the primary factor in determining its capacity to reduce future risk and create a sustainable relationship with its environment. An adequately specified information structure is one that enables the system to learn in a changing environment. That is, the system is capable of adapting its internal performance to new information from the external environment, and allowing its different components to adjust appropriately to one another in constructive interaction. Environmental change may affect different components of the system differently, resulting in markedly different rates of response, learning, performance, and adaptation among the separate parts, which then need to be integrated into a functioning whole at the macro level.

The thesis of this article is that the information function drives the processes of order and entropy within a complex system, altering both the internal relationships between the parts and the whole and the external relationships between the system and its environment. These dynamic relationships further calibrate the degree of creative innovation which the system is able to produce and maintain in its actual performance, given the constraints and opportunities of its environment.

**Methodology**

Studying the dynamics of complex, adaptive systems in actual practice presents a special challenge, because these systems often evolve over long periods of time. Disaster environments create unique opportunities to study the generation of multiorganizational response systems that evolve rapidly, in part in response to structural requirements established by law and in part due to random events and interactions. This article examines the set of four theoretical characteristics that define a complex, adaptive system in action against the interorganizational disaster response system that evolved in the dynamic environment following the Northridge, California Earthquake of January 17, 1994.

This analysis is essentially an explanatory case study (Yin, 1984, 1993), which examines the concepts of search and adaptation in complex systems discussed above in the context of an actual disaster. It seeks to assess the extent to which these concepts explain the rapid evolution and performance of the interorganizational, interjurisdictional disaster response system following the Northridge Earthquake of January 17, 1994.

Source materials for this analysis[5] include: 1) a set of semi-structured interviews with 44 managers engaged in disaster response from federal, state, county, city, and volunteer agencies conducted within three weeks of the disaster; 2) situation reports from federal and state planning meetings held at the Joint Federal-State Disaster Field Office in Pasadena, California to coordinate the response; 3) professional observation of the interaction among organizational participants at those meetings from January 28 to February 11, 1994; 4) professional notes and the verified transcript of hearings on response to the Northridge Earthquake conducted by the California Seismic Safety Commission, February 10-11, 1994; and 5) daily media accounts of disaster operations for a three-week response period, January 17, 1994 - February 11, 1994.

**Interorganizational Learning in the Northridge Earthquake**

Seismic risk in California offers an apt context for the study of complex, adaptive systems for at least four reasons. First, the threat of seismic risk is well-known in California and has been the focus of a significant agenda in research, legislation, professional training, and public education for over fifty years. These activities have produced a cumulative store of knowledge, skills, resources, and public awareness regarding seismic risk that provides an invaluable basis for informed action within the state.

Second, six significant earthquakes[6] have tested the plans, training, experience, and operational capacity of the state emergency response community within the last seven years. The earthquakes have been augmented by other types of disaster --

fires, floods, and civil riots -- to produce ten federally declared disasters in California within thirty-two months.[7] Citizens, private organizations, as well as the emergency response community are alert to the danger and costs of disaster.

Third, the potential danger posed by seismic risk to California is enormous and continuing. Its major cities lie astride earthquake faults, most of which have been mapped. But geology is a very young science, and much of the network of thrust faults, such as that which generated the Northridge Earthquake, underlying the Los Angeles Basin is still unexplored and unmapped.[8] Many of the engineering designs developed to mitigate earthquake hazards are still untested under actual conditions, and some of those designs failed in the Northridge Earthquake.[9] These conditions contribute to the continuing uncertainty caused by seismic risk in California.

Finally, 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.[10] On February 2, 1994, federal and state agencies reported over 6,000 employees serving 300,000 clients in disaster response and recovery activities.[11] The

Northridge case provides an extraordinary laboratory to observe the dynamics of complex, adaptive systems in action. The next section will briefly outline the context of this evolving disaster response system and analyze its performance on three selected problems against a set of defining characteristics for complex, adaptive systems.

The Northridge Earthquake: Context and Consequences

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 week-end, 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.[12] 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, except 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, property, jobs, transportation, and access to other services such as medical care and nutrition.[13] 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 is clearly a national disaster, as reserves and resources from the entire nation are directed toward re-establishing the economic, social, and infrastructure systems of the Los Angeles Basin.

In what ways, if any, did the interorganizational, interjurisdictional disaster response system exhibit the balance between anticipation and resilience that Wildavsky sought, or the innovation, flexibility, and mutual adjustment based upon timely information flow characteristic of a complex, adaptive system? To what extent can the strengths -- and weaknesses -- of the interjurisdictional disaster response system be explained by the dynamic evolution of a complex, adaptive system from this particular environment of seismic risk? The next section will address these questions by examining the performance of the system in reference to three problems that confronted all organizations operating in the Northridge disaster response system. The problems are: 1) establishing interactive communications and timely information processing among participating organizations; 2) managing or interacting with multiple organizations in the performance of diverse tasks simultaneously; and 3) mobilizing available resources and knowledge across jurisdictional boundaries for timely action at the local level. Each of these problems will be analyzed briefly in terms of the schema of four characteristics discussed above (pp. 5-10).

Interactive communications and information processes.

Extensive use of advanced technology in communications and information processes distinguished the Northridge Earthquake disaster response system from response operations following any previous disaster in the United States. These technologies, together, made a major difference in the speed, interactive exchange, and analytical capacity for the organizations participating in the disaster response and recovery system. The technologies include:

1) Caltech USGS Broadcast of Earthquakes/Rapid Earthquake Data Integration (CUBE/REDI) system
2) Operational Area Satellite Information System (OASIS)
3) Emergency Digital Information System (EDIS)
4) Geographic Information System (GIS)
5) Recovery Channel and two-way satellite communication
6) mobile, cellular telephones for intra-agency communication

The CUBE/REDI system is a sophisticated computerized network that monitors seismic activity and transmits data describing the location, magnitude, and duration of earthquakes to subscribing members within seconds of occurrence. It was initiated by the California Institute of Technology and the U.S. Geological Survey in Southern California approximately three years ago (1991)[14] and by the University of California, Berkeley and U.S. Geological Survey, Menlo Park in Northern California in 1993. The CUBE/REDI system combined provides for almost "real time" monitoring of earthquakes in most of California to a limited number of subscribers. The system links the technical resources and expertise of two major universities with that of the leading federal agency engaged in seismic research to create a means of rapid dissemination of seismic information critical to response. It enables subscribing members to focus scarce attention and resources more accurately and more efficiently in mobilizing response actions. Although it is still in its nascent stages, the system did operate in this earthquake and provided subscribing public and private agencies with vital information within minutes of the event.

The Operational Area Satellite Information System (OASIS) is a statewide satellite information system, funded in part by the Federal Emergency Management Agency (FEMA), but implemented under the design and direction of the California Office of Emergency Services. This system was not fully in operation during the Northridge Earthquake disaster operations, but its potential is recognized in terms of linking statewide resources to the disaster response system. OASIS did function in this earthquake response in conjunction with EDIS, a federally supported news and data dissemination program.

The Emergency Digital Information System (EDIS) is a means of transmitting information simultaneously to multiple recipients via satellite. Sponsored and implemented by FEMA, it uses the OASIS satellite system as its channel of transmission in California. Again, the system is very new, with limited subscribers, primarily local news organizations. Yet, it was used successfully in disaster response operations for Northridge, and serves as a model for transforming communications between the responsible public agencies, their target audiences, and the media.[15]

The Geographic Information System represented a remarkable effort pulled together with minimal resources by the California Office of Emergency Services. Introduced in the second week of operations, the GIS was used more for recovery than response. Nonetheless, this technology, which produces computerized maps of selected features of response and recovery operations, provides a major tool for tracking the flow of resources and assistance to those who need it most. Examples of GIS products include maps of the geographic locations of the Disaster Assistance Centers by severity of earthquake damage, modified Mercalli intensities of ground shaking in the Los Angeles area by municipality and district, and the geographic distribution of individual assistance applications by per capita income and zip code.[16]

More significant is the model of loss estimation, which uses GIS technology to map likely earthquake damage, plotting measured characteristics of the earthquake against known information about the housing structure in the area. The model was run within hours of the earthquake,[17] and the results were used as the basis for damage estimates which were incorporated into the requests for state and federal disaster declarations. As a result of the timely presentation of damage information, the response mechanisms of the public agencies functioned much more quickly than in previous disasters.

The rapidity with which the response mechanisms were activated illustrates the impact of advanced telecommunications and information processing technology upon the disaster response system. The earthquake occurred at 4:31 a.m. on January 17, 1994, which immediately activated the emergency response departments of the City and the County of Los Angeles. By 5:45 a.m., the City departments reported their assessment of damages to Mayor Richard Riordan, who declared a state of emergency in the City of Los Angeles immediately thereafter. The County of Los Angeles followed closely with a declaration of emergency by 6:00 a.m.[18]

The City and County declarations, with accompanying documentation, were forwarded to the Governor of California, Pete Wilson, who declared a state of emergency in the counties of Los Angeles, Ventura, and Orange at 9:10 a.m., making state-wide resources available to the stricken areas.[19] The damage estimates, forwarded to the President Clinton with additional reports, resulted in a federal declaration of disaster by 2:08 p.m. on the same day.[20] The computerized estimation techniques for damage assessment and satellite communications capabilties that facilitated the information exchange between jurisdictions enabled the local, state, and federal agencies to implement their response mechanisms within ten hours of the disaster event, much more quickly than in previous disasters.[21]

The Recovery Channel, sponsored by FEMA, disseminated timely, accurate information about response and recovery operations to multiple audiences simultaneously. The Recovery Channel provided full-color video transmission of news regarding disaster response and recovery operations via satellite to interested audiences in the nation: The White House and Congress in Washington, DC; participating federal, state, and local agencies at both field and office locations; Disaster Assistance Centers in the Los Angeles area, serving individuals who suffered damage during the earthquake, and other organizations - private and voluntary - who engaged in the response process. This news channel, implemented almost immediately at the Joint Federal/State Disaster Field Office and dedicated to reaching the maximum number of persons affected by the earthquake, played a major role in transmitting accurate, timely information to multiple audiences simultaneously.

Cellular telephones proved to be a remarkably effective means of facilitating communication within as well as between agencies. Relatively simple devices, they freed agency personnel from their desks and enabled them to communicate with one another in transit. By facilitating mobility, the telephones increased access and responsiveness among members participating in the system.[22] This technology also demonstrated the significant role of the utilities in disaster response.

Most of the technical equipment used in disaster response is leased by FEMA. Telephone instruments are purchased, used in a disaster, packed and reshipped to FEMA Regional Headquarters where they are stored until the next disaster.[23] While telecommunications companies recognize the business opportunities in disaster response, they also contribute substantial amounts of personnel, equipment, and time to serve the public interest and restore basic services in a damaged community.

Each of these technologies represents a major advance in the processes of collecting, integrating, and disseminating timely information to participating organizations and personnel in the disaster response system. Each serves different purposes and addresses different primary, if overlapping, audiences. None was completely in place prior to the earthquake, and the set represents major innovations and efforts at federal, state, and local levels of government to facilitate communications and information processes that support timely, informed, response action. The use of these technologies had a profound effect upon the way work is performed in emergency response operations, substituting conference calls across time zones and distance to transform problem-solving approaches and to incorporate a wider array of organizations and information into decision processes. In the words of an experienced FEMA official, the use of current telecommunications "has changed the function of the organization."[24]

Funding for these information technologies came primarily from the federal level. Yet, by establishing the means and setting the example of their use, FEMA supported state and local levels of government as well. The communications technologies served to link the set of participating agencies more effectively into a responsive system through timely information exchange. Their immediate adoption and ready use transformed communication and information processes not only within and between organizations operating in the disaster response system, but also between the system and its various audiences - disaster-affected families, contributing organizations, public authorities, legislative bodies, and the wider American public.

To what extent did the use of advanced information technologies in disaster response contribute to the definition of a complex, adaptive system? First, the uses were creative in linking organizations involved in disaster response that had previously not had access to such rapid dissemination of information. Second, the various technologies are best considered as a set, for each served some purposes but not others. In terms of facilitating the adjustment of the various parts to the whole system, satellite communications established and supported by FEMA allowed interactive communication and information exchange across the set of jurisdictions, organizations, and population groups engaged in disaster response activities.

For example, satellite communications allowed interactive video testimony and dialogue between the Senate Appropriations Subcommittee chaired by Senator Barbara Mikulski in Washington, DC and FEMA Director James Lee Witt at the Disaster Field Office in Pasadena.[25] This exchange facilitated the rapid consideration by Congress of the $9.71 billion supplemental disaster appropriations bill to finance response and recovery needs generated by the earthquake. This testimony was also video recorded and later transmitted on the Recovery Channel to all Disaster Assistance Centers and its other recipients, allowing the public in the disaster-affected area to hear and observe the Senate hearings on the issue. On Saturday, February 27, 1994, President Clinton signed a supplemental appropriations of $8.6 billion that provided public and private disaster assistance to communities affected by the earthquake, twenty-seven days after the earthquake.[26] This use of satellite communications demonstrated the third characteristic of a complex, adaptive system, that of facilitating timely communication between the disaster response system and its wider environment in order to achieve a shared goal.

Managing multiple organizations in the performance of diverse tasks simultaneously

Following the Northridge Earthquake, two factors contributed significantly to maintaining a balance between anticipation and resilience, order and chaos. These factors represented significant structural innovations introduced at both the federal and the state levels of jurisdiction in managing the complex tasks involved in disaster response operations. They are the Federal Response Plan (FRP),[27] which serves as the organizing structure for federal agencies responding to disaster, and the Standardized Emergency Management System (SEMS),[28] newly adopted by the State of California to coordinate emergency response operations within and among governmental jurisdictions.

Activated immediately following the Presidential declaration of disaster in Los Angeles, Ventura, and Orange Counties on January 17, 1994, the FRP served as the vehicle under which experienced federal personnel from all regions of the country were mobilized into a unified system in response to the Northridge Earthquake. Prior to its activation, however, city, county, and state plans were activated and emergency personnel from these jurisdictions were already engaged in response actions. The federal task was not to replace these efforts, but to provide financial support and technical assistance to the response processes already in place at the local level.

In the City of Los Angeles, the emergency plan does not require a formal declaration for response activities to begin. An earthquake of 5.0 magnitude or greater on the Richter scale generates an automatic response from trained personnel in emergency response departments, who report for duty immediately when they experience the shock.[29] At the local level, emergency response personnel from the City of Los Angeles respond to needs within the city. Emergency response personnel from the County of Los Angeles provide fire services to 51 of the 88 cities within the county and respond to needs within the unincorporated areas. Los Angeles County is the largest county jurisdiction in the United States, covering a geographic area of 4,083 square miles and serving a population of approximately 13 million.[30] Providing adequate protection to life and property in this area on a daily basis requires sophisticated equipment, training, and response capability by local personnel. The size and needs of the County and the professionalism of its response services represent important "initial conditions" at the local level that create a strong basis for building advanced capacity in an interjurisdictional disaster response system.

The need for broader coordination in emergency response occurs when a damaging event escalates to a state-declared disaster, bringing in State of California resources to overwhelmed local areas. Further, the need for coordination increases when an incident is declared a federal disaster, making available the full complement of resources to a disaster-affected area provided under the Federal Response Plan.

The management requirements for mobilizing the full complement of resources from twenty-seven federal agencies[31], seven primary and twenty-eight supporting state agencies[32], and coordinating these resources to support and complement the city and county response efforts are significant. Performing this task under the urgency of disaster within a very short period of time is even more demanding. It is a situation which has, repeatedly, in previous disasters veered sharply toward chaos.

Both federal and state disaster plans are products of relatively recent efforts to reorganize and restructure emergency response capacity for greater efficiency and effectiveness. The Federal Response Plan was formally adopted in April, 1992 and implemented partially in Hurricanes Andrew and Iniki in 1992. It was fully implemented for the first time on a national basis in the Northridge Earthquake. The Standardized Emergency Management System (SEMS) essentially formalizes the adoption of the Incident Command System (ICS), widely used and practiced in California, as the statewide management system for emergency response. The federal design and state procedures are not wholly consistent with one another, but there is sufficient complementarity that the two jurisdictional levels adopted a unified approach to disaster operations and colocated their disaster response efforts in a Joint Federal/State Disaster Field Office.

Creating a smoothly functioning Joint Federal/State Disaster Field Office is a major management task. Rapid mobilization of staff under the stress of disaster requires extraordinary effort, organization, and professional training. For example, the number of FEMA staff working at the Disaster Field Office in Pasadena increased from 125 to 2,000+ in a period of eight or nine days.[33] The logistics alone of mobilizing 2,000 personnel and finding space, equipment, communications, and transportation to support their activities within a period of nine days represents a tremendous organizational effort. Keeping this number of personnel functioning productively, interactively, and focused on performing separate specific tasks directed toward a common goal required an extraordinary degree of professionalism, patience, experience, and commitment to the shared mission of response and recovery.

A new style of management at the federal level, the full implementation of the FRP, experienced professionals at both federal and state levels, and the introduction of management procedures from the ICS to serve as the basic operating procedures for the disaster, in combination, achieved a relatively high degree of coordination between federal and state agencies operating under very demanding conditions. At the federal level, the new director of FEMA, James Lee Witt, introduced a low-key, "hands on", problem-solving, performance-oriented approach which focused on the primary task of meeting human needs as quickly and humanely as possible.[34] His management style set the standard for professional performance and mutual respect among disaster response personnel working under urgent, difficult conditions, a style which was reinforced by experienced professionals in federal, state, and local agencies.

At the state level, experienced professional managers established a schedule of management meetings every morning and evening for directors of state agencies involved in response and recovery operations. At the morning meeting, which was scheduled for one hour, managers for each of the participating agencies would review tasks to be accomplished that day in order to achieve the goals of disaster response defined for the state. At the evening meeting, the managers would report on the extent to which those tasks were accomplished and identify any new problems, needs, or difficulties that emerged during the day. As the urgency of needs decreased and resources were being demobilized, the operational periods were lengthened from 24 hours to 48 hours to three days and finally to four days.[35] These procedures kept the state agencies focused on the main goal of response and recovery, while allowing the identification and specification of requirements for task performance in different areas of need and operation. This exchange of information created a common knowledge base, or "mutual information" in Gell-Mann's terms, reinforced by common training in ICS procedures at the California State Training Institute that allowed the agencies to adjust and coordinate their activities with one another more carefully. This function created the flexibility in relationships between the parts and the whole of the State response system that is essential in a complex, adaptive system.

Federal managers also have a long tradition of daily meetings for coordination and planning of disaster response operations. Although the number of federal employees working in the Northridge response operations outnumbered the state employees by 30 to 1 in the first weeks of the disaster, the larger federal staff incorporated some of the management principles exercised by the state agencies into their own meetings. The importance of common training, shared disaster experience, and a base of common information, observed in the California, is crucial to uniting a committed, practiced, knowledgeable group of emergency management professionals from diverse backgrounds and regions in action. While not perfect, the management procedures of both federal and state agencies brought flexibility and focus to this very large, rapidly evolving disaster response system that allowed it to function remarkably free of major discord under the first stressful weeks.[36]

Mobilizing available resources and knowledge across jurisdictional boundaries

A disaster, by definition, means that local jurisdictions have exceeded their resources in terms of meeting the needs of their populations created by a damaging event. This condition requires public agencies to mobilize resources across organizational and jurisdictional levels to engage in response operations in the very specific context of the disaster-affected community. Organizing the response operations -- moving personnel, equipment, and supplies quickly to the disaster-affected area and coordinating actions of personnel from many agencies, many who have never worked together before or in a disaster of this magnitude -- requires emergency response personnel to operate in a different mode from their daily operations.

This task of coordinating the activities of multiple organizations across jurisdictions and across professional disciplines and training can easily disintegrate into chaos. In the Northridge Earthquake disaster response operations, this task was greatly facilitated by a combination of advanced professional training among local emergency response personnel, sophisticated local communications and information technology, and actual experience in disaster operations.

Three incidents in the Northridge response operations demonstrate the prior investment in professional training, equipment, and experience of emergency response personnel at the local level in the City and the County of Los Angeles, which created an advanced set of initial conditions on which to build professional performance in the overall disaster response system. First, the activation of the Los Angeles County Urban Search and Rescue (USAR) team in the urgent first hours following the earthquake illustrated a new capacity previously not available in California. Developed, trained, and financed by funds provided by FEMA, the 56-member team had the skills and equipment to carry out an eight-hour live rescue of a man trapped under tons of concrete in a collapsed parking structure.[37] Seven other USAR teams based in California arrived in Los Angeles on January 17, 1994. Seventeen USAR teams across the nation were placed on stand-by alert to fly immediately to Los Angeles, if needed. These teams demonstrated a national USAR capability that did not exist during the 1989 Loma Prieta Earthquake. More significant, a trained, well-equipped, professional

USAR team was available locally to respond within minutes to local needs.

Second, calls for assistance to the Los Angeles County Fire Department were taken through a sophisticated computer-aided dispatch system which was able to handle the increased volume of calls in this disaster efficiently and effectively. The frequency of calls for assistance during normal operations in Los Angeles County is approximately 500 calls per 24-hour period. During a small earthquake, the number of calls increases to approximately 400 calls in a 4-hour period. During the Northridge Earthquake response operations, the County Fire Dispatch received approximately 800 calls during the first four hours, which is 200 calls per hour, or approximately 3.33 calls per minute.[38] Ordinarily, this volume of calls would create a serious backlog for the dispatcher, resulting in delays in response and likely increased losses.

The Communications Center, however, was able to receive such a high volume of calls and dispatch the appropriate Fire personnel promptly with the use of advanced communications and computerized GIS technology. Calls are taken using standardized forms on screen consoles to elicit critical information about the specific incident, and the data are entered into a computerized knowledge base linked to a GIS. The reported incident is located on a computerized County map by latitude and longitude, with a basic description of the event and estimated resource needs. With this information, a computerized resource directory locates the needed resources closest to the site of the fire and identifies the most direct route to the scene for Fire vehicles and equipment. This proposed course is verified by the Operations Chief and transmitted via Fire radio to field personnel for action. Using this technology during the Northridge Earthquake response operations, the Communications Center of the Los Angeles Fire Department reached a new level of efficiency in receiving incoming requests for help and dispatching appropriate resources to meet those needs.

Third, emergency managers recognized the need for professional assistance in this disaster, and extended the concept of "mutual aid" to assist overburdened emergency managers. Mutual aid agreements have long been used by the first responder departments of police, fire, and public works to extend their capacity under the urgency of disaster. In the Northridge Earthquake, the California Office of Emergency Services (OES) initiated an Emergency Managers Mutual Aid (EMMA) program that allowed sister communities to lend their managers to the afflicted community at no cost.[39] The sending county would donate the manager's time, and OES would pay the costs of travel. The concept, now formalized by agreement and accepted as part of California's Emergency Response Plan, has been incorporated into the State's set of strategies to facilitate response and recovery in future disasters.

Each of these incidents documents the high level of training, knowledge, and equipment necessary for rapid response at the local level. Emergency response procedures were already in place, and trained, professional organizations were ready and able to act, representing a 'strategy of anticipation' in Wildavsky's terms.

However, the random effects of seismic waves rippling through urban infrastructure caused different consequences in different locations with varied types of soils and building structures, which required emergency response organizations to invent new ways to use their technical and organizational capacity, a 'strategy of resilience'. Nonetheless, the initial response to community needs in the first thirty-six hours following the destructive earthquake was carried out almost wholly by local agencies and functioned very professionally. The "initial conditions" for disaster response in the City and the County of Los Angeles were the result of years of prior training, planning, and experience with disaster. Nonetheless, these organizations also demonstrated a significant capacity for self organization, or creative adaptation to the needs of the community, at the local level.

Conclusions

Five basic findings can be drawn from this analysis of the Northridge Earthquake disaster operations concerning what conditions contribute to, or inhibit, effective performance among a set of interdependent organizations engaged in reducing risk from recurring danger. They are:

1. Information drives the processes of order and entropy within a complex, adaptive system, such as interorganizational disaster response, altering both the internal relationships between the parts and the whole and the external relationships between the system and its environment

2. Advanced information and telecommunications technology is crucial to gathering, analyzing, and transmitting critical information that activates timely response among multiple organizations simultaneously

3. Use of this advanced technology requires a substantial investment in equipment, training, and development of appropriate procedures prior to a disaster to be fully effective under the urgent requirements of action following a destructive event

4. Flexible organizational structure is essential to maintain the focus of attention after a disaster event for multiple organizations working toward a common goal in response to rapidly changing conditions

5. Organizational structure needs to allow adaptation both at the system level in response to changes in the environment and, interactively, at the sub-system level, to orient multiple sub-systems toward a shared goal under constraints of time and resources

In summary, the Northridge Earthquake disaster response system illustrates the most vital characteristic of a complex, adaptive system -- a capacity for learning from one set of conditions and actions and incorporating that new knowledge into the decision process for the next stage of action. Striking the balance between order and chaos, anticipation and resilience, requires a process of continual learning. If the "secret of safety lies in danger,"[40] structuring a process for continuous learning is a primary requirement for maintaining creativity in practice.

We have learned from Aaron Wildavsky's formulation of the problem of risk. We honor his memory by transforming risk into learning in complex operating systems.

## Notes

1. Aaron Wildavsky, in his book, Searching for Safety, (1988:92-93) distinguishes between certainty, uncertainty, and ignorance. He defines certainty as "the ability to predict accurately the consequences of actions;" uncertainty as "knowing the kind or class of events that will occur, but not the probability of their happening;" and ignorance as "knowing neither the class nor the probability of events."

2. S. Kauffman. 1993. The Origins of Order: Self Organization and Selection in Evolution. New York: Oxford University Press:174, 208-227.

3. To support this point, Wildavsky (1988:219) cites Michael Polyani who asserts: "It is possible to improve the safety of the system because all of its parts are not required to be equally safe."

4. In discussing this phenomenon, Gell-Mann (1994: 92-96) cites Zipf's Law, which identifies a power law governing diminishing resource distribution that marks transition phases in complex systems.

5. Data collection for this study was supported by a National Science Foundation Small Grant for Exploratory Research, Self Organization in Disaster Response: The Northridge Earthquake of January 17, 1994, #BCS 94-10896.

6. The six recent California earthquakes are:
Whittier Narrows, M = 5.9, October 1, 1987
Loma Prieta, M = 7.1, October 17, 1989
Mendocino Coast, M = 6.9, 6.0, 6.5, April, 25-26, 1992
Landers, M = 7.5, June 28, 1992
Big Bear, M = 6.6, June 28, 1992
Northridge, M = 6.7, January 17, 1994
The Landers and Big Bear Earthquakes occurred on the same day in relatively unpopulated areas about 100 miles east of Los Angeles. They may be related, but are reported as separate events by seismologists.

7. Richard Andrews, Director, California Office of Emergency Services. Statement made to the California Seismic Safety Commission at its Hearings on the Northridge Earthquake, February 10, 1994, Van Nuys, California.

8. H. Kanamori, Professor of Seismology, California Institute of Technology, Briefing on the Northridge Earthquake, Pasadena, CA, February 4, 1994.

9. Councilman Hal Bernson, Chair, Ad Hoc Committee on Response to the Northridge Earthquake, Los Angeles City Council, Interview, February 8, 1994; John F. Hall, Department of Engineering, California Institute of Technology, Professional Presentation at the Annual Conference of the Earthquake Engineering Research Institute, Pasadena, CA, April 9, 1994.

10. 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.

11. Director's Meeting, *Federal Emergency Management Agency*, Disaster Field Office, Pasadena, CA, February 2, 1994.

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

13. 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.

14.The CUBE system was demonstrated by Professor Kanamori at the California Institute of Technology to an interdisciplinary group of professionals interested in earthquake research on Friday, February 4, 1994. In his presentation, he explained the operation and membership of the system.

15.Interview, Deane Hartman, EDIS Coordinator, FEMA, Disaster Field Office, Pasadena, CA, April 9, 1994.

16. These maps were produced by the GIS section of ESF 5: Information and Planning. The work was largely organized and developed by the Planning Section of the California Office of Emergency Services. Interview, Dave Kehrlein, California Office of Emergency Services, Planning Section, January 30, 1994.

17. The model was designed and run by EQE International, a professional engineering firm in Irvine and San Francisco, under contract to the California Office of Emergency Services.

18. Interview, Michael Henry, County Administrator's Office, Los Angeles County, February 10, 1994.

19. The California Public Information Office reports the declaration at emergency at 9:10 a.m., Monday, January 17, 1994.

20. Federal Emergency Management Agency. 1994. Reinventing Disaster Response: Northridge Earthquake - The First Five Weeks. Washington, DC: Chronology, p.2. This chronology lists the time of the State declaration as 9:05 a.m.

21. In contrast, it took four days for the federal government to respond to requests for assistance from the State of Florida following Hurricane Andrew on August 24, 1992.

22. Interview, Larry Shiffrin, Coordinator, ESF 2: Communications, Joint Federal/State Information Center, Disaster Field Office, Pasadena, CA, February 9, 1994.

23. Interview, Larry Schiffrin, Federal Emergency Management Agency, ESF 2: Communications, Pasadena, February 9, 1994.

24. Interview, Larry Schiffrin, FEMA Region IX, Manager, ESF 2: Communications, February 9, 1994.

25.Professional observation, Disaster Field Office, Pasadena, CA, February 3, 1994. See also Federal Emergency Management Agency. 1994. Reinventing Disaster Response. Thursday, February 3, 1994, Day 18, Chronology:48.

26. Los Angeles Times, February 13, 1994, p. 1. See also FEMA. 1994. Reinventing Disaster Response,"Streamlined Declaration Process":7.

27.Federal Emergency Management Agency. 1994. The Federal Response Plan for Public Law 93-288, as amended. Washington, DC: U.S. Government Printing Office:1994-517-748/80726.

28. Earthquake Engineering Research Institute. 1994. Northridge Earthquake, January 17, 1994: Preliminary Reconnaissance Report. Oakland, CA. Chapter 9: Social Impacts and Emergency Response:91.

29. Interview, Sgt. Robert T. Gandy, Los Angeles Police Department, Supervising Officer for the Emergency Operations Center, Los Angeles, CA, February 2, 1994; Interview, Chief Meehan, Los Angeles County Fire Department, Los Angeles, February 8, 1994.

30. Interview, Chief Jay Corbett, Incident Commander, Northridge Earthquake, Los Angeles County Fire Department, Los Angeles, February 1, 1994.

31. The twenty-seven federal agencies and their functions in disaster response are specified in detail in the Federal Emergency Response Plan. The lead agencies for the twelve emergency support functions are stated briefly as:

ESF 1: Transportation - Department of Transportation
ESF 2: Communications - National Communications System
ESF 3: Public Works & Engineering - Department of Defense, U.S. Army Corps of Engineers
ESF 4: Firefighting - Department of Agriculture, U.S. Forest Service
ESF 5: Information & Planning - Federal Emergency Management Agency
ESF 6: Mass Care - American Red Cross
ESF 7: Resource Support - General Services Administration
ESF 8: Health and Medical Services - Department of Health & Human Services, U.S. Public Health Service
ESF 9: Urban Search and Rescue - Department of Defense
ESF 10:Hazardous Materials - Environmental Protection Agency
ESF 11:Food - Department of Agriculture
ESF 12:Energy - Department of Energy

32. Seismic Safety Commission. 1989. California at Risk. Sacramento, CA: Report SSC 89-02:149-165.

33. Interview, Olcen Banks, FEMA, Manager, Logistics, Disaster Field Office, Pasadena, CA, April 9, 1994.

34.Interview, James Lee Witt, Director, Federal Emergency Management Agency, Disaster Field Office, Pasadena, CA, January 30, 1994.

35. Professional observation, State Planning Meetings, Disaster Field Office, Pasadena, CA, January 28 - February 11, 1994. See also Situation Reports prepared by the California Office of Emergency Services, January 18 - February 11, 1994.

36.Interviews, federal and state personnel, Disaster Field Office, Pasadena, January 28 - February 11, 1994.

37. Los Angeles Times, January 18, 1994.

38.Interview, Operations Chief, Communications Center, Los Angeles County Fire Department, February 8, 1994.

39. Director's Briefing, California Office of Emergency Services, January 31, 1994.

40. Please see A. Wildavsky. 1988. Searching for Safety, Chapter 10:207-208.

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