Anticipating Fire:
A Sociotechinical Approach to Mitigation

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ABSTRACT

Fire is a complex, dynamic phenomenon in which small differences in initial conditions lead to large differences in outcome. Designing structures to reduce risk of fire in the first place, and to facilitate rapid intervention should it occur, are critical elements in a risk mitigation strategy. I propose a sociotechnical approach that will integrate critical information about buildings, people, and environmental hazards to reduce the risk of fire in engineered buildings and communities.

A sociotechnical strategy combines technical with organizational systems to increase the capacity of a community to reduce risk and loss. Such a strategy assumes that an engineered building, with its occupants, constitutes a sociotechnical system, and that many buildings, with their occupants, create a wider community that can anticipate, reduce, or increase risk. The systems are nonlinear, and require dynamic information processes for effective mitigation.

I review conditions that led to rapid fire spread in two cases: the intense fires that erupted in Kobe, Japan following the Hanshin-Awaji Earthquake of January 17, 1995, and the firestorm that engulfed the Oakland/Berkeley Hills in northern California on October 20, 1991. I conclude that the design of sociotechnical systems presents the potential for mitigating risk of fire in interdependent communities.

Keywords: Risk, design, sociotechnical systems, mitigation, interdependence, complexity, dynamics, fire, information processes, self organization.

1. RISK AS A PROBLEM IN DESIGN

Risk implies uncertainty, and consequently constitutes a continuing problem for design, particularly in the design of built infrastructure for human communities. The practice of design, therefore, carries with it a professional responsibility to reduce risk in its technical, social and economic dimensions. This responsibility falls most heavily on architects, engineers, planners and public policy makers who play major roles in the design and construction of our buildings and infrastructure. The design of human settlements is necessarily interdisciplinary, and consequently, risk perceived in one aspect of the infrastructure needs to be communicated to those working on other aspects, if the total risk for the community is to be reduced. Unrecognized, risk in one area may be compounded inadvertently by conflicting or inappropriate actions taken in constructing another area. Instead of a coherent design to minimize risk across multiple components of the community's infrastructure, actions taken separately, without knowledge of the interdependencies among these components, may lead to sequential failure of interrelated components and catastrophic consequences for the entire community.

2. SHARED RISK IN THEORY

2.1 The Context of Interdependence

Buildings are systems composed of interdependent subsystems: electrical, heating, plumbing, foundation, walls, ceilings, floors. Each building is itself a sub-system located within a wider set of interacting systems that constitutes a community. In addition to a stock of buildings, the community includes other types of interconnecting systems: transportation, communications, power, water, waste disposal, gas lines, as well as organizational systems of finance, employment, commerce, education, and service delivery. The community, or a set of interacting systems with their constituent subsystems, is interdependent. That is, effective performance of one function depends upon effective, consistent performance of several other functions simultaneously. If electrical power goes out, the traffic lights don't function, and traffic is stalled. If traffic is stalled, accidents occur, business deliveries are delayed, appointments are missed, and commerce is disrupted. Simultaneously, elevators don't function, water pumps don't function, fire house doors don't open, and risk ripples through the community as ordinary services are disrupted and large groups are exposed to new vulnerabilities. Interdependence creates a distinct form of risk -- shared risk -- in which the state of any one building, group or function is affected by alterations in the state of its near neighbors and/or the whole system.

2.2 Characteristics of Interdependent Systems

Interdependent systems are complex systems, involving multiple sites of action and several levels of action at each site. Design for complex systems, such as buildings and communities, needs to consider multiple sites, each with several levels of function, simultaneously. These levels of performance include the detailed level of a single function, such as electrical power; the interaction between that function and others in a specific sub-system, e.g. doors, elevators, special equipment; the interaction between the electrical sub-system and its companion sub-systems, for example, plumbing, heating, water and waste disposal, within the larger system of the building. Community design includes the interaction between the building systems and their immediate external environment.

Given the complexity of interdependent relations in a community, multiple disciplines are involved in the design and operation of these systems on a daily basis. Each has its particular techniques, terminology, constraints and requirements for operation. Integrating the separate components and their respective functions into a coherent whole is critical to the operation of an effective community. It requires the acceptance of common goals, articulation of clear strategies for action, and adoption of valid means for evaluatingthe performance of each function and the system as a whole.

Anticipation of risk becomes a major goal for the entire community, so that timely, appropriate action may be taken to reduce likelihood of loss at each level of operation. For the community, anticipating risk pays high dividends in terms of protecting lives, reducing expenditures for emergency services, and minimizing property losses.

2.3 Dynamic Processes in Interdependent Systems

Because complex systems are interdependent, they are also dynamic. That is, the state of the system varies with the degree of interaction among sub-systems within the system and the degree of interaction between the system and its wider environment.[1] Since these systems are designed for action, there is a continual flow of information, communication, energy, and activity through them. This flow creates demands for system performance that cannot be controlled by linear cause-and-effect measures.[2] No amount of regulation, for example, can anticipate all possible adverse circumstances that create risk to a building or its occupants. Neither can regulation compel the occupants of a building to follow safe practices, if they choose not to do so. It can only punish them after the damage has been done. Mitigating risk under these conditions requires an anticipatory approach, one that identifies potential problems before they occur, and initiates timely action to adjust performance in keeping with an overall goal of protection of life and property.

Risk to a building and its occupants emerges from interaction with the wider community. Conversely, the building and its occupants may generate risk that spreads to the wider community. The process of managing risk is interactive between any given building and its immediate environment, the community within which it is located.

In dynamic, interdependent systems, the information available to each actor becomes critical to informing his or her actions in reducing risk.[3] The technical functions of a building become dependent upon the organizational systems of communication and coordination in anticipating risk and mobilizing action to reduce that risk before danger occurs. This condition is especially important in minimizing the risk of fire, which spreads very rapidly, and once out of control, consumes everything in its path.

The built environment of any community includes its information infrastructure, which may vary in sophistication and validity from word-of-mouth communication and neighborhood flyers to satellite communication and WEB pages on the Internet for public agencies. This information infrastructure is critical to providing decision support for communities that confront the need for urgent action to minimize risk or suppress danger. In dynamic systems, the information infrastructure enables the component units to search for relevant information to a sudden threat, exchange information about the existing condition and its alternatives for action, learn from other sources in the wider system, and adapt behavior appropriately in accordance with rapidly changing conditions.[4] The initial conditions of this information infrastructure determine in important ways the outcome of efforts to combat fire as an dynamic,unpredictable phenomenon.[5]

2.4 Increasing Complexity in Interdependent Systems

Interdependent systems pose a serious challenge to administrative management and policy, as they lead, almost inexorably, to increasing complexity in organizational response. At least four conditions affect the degree and rate of increasing complexity in interdependent systems. These include:

1) the degree of urgency for action,
2) the degree of uncertainty for outcomes of actions,
3) the number of actors participating in the system, and
4) the constraints on resources accessible to the system.

If any one of these conditions is present, and all are present under the conditions of a rapidly developing urban fire, the standard organizational system of fire protection is likely to fail. The problem is rooted not only in the limits of our technical and organizational infrastructure, but also in the limits of human cognitive capacity.

Administrative theorists have engaged in a long and vigorous debate over the influence of increasing organized complexity upon social system performance.[6] The dominant perspective has been that as organized complexity increases in social systems, performance drops, often sharply.[7] The reason most often cited for this drop in performance is the limited cognitive capacity of human decision makers.[8] Increases in organized complexity require significant increases in information flow, communication, and coordination in order to integrate multiple levels of operation and diverse requirements for decision into a coherent program of action. The difficulty, however, is that human decision makers are unable to process the amount and range of information required to make timely, informed decisions for adequate coordination among the multiple components of the system. Accordingly, complex development in social organizations was viewed as necessarily limited by human information processing capacity. Todd La Porte[9] stated this position as follows:

> "The crucial limit on complex development is the capacity of individuals to process information, thus limiting the number and kinds of interaction they can engage in."

A similar view is expressed by Stuart Kauffman, a biologist writing on complexity, who notes the increase in reciprocal actions generated among components of a system as that system increases in size. He[10] states:

> "As systems of many parts increase both the number of those parts and the richness of interactions among the parts, it is typical that the number of conflicting design constraints among the parts increases rapidly. Those conflicting constraints imply that optimization can attain only ever poorer compromises."

While these observations are based upon increased organizational complexity within single systems that have distinct limits on resources, they do not take into account the possibility of expanding the operating system by selective integration with other systems or transition to a different mode of operation that allows improved coordination among components. LaPorte and his colleagues,[11] in his later research on high reliability organizations, found that certain organizations, such as aircraft carrier groups and air traffic controllers, were able to achieve near "failure-free" performance, but in settings of intense training, socialization, and single-purpose tasks. Such settings, however, are very different from a disaster environment in which organizations are working together often for the first time as well as interacting with citizens, business organizations, and voluntary groups, many of whom have little to no training in coordinated disaster response.

Advances in information technology and telecommunications allow us to consider alternative means to diminishing organizational performance in complex environments. The technical capacity to order, store, retrieve, analyze, and disseminate information to multiple users simultaneously creates the potential for innovative approaches to collective learning and self organization. These means extend information processing capacity beyond the limits of single individuals, and provide decision support to multiple managers addressing the same problem at different locations at the same time. Linking organizational capacity for mobilizing the resources of a community to appropriate uses of information technology creates a 'sociotechnical system' in which the technical capacity to exchange timely, accurate information among multiple participants increases the organizational capacity to solve shared problems that require action at both local and national levels.

Such sociotechnical systems function through the exchange of timely information, using feedback processes to create a consensual knowledge base that activates members of a community in pursuit of a common goal. Interactive communication enables them to perform at a more sustained and creative level as a whole system than any had previously achieved individually. Instead of leading inevitably to diminished performance, I propose that increased organizational complexity offers an opportunity for interorganizational learning and, consequently, improved system performance among organizations confronting interdependent problems, such as response to a major fire that crosses jurisdictional lines. Interactive system performance requires, however, an information infrastructure to support the exchange of timely, accurate information and regular feedback processes that enable participants to engage in a process of continuous learning and improvement.

2.5 Methods of Reducing Risk: Control vs. Inquiry

If we think of communities as complex, interactive systems, and buildings and their occupants as dynamic subsystems that exist within the larger, more complex community, we can observe the dynamic exchange that occurs between buildings and their immediate environment. Managing risk effectively compels us to acknowledge the potential spread of risk as a threat advances from level to level of severity and complexity. Each shift in level of exposure to threat, each addition in numbers of interactions, and each expansion in the number of actors involved in response to threat leads to a corresponding increase in the complexity of organizational interaction that is needed to protect lives and property in the community. Such actions require an information infrastructure that is capable of receiving, storing, retrieving, analyzing and disseminating information to all participants involved in risk reduction and response. This infrastructure includes both the technical and organizational components to support communication and coordination processes for interorganizational decision making. Managing risk is a sociotechnical process that involves interaction between people and their built environment through communicative mechanisms. In open, interdependent systems, this process is decidedly nonlinear.

Nonlinear, dynamic systems thus generate distinctive characteristics that set them apart from linear systems. Most importantly, nonlinear systems exhibit the capacity for self-organization. That is, they spontaneously reallocate resources and readjust their activities to create a better 'fit' between their internal operations and the demands of their immediate external environment. The search for a better fit often leads to more complex relationships as different actors adjust their performance to one another as well as to the environment. While adaptation does not always result in improved performance, nonlinear systems reveal energies directed to change their structure through internal dynamics. Linear systems, relying on external direction, are not able to generate spontaneous, endogenous re-organization.[12] In nonlinear systems, it is critical to assess the degree to which the system is able to generate, maintain, conserve, and redirect energy within the system in order to achieve its desired goal.

Given these conditions, managing risk in nonlinear systems implies a fundamental shift from designed mechanisms of control to active processes of inquiry and collective learning leading to change. More important than preventing change in performance -- a strategy of control -- is determining the current state of the system and its future vulnerabilities -- a strategy of inquiry. A strategy of control seeks to ensure responsible performance and prevent possible destruction to the system by following carefully prescribed procedures, for example, the command system used in the military.[13] A strategy of inquiry focuses on anticipating, identifying and reducing risk before threat occurs, for example, the practices of some business organizations as they enter uncertain markets.[14] While it is not always possible to prevent hazards, a strategy of inquiry nonetheless informs action and enables more rapid, efficient response when a threat does occur. Action within the system shifts from command to self organization. Guided by a common goal of protection of life and property, self organization facilitates mutual adjustment among the components of the system to the performance of one another within specified parameters at each level of organizational responsibility. The process allows a more rapid and efficient adjustment in performance to internal changes within the system. Further, it enables the system to respond more appropriately as a whole to demands from the wider environment. This flexibility in allocating resources and attention in accordance with shifting demands from a changing environment is vital to effective performance. Without such flexibility, both organizational and technical systems fail. This pattern is shown vividly in two cases of rapid fire spread.

3. SHARED RISK IN PRACTICE: THE EXAMPLE OF FIRE

3.1 Fires in Kobe Following the Earthquake of January 17, 1995

When a severe earthquake struck the Hanshin region of Japan on January 17, 1995 at 5:46 a.m., registering 7.2 on the Richter scale of magnitude, the built infrastructure suffered enormous damage. Transportation systems and buildings collapsed. Underground gas, electrical, water, and sewage distribution systems fractured, causing major disruption to service delivery in this densely-populated metropolitan region. Fires immediately followed the earthquake, triggered by damage incurred in the first shock and causing a secondary disaster.

The epicenter of the earthquake was located on northern Awaji Island, just off shore from Kobe, a city of 1.5 million people. The rupture registered strong ground motion directly through downtown Kobe and northward to the neighboring cities of Nishinomiya, Ashiya, Itami City, Amagasaki, Takarazuka, and other towns in Southern Hyogo Prefecture. Organizational response to this event revealed aspects of the process of self organization in dynamic, uncertain environments, but also illustrated large gaps in the information process of multiorganizational decision making.

3.1.1 The Initial Conditions

The initial conditions prevailing in the Southern Hyogo Prefecture of Japan in January, 1995 shaped in significant ways the response system that evolved following this disaster. The technical, organizational, and social conditions of this metropolitan region were those of an advanced industrial society. Kobe, the principal city in the Hanshin region, is located in the south central section of Honshu, the main island of Japan. Geographically, the city stretches 30 kilometers east to west along Osaka Bay, with the Rokko Mountains rising steeply to the north. Kobe is a modern city, with interdependent systems of transportation, industry, trade, banking, education, and medical care linking the city to others in the region. The transportation system, for example, is an advanced mix of highspeed rail transport, local railways, city bus lines, and expressways, connected to international transport via a major new regional airport and a busy international shipping port, the sixth largest in the world. Extensive networks of telecommunications, electrical, gas, and sewer lines provide efficient, modern services to this metropolitan region of over 10 million people. Building structures represent a mix of types, with sophisticated seismic engineering in high-rise buildings interspersed with old style wooden houses with heavy tile roofs. The technical profile of the region is generally strong and, prior to the earthquake, was a matter of pride for residents of the region.

Organizationally, however, the area was not well prepared for seismic risk. Although the islands of Japan are located at the juncture of three tectonic plates and seismic risk is well known in the nation, residents generally believed the Hanshin region, which had last experienced a moderate earthquake (6.1 Richter scale) in 1916, was relatively stable in contrast to the Tokyo Region, which had suffered a major earthquake with heavy losses in 1923. Consequently, relatively little investment had been made in earthquake preparedness, either by public organizations or residents. While cities in the region had emergency plans, their preparation had been oriented toward small, local disasters of fires and floods.

Private utility companies, such as Kansai Electric Co. and Osaka Gas Co., demonstrated substantial investment in seismic mitigation efforts to protect their operations, but were not directly linked to the public agencies. Socially, there existed little tradition of voluntary organizations or community self help associations. Most people focused their lives on their work associations and their families.

Although the initial technical systems were strong, there was little interorganizational capacity to reallocate resources and action in timely response when these interdependent systems failed under the severe shock of the unanticipated earthquake. In the densely populated, complex urban environment of the Hanshin region, the Magnitude 7.2 earthquake set off a cascading effect in the area's network of interdependent systems. Failure in one system triggered failure in the another which triggered further failure in a third, each failure compounding the damage and leading to full-scale disaster, affecting approximately 4 million people in the metropolitan region.

The damage was extensive. The death toll climbed past 6,300 in recent reports (National Land Agency , 1995) [15] and the number of wounded totaled 41, 648 in the April 25, 1995 report. In housing, the National Land Agency reported 101, 233 homes totally destroyed, 107, 269 homes half destroyed, and 182,190 homes partially destroyed, for a total of 390,692 damaged homes. A total of 3, 669 public buildings were damaged or destroyed. Fire claimed a major toll, with a total of 294 separate fires reported in the Hanshin Region immediately following the earthquake.

The dynamics of the destruction were sobering. The strong vertical ground motion ruptured underground gas and water mains, causing leaks and disrupting service throughout the region. An estimated 4,500 km. of gas lines were heavily damaged, and 1,200,000 houses were left without water. Electrical facilities were also damaged, cutting off sources of electrical power to 850,000 city departments, businesses, and households. The total cost of the disaster is estimated at US $200 billion. As the gas mains ruptured, fires broke out. With no water available for fire suppression, the fires raged largely unchecked through seriously damaged sections of the city. In Kobe, 60 fires broke out before 6:00 a.m. on January 17, 1995, and burned simultaneously. Before 9:00 a.m., the number of fires burning simultaneously had increased to 85, with a total of 109 fires reported for the city of Kobe, and a total of 294 fires for the entire earthquake-affected area. The major cause of the fires was broken gas mains. Debris from collapsed buildings blocked the streets, preventing fire trucks from getting through. Over 9,403 blockages in roads were reported for the area.

These conditions proved overwhelming for the Kobe Fire Department which had primary responsibility for emergency response, but a total of 11 fire stations in the city, 176 engines, and 305 personnel on duty when the earthquake occurred. Three of the 11 stations were damaged in the earthquake, and even with emergency call-out procedures, only 663 personnel were able to report for duty within the first two hours. The actual destruction was beyond any training scenario for municipal emergency response.

3.1.2 Information Search

Interdependent emergency response organizations were unable to make a rapid transition to an emergency response system vital to saving lives in the first hours following the earthquake. Under the urgent conditions of disaster, communications capability was critical. The Kobe Fire Department had just installed an advanced computerized dispatch system with video monitors in December, 1994. However, it was not yet operational and was not used in disaster operations. Telephone lines were out of order during the first day in large areas of the region, while others were overloaded. Over 1800 emergency calls made on 118 emergency circuits were recorded on the 119 dispatch logs on January 17, 1995, at roughly 100 calls per hour or 1.7 calls per minute. Further, these were only the calls that could get through. The number of calls attempted, but not completed, cannot be estimated. Fire departments had their own radio systems, but could not communicate with other departments. Communications capability proved very limited in the first critical hours following the earthquake. The basic information infrastructure needed to support the search for, and exchange of, information in the dynamic disaster environment was either not available or not functioning.

The business sector had invested in information technology that performed well within its limited range, but business organizations did not have clear, effective communication linkages with public sector agencies responsible for life and property. Public sector investments in information technology either were not fully operational, e.g. Kobe Fire Department's GIS and computerized dispatch system, or failed, e.g. Hyogo Prefecture's satellite communication system, to support decision making in disaster operations.

3.1.3 Information Exchange

The damaged communications infrastructure severely restricted information exchange in response operations during the first critical hours following the Hanshin Earthquake. During this time, the fires broke out of control and spread rapidly throughout the city. Valiant efforts were made to suppress the fires, but the combination of simultaneous ignition, lack of water, lack of electrical power for pumping water, the direction of the winds, and the number of wooden buildings fueled the fires and completely overwhelmed the local fire resources. Only hours after the initial outbreak of fires did prefectural and national response agencies learn of the severe conditions in Kobe, late, almost too late, to provide much needed support. The operations logs from municipal, prefectural and national fire agencies reveal the limits of information exchange during this period, and its consequent effects upon response operations.

Table 1

KOBE CITY FIRE DEPARTMENT

Record of Fire Fighting Operations in the Kobe Area
January 17, 1995

Operations

5:46	Earthquake occurred; almost all of the 119 emergency lines were occupied; emergency summons issued to personnel.
5:53	First fire report and three others followed; at least 60 fires were burning simultaneously.
6:15	Chief, Fire Department arrived at Kita Suma branch office, called the control center, and received reports of the disaster situation and rescue operations.
6:25	Chief, Fire Department left Kita Suma branch office for the Fire Department. On the way, he observed the disaster situation.
6:40	Fire Chief ordered a pump truck team at Tarumizu Fire Station sent to the Nagata area.
6:50	Center control room was established; Mayor arrived at control room.
7:00	Kobe City Disaster Operations Center was established.
7:10	Chief, Fire Department arrived at the Operations Center; vice head, Operations Center tried to call prefecture to report disaster, but could not get through.
7:20	Chief ordered two pump truck teams at Kita Fire Station sent to Hyogo area.
7:30	Chief, Operations Center reported disaster and prevention activities to mayor.
8:00	Chief ordered a pump truck team at Tarumizu Fire Station sent to Nagata area.
8:30	Chief ordered a pump truck team at Kita Fire Station sent to Nagata area.
9:05	Vice Chief, Operations Center briefed prefectural government on the disaster.
9:20	Operations Chief ordered a Fire Defense Mobile Unit helicopter to gather information on status of disaster in the entire city.
9:30	Chiefs of Fire Departments of Kyoto City and Osaka City offered support. Asked the prefectural government for the possible mobilization of Self Defense Force (Planning Adjustment Department).
9:40	Received a report from the Fire Defense Mobile Unit helicopter. At least 20 additional fires were reported, and building collapses were observed all over the city, especially in the eastern part.
9:50	Chief, Fire Department advised the mayor to request a wide area fire fighting support and mobilization of Self Defense Force; suggested that Fire Departments deal with fires and Police and Self Defense Force carry out rescue operations. The mayor requested the governor of Hyogo Prefecture to send wide area fire fighting support.
10:00	Mayor of Kobe requested the governor of Hyogo Prefecture to mobilize the Self Defense Force. The Minister of Fire Defense Agency, the Ministry of Home Affairs accepted the request. The Governor of Hyogo Prefecture reported that relevant governors had received the order.

Source: "Hanshin - Awaji Daishinsai (Kobe Shiiki) ni okeru Shobokatsudo no Kiroku", Kobe City Fire Department, Kobe, Japan, March, 1995.

HYOGO PREFECTURE
Fire Fighting Operations in the Kobe Area
January 17, 1995

Operations Control

9:20: Helicopters of Kobe Fire Department were activated, and officials gave a disaster report to the Operations Center by radio; operations were delayed due to liquefaction at heliport. In the afternoon, the Fire Defense heliport was moved to Hiyodori Dai.

9:50: Governor of Hyogo Prefecture receives request from Mayor of Kobe for wide area fire fighting support

10:00: Governor of Hyogo Prefecture receives request from Mayor of Kobe for mobilization of Self Defense Force. from National Fire Defense Agency in Tokyo.

10:01: Governor of Hyogo Prefecture requests wide area fire fighting support and mobilization of Self Defense Force from National Fire Defense Agency in Tokyo.

10:30: Disaster Prevention Center organized seven special teams to carry out mission, with 6 personnel to a team. The first medium team (three small teams, 18 personnel) was mobilized in Nagata area. It carried out fire fighting and rescue operations, securing water from fire fighting ships, etc.

11:10: Fire brigades from Mita City (north of Kobe) arrived at Nagata-ku.

13:15: Self Defense Force, the Third Division, Himeji Special Regiment arrived with 216 members.

13:40: Ten fire fighting teams from Osaka City arrived. Thereafter, fire brigades arrived one after another. Tokyo Fire Defense Agency, Nagoya City Fire Department, and Hiroshima City Fire Department responded with support teams. Yokohama City Fire Department, Kawasaki City Fire Department, Kyoto City Fire Department sent helicopters.

24:00: Reinforcements arrived: 182 pump truck teams with 860 personnel, 9 helicopters with 52 personnel, and 2562 Self Defense Force members to assist in fire fighting operations.

Source: Summary of Fire Defense Operations, Hyogo Prefecture, "Hanshin - Awaji Daishinsai (Kobe Shiiki) ni okeru Shobokatsudo no Kiroku". Kobe City Fire Department, Kobe, Japan, March, 1995.

NATIONAL FIRE DEFENSE AGENCY, TOKYO
Summary of Fire Fighting Operations,
January 17, 1995

Director's Report:

6:30: Awakened at home at usual time; turned on television; learned of earthquake from news report. Did not receive any calls; planned to go to office at usual time, 9:30 a.m.

7:30: At breakfast, watched the news, saw the photos of the shinkansen collapse. Realized that the earthquake was serious; but did not know scale of damage.

8:40: Arrived at office, earlier than usual. No communications were available between Tokyo and Kobe. Telephones were out. Tokyo Fire Department called to ask the status of Kobe. Without knowing the damage, they were preparing a support team and two helicopters to send to Kobe. In Fire Department, protocol is not to send assistance unless requested.

9:00: Established communication with Kobe; established a support team.

10:01: First report from Kobe -- they requested support -- request came from Kobe City Mayor through the governor of Hyogo Prefecture via telephone

10:02: Called Fire Defense Agencies that had helicopters, e.g. Hiroshima; there are 12 Fire Defense Agencies with helicopters; some helicopters couldn't fly, they under inspection. Mobilized response to Kobe.

Source: Interview, Director, Ambulance and Rescue Service Division, Fire Defense Agency, Ministry of Home Affairs, Tokyo 100, Japan. Tuesday, May 16, 1995.

3.1.4 Organizational Learning

Operating under the urgent, stressful conditions of disaster, participating response organizations had little time for reflection and less opportunity for learning new methods of coping with their dynamic environment. Time for reflection, organizational learning and redesign came after the initial crisis passed, and still continues, more than two years after the event.

3.1.5 Adaptive Behavior and/or Self Organization

Self organization did occur, but later and more sporadically in the response period. Instances of innovative behavior characterized the response, as firemen sought to halt the destructive force of fire. Without water pressure in the mains, fire companies connected long hoses and ran them for several kilometers to pump water from Osaka Bay to suppress fires in the most severely affected wards. After this destructive event, the Kobe Fire Department, working in conjunction with a computer scientist at a local university, has modeled the spread of the fire to study the dynamic conditions of its rapid escalation in order to mitigate risk of fire in future earthquakes.[16] The challenge is to build upon this spontaneous base of interest and experience to foster a continuing exchange of information, knowledge, and skills in the mitigation of risk in Japan and other nations.

3.2. The Oakland Hills Firestorm, October 20, 1991

The dynamics of an urban/wildlands fire illustrates a painful pattern of events, consciously tended, going wildly out of control. The sequence of events depended upon a rapid and accurate exchange of information among multiple agencies, which failed without adequate infrastructure or support. On Saturday afternoon, October 19, 1991, a small brush fire ignited in the backyard of a home in the Oakland Hills. The homeowner called the Oakland Fire Department; trucks rolled; a crew put out the fire, and posted watch. The Oakland Fire Chief, concerned with the economical use of resources, asked the crew to return every hour. The crew returned every hour throughout the night, and damped embers lingering under the grass. On Sunday morning, the fire crew checked back at 8:00 a.m.; 9:00 a.m. and 10:00 a.m. They were scheduled to return at 11:00 a.m. At 10:50 a.m., the hot, dry Santa Ana winds from the San Joaquin Valley started to blow, fanning embers underneath the grass into a sudden inferno, and by 11:00 a.m. it engulfed the hillside. Fire trucks, returning to the scene, were unable to stop it. Within two hours, the fire had swept over hundreds of acres, leaping the freeways and a lake. By late afternoon, the fire had claimed 24 lives and 3,000 homes were totally destroyed. What were the circumstances that allowed this seemingly minor incident to escalate so rapidly and destructively?

3.2.1 The Initial Conditions

The initial conditions in which the fire occurred greatly shaped its escalation. In October, 1991, northern California registered its seventh year of drought. The wild grasses and underbrush close to the residential areas were tinder dry. The California Department of Forestry had posted red notices of Extreme Fire Hazard along the roadways. Homes were nestled into the hillsides, close to the trees, close to the grass and underbrush. Streets were narrow and winding, providing spectacular views but little access for fire trucks or alternative routes to safety. The risk of fire was extremely high, but the level of awareness among residents and community organizations was one of ordinary indifference. The Oakland Fire Department had endured internal difficulties and had brought on a new chief only ten days before the fire, after months of tensions. The City of Oakland was still reeling from the shock and costs of the Loma Prieta Earthquake in October, 1989, worsened by the state's prolonged economic recession. Minimizing costs was a primary goal, for both the Fire Department and the City.

3.2.2 Information Search

Information search in this event was limited. Although well-intentioned, the hourly watch established by the Oakland Fire Department, trained in structural fire suppression, did not take into account the possibility of fire creeping under the dry grass, characteristic of wildlands fires. Nor did it fully anticipate the deadly combination of Santa Ana winds, unusual in northern California, and the lingering embers of a grass fire. The lack of adequate knowledge of the immediate conditions and local region limited the subsequent actions available to responding organizations.

3.2.3 Information Exchange

The fire escalated so rapidly that ordinary means of information exchange failed. Telephone poles, for example, burned along with the houses and trees. Radios jammed; the command post moved again and again, barely staying ahead of the flames. In neighboring Berkeley, the Fire Department watched the fire, trucks and hoses at the ready, waiting for the request for mutual aid that never came. The information that did come in changed by the minute, and did not provide a coherent basis for informed decision among the response organizations that rushed to assist.

3.2.4 Organizational Learning

Under these extreme conditions, organizational learning turned into coping for survival. Eventually, the multiple fire companies responding to the event were able to coordinate their actions, but the dynamics of the fire were so intense that their primary effort was to evacuate the residents of threatened areas to safety.

3.2.5 Adaptive Behavior and/or Self Organization

Instances of self organization emerged in this extraordinary set of events. A few residents, determined not to lose their homes, ignored the calls for evacuation and managed to save them, aided by a miraculous shift in the wind or a visiting fire company seeking to assist. But this extreme situation led to an overall pattern of flight from danger. Only after the fire has there been substantial reflection and redesign of practices, both by the City of Oakland and its residents, in terms of minimizing risk from the interface between wildlands and urban residences.

4. Future Strategies for Mitigating Risk: The Design of Sociotechnical Systems

In both cases -- the Kobe Fires and the Oakland Hills Firestorm -- the respective communities and their response organizations did not adequately acknowledge the interdependence between built structures and the environments in which they were located. Equally, in both cases, the cost in lives and property might have been significantly reduced by a different conception of design for the communities. Such a design would acknowledge the complex interdependencies of built and social environments, and the critical factor of time in enabling informed action to possible threat.

Anticipating risk means the design of self organizing systems that are capable of reallocating their attention and resources to meet threats from both the internal and external environments. This process, in rapidly evolving, complex environments, can be assisted by the appropriate use of information technology. Advanced information technology facilitates the timely search, storage, retrieval, analysis and transmission of large amounts of interdisciplinary information needed for effective policy decisions. It also facilitates the transition between levels of analysis that is essential for effective adaptation to changing environments.

5. Conclusion

If we shift our strategy of risk reduction from control to inquiry, and broaden our conception of design to include social as well as technical systems, we will be much more effective in anticipating and reducing the kinds of risk to which the built environment is exposed.

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