INFORMATION TECHNOLOGY AND EFFICIENCY IN DISASTER RESPONSE:
THE BHUJ, GUJARAT EARTHQUAKE OF 26 JANUARY 2001

Louise K. Comfort
Graduate School of Public and International Affairs
University of Pittsburgh, Pittsburgh, PA 15260 USA
E-mail: lkc@pitt.edu

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SUMMARY

This article examines the uses of information technology in disaster operations among the jurisdictions and organizations participating in the multi-organizational disaster response system that evolved following the Bhuj Earthquake in Gujarat, India. The article is based on field observations and interviews conducted with local, state, and national officials responsible for disaster management, as well as staff from non-governmental organizations engaged in relief operations. The field trip was organized as an international, interdisciplinary reconnaissance trip to Gujarat, India by the World Seismic Safety Institute and Earthquakes in Megacities Initiative, and welcomed by the Gujarat State Government.

The study frames the problem as one of creating the best fit between information processes used in disaster management and the degree of risk to which a community is exposed. Three principal findings are reported regarding the uses of information technology and their impact upon the efficiency of disaster operations. First, different types of information technology were used at different jurisdictional levels. Second, information processes, using different information technologies, produced different results in response operations. Third, differences in information management created major obstacles for effective crisis operations. The article concludes with a conceptual model of increasing efficiency in disaster operations through improved information processes and organizational learning.

1. INTRODUCTION

On the morning of 26 January 2001, preparations were underway for celebrating Republic Day, the nation's fifty-first anniversary of independence, in cities across India. In old Anjar, a city in the western state of Gujarat, 400 school children were assembling to march down the main street, in proud recognition of their citizenship in the world's largest democracy. At 8:46 a.m., a powerful earthquake rumbled through the town, collapsing buildings on both sides of the street. Debris falling inward toward the center of the street struck the children as they were marching, killing at least 200 and injuring many others. This sudden loss of life, severe damage, and injury was repeated in villages, towns, and cities throughout the districts of Kachchh, Jamnagar, Rajkot, Surendranagar, and Ahmedabad, as the most severe seismic event in India in nearly 200 years took its toll.

The epicenter of the earthquake was located about 20 km. north north-east of the town of Bhuj, in the Kachchh District, UTC 23.40N 70.32E at a depth 23.6 km. The Indian Meteorological Department reported the earthquake as registering 6.9 on the Richter scale, with the US Geological Survey registering the event as 7.7 Richter, Ms. (EERI 2001) Strong motion records obtained from Ahmedabad, some 250 km. from the epicenter, indicated a

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[1] Graduate School of Public and International Affairs, University of Pittsburgh, Pittsburgh, PA 15260 USA, lkc@pitt.edu.

peak ground acceleration of about 0.11g., a powerful force. Official statistics reported 20,005 dead from the event, with approximately 166,836 injured. Of this number, 20,717 were seriously injured. The earthquake cut a wide swath of damage, with 21 of the 27 districts of Gujarat were affected to some degree. This area included 7,904 villages in 182 talukas. Damage to housing created a major problem; 332,188 houses were destroyed, while 725,802 houses suffered damage to varying degrees. An estimated 1,590,000 people were affected out of a population of approximately 4,780,000 who lived in the area, or roughly one out of every three persons incurred damage. The Ministry of Agriculture, which has responsibility for disaster management under India's disaster laws, reported total losses for the region at US$2,126,200,000 in March, 2001, while estimates from other agencies ranged over US$3 billion. The size and scope of these losses for India compel a careful analysis of means of reducing risk and managing the recurring threat of earthquakes in the region. The problem is not simply India's concern, but also that of the international community of scientists, researchers, policy makers, and professional managers who are committed to hazard reduction and improving response operations in areas vulnerable to seismic risk.

While the Kachch District of Gujarat was known to be prone to seismic activity and was assigned the highest rating of V on India's scale of seismic risk, the sobering losses suffered in Gujarat reflected the initial conditions in which the earthquake occurred. Five types of conditions interacted to amplify the consequences of this earthquake, resulting in its extraordinarily high costs. These types include technical, organizational, economic, scientific, and cultural conditions. Regarding technical conditions, the number of buildings that collapsed and the heavy damage to rail and roadways document the discrepancy between design practices used in constructing the built environment and the seismic risk for the area. Although a well-designed building code exists in India, the nation, struggling with poverty and development, had made little investment in ensuring the enforcement of the code in the actual construction of the buildings.

In terms of organizational capacity to mitigate risk and mobilize response, the heavy losses in lives and the high numbers of injured and displaced families illustrate the need for increased attention and investment in disaster plans and preparedness. Disaster management is a relatively new concept to India, as its traditional response has been to mobilize relief after a disaster occurred. After the devastating cyclone of 1998, initial steps had been taken to develop an emergency plan for cyclones in Gujarat State, but no similar effort had been made to develop an equivalent plan for seismic risk. In the January 2001 earthquake, the geographic area and population of the affected region exceeded the limited capacity of the local managers to respond to the enormous need. Although extraordinary efforts were made by state, national and international organizations to mobilize personnel, equipment, and supplies to meet immediate needs, the scale of operations and resources for response necessary for a disaster of this magnitude required organizational capacity and skills that can only be developed over time.

Economic conditions also exacerbated the vulnerability of the area to hazards. Struggling with issues of poverty and development, India had not invested heavily in disaster preparedness. Yet the heavy losses incurred by the number of vulnerable communities and the high costs of reconstruction meant that India could continue to ignore the issue of emergency preparedness only at peril of endangering further economic development efforts in the region.

Lack of scientific knowledge at the local level also exacerbated the vulnerability of the area. Although the Indian Meteorological Department had identified the Kachch District as an area of high seismic risk, this assessment was not widely known among the people living in villages, nor were most local officials aware of the degree of risk to which their communities were exposed. Scientific knowledge of the geologic conditions and seismic history of the region had not been incorporated into local planning or community awareness programs.

The fifth condition, identified as cultural but observed largely as openness to new information and willingness to act on that information, was shown by a population that, absorbed in meeting the demands of daily life, had little reserve or capacity to attend to new information, and less ability to act on it. Again, the discrepancy between known seismic risk and informed action to reduce that risk at multiple levels of governmental, nonprofit and private organizational responsibility compounded the damaging consequences of the earthquake.

These five interdependent conditions illustrate that seismic risk reduction cannot be achieved by any single disciplinary or professional perspective. The problem is complex, interdependent, and dynamic. It can be addressed most effectively by designing a sociotechnical approach that relies upon human capacity to learn and adapt to conditions of risk. This approach also requires the construction of a information infrastructure to support the continuous process of inter-organizational learning and action as conditions change.

2. Policy Problem

The core issue for India and other nations that are vulnerable to seismic risk is how to create a better fit between its sociotechnical infrastructure and the latent risk to which it is exposed. This problem is made more complex because the interaction is dynamic and continually changing. It means that risk reduction measures need to be continually re-calibrated against the changes in technical, organizational, economic, scientific, and cultural conditions as the degree of exposure to seismic movement increases or decreases. This is not a trivial problem, and it clearly identifies information processes as a major factor in enabling communities to manage their own risk.

Focusing on information processes, however, is only an initial step in structuring this policy problem for responsible action. Developing a coherent strategy of action for the multiple jurisdictions and many organizations within each jurisdiction that are involved in response operations following a major disaster relies on the human ability to learn and adapt prior knowledge to severely altered conditions. This capacity does not occur by chance, but can be developed by creating a better fit between knowledge of the existing infrastructure and the region's exposure to risk. Since exposure to risk changes over time, and the existing technical and organizational infrastructure is also subject to deterioration or reconstruction over time, managing risk to the community requires a continual re-calibration of the degree of exposure to threat (demand) against the community's capacity for response under changing economic, scientific, and cultural conditions. In this highly interdependent context, carefully designed and maintained information processes are central to managing risk in a vulnerable community.

In studying response operations following the Gujarat Earthquake, I sought to assess the extent to which different types of information technology affected the degree of efficiency attained in inter-organizational response to disaster. Were there ways in which the technical characteristics of the information infrastructure could facilitate inter-organizational communication and learning to produce innovative performance in disaster management? Conversely, were there ways in which this infrastructure might inhibit or obstruct innovative response in an environment suddenly altered by disaster? This relationship between technical function and inter-organizational performance appears critical to organizations participating in a rapidly evolving, inter-jurisdictional disaster response system. Four research questions guided this inquiry. They are:

1. What types of information infrastructure were used by which organizations to support inter-organizational coordination and performance in disaster response following the Bhuj Earthquake?

2. What patterns of communication in terms of frequency, direction, and content were used among organizations participating in disaster response?

3. To what degree did these patterns of communication produce a shared knowledge base that supported collective action in disaster operations?

4. What points of disruption and/or delay in information processes inhibited the performance of the disaster response system, with consequent effects for the community?

3. METHODS OF INQUIRY

Three primary types of activities were undertaken to carry out these objectives and to answer the four research questions listed above. First, L. Comfort visited the damaged areas of Gujarat State for a period of eight days, February 25 - March 4, 2001 as a member of an international, interdisciplinary reconnaissance team. The reconnaissance team included 21 members, with disciplinary backgrounds in the fields of engineering, public policy and administration, political science, social geography, meteorology, architecture and seismology [Mistry, Dong, and Shah 2001]. Team members included researchers from fourteen countries including Bangladesh, Germany, India, Indonesia, Iran, Japan, Kyrgizia, Malaysia, Norway, Nepal, The Philippines, Uganda, United Kingdom, and United States. The team visited four of the most severely affected districts of Gujarat: Kuchchh, Rajkot, Surendranagar and Ahmedabad. In these districts, the team assessed field conditions in the following cities/towns/villages: Ahmedabad, Anjar, Bhachau, Bhuj, Gandhidham, Kandla Port, Limbdi, Morbi, Malia, Mandvi, Navlakhi, Rajkot, and Surendranagar and observed the general condition of the villages, roads, bridges, railways and electrical power stations affected by the earthquake en route.

In the visits to the cities and towns, the interdisciplinary team would break into small groups that would each examine different conditions that resulted from the effects of the earthquake. L. Comfort joined a small group that examined conditions in telecommunications and interviewed managers of the telecommunications and telephone systems in Anjar and Gandhidam and visited the sites of the damaged telephone exchanges in Bhuj and Bachau. At these sites, L. Comfort also was able to take GPS readings of the locations of the damaged communications facilities to determine the distance between the nodes of the telecommunications network prior to the earthquake. These data were used to compare the distances between functioning nodes that remained after the earthquake.

In each of the major cities in the four damaged districts, the reconnaissance team had a group interview with the District Collector. The District Collectors of Ahmedabad, Surendranagar, Rajkot and Kachch (located in Bhuj) each presented a brief summary of the consequences of the earthquake in their respective districts, the existing conditions and recovery operations that were currently underway, and their recommendations for disaster mitigation against future seismic risk. The collectors willingly accepted questions from members of the group, and responded candidly to them. While these group sessions did not produce information as specific or detailed as individual interviews would have, nonetheless they did yield a significant amount of information about the consequences of the earthquake in each district and the impact upon the district's population and continuing operations.

A good deal of informal exchange of observations occurred in conversations among team members on the bus rides from city to city and over dinner at the end of the each day. The interdisciplinary make-up of the group enriched the range of perspectives that were shared on the consequences of the earthquake for the affected population. The different disciplinary perspectives were integrated into a group report that was published jointly by WSSI and EMI [Mistry, Dong and Shah 2001].

Second, after returning to the U.S., L. Comfort continued to search for, and review, documentary materials on the uses of technology by different public, private and nonprofit organizations that were involved in response and recovery operations. This information search included review of official reports as they were updated by agencies of the Indian Government, including the newly-established Gujarat State Disaster Management Authority (GSDMA) in Gandhinagar, reports of professional reconnaissance teams, summaries of activities by major non-governmental organizations that were engaged in recovery operations in the area, and a continuing review of news reports from English-language newspapers. This analysis identified new initiatives in uses of information technology that were being adopted by public, private and nonprofit organizations to strengthen performance in future disasters.

Third, based upon the review of documentary materials and continuing reports from Indian government agencies, it was clear that the Government of India had used several types of information technology to support multi-organizational response to the Gujarat Earthquake that were not mentioned or observed during the initial reconnaissance trip. With the assistance of RMSI, Noida, and the GSDMA, L. Comfort arranged a follow-up trip to New Delhi, Gandhinagar and Ahmedabad, May 4 - 12, 2002. On this second trip, L. Comfort interviewed managers of national, state and nonprofit organizations regarding uses of information technology both during the response operations and in the complex process of recovery and reconstruction of the damaged homes, villages, towns, and cities. Data from these interviews filled critical gaps in the earlier profile of the uses of information technology in the multi-organizational response system.

4. FINDINGS

This inquiry produced three major findings regarding the uses of information technology in disaster operations following the 26 January 2001 Gujarat, India Earthquake. These findings are not surprising, but it is significant to document them in actual field operations and to use them as a basis for designing more efficient means of decision support in multi-organizational and multi-jurisdictional disaster operations.

4.1 Different types of information technology were used at different jurisdictional levels

The types of information technology used in disaster operations reflected the significant variation in technical structure and organizational capacity at the different levels of jurisdiction. At the village level, residents of the villages learned of the status of their community, its facilities, and the welfare of their neighbors via word of mouth, and through networks of family and friends. The most effective and most trusted sources of information were those persons who were familiar. Non-governmental organizations that had prior associations with the village residents through health clinics or humanitarian assistance were also accepted. But the primary information technology in areas with substantial illiteracy (in some areas, as high as 60%) is face-to-face communication. This means that many villages, distant from the larger towns and cities, were essentially without communication and without assistance for days, even weeks, after the earthquake.

At the district level, the State Government of Gujarat distributed satellite phones to each of the district collectors, but in practice, the use of these telephones was mixed at best. Only in the Kachch District did the experienced district collector, with his office to Bhuj, use his satellite phone regularly. Communications were most severely disrupted in the Kachch District, and it required more than eight days to restore basic services. In the other three districts, Rajkot, Surendranagar and Ahmedabad, regular telephone lines were restored to operations largely within forty-eight hours. After service was restored, managers primarily used regular telephone lines for communication, although traffic was heavy and the largest proportion of households did not have telephones.

In the larger towns and cities, communications were augmented by police radio networks and army communications. In Bachau, for example, residents of the damaged cities asked the local police for immediate assistance, and the police used their wireless radio channel to communicate with other police stations in neighboring cities and with the police department at the state level in Gandhinagar. When the Indian army troops arrived in cities and towns, they brought with them communications facilities that enabled direct communications with other army bases and state agencies.

At the state level of disaster operations in Gandhinagar, information technology was sophisticated and functional. The Remote Sensing and Communication Centre (RESECO), Government of Gujarat, maintains a dedicated station for the Indian Satellite System. On 27 January 2001, the day after the earthquake, RESECO staff shifted the satellite cameras to focus on the EQ-damaged area, and obtained detailed orthophoto images by 29 January 2001. RESECO has established dedicated satellite links, 2 MBS bandwidth, from offices of state agencies in Gandhinagar to the district collectors to support communication and transmission of information between state and district offices. When the State Government created the Gujarat State Disaster Management Authority (GSDMA) under the office of the Chief Minister to manage the response and recovery process immediately after the earthquake, GSDMA distributed satellite telephones to the district collectors to facilitate communications in the heavily damaged areas. As stated above, this effort yielded mixed results at the district level in the weeks immediately following the earthquake, but more than a year later, in May, 2002, GSDMA was using the high degree of connectivity provided by an Optical Fibre Cable network, a wide area network (WAN) that links state agencies to district collectors' offices. Almost all offices among state agencies in Gujarat were connected via this WAN in May 2002.

Standard telephone connections within Gandhinagar were functioning in the first hours and days after the earthquake, but connections could not be made to the major cities and towns in the damaged areas. State agencies used the Indian Satellite System to report conditions to the Prime Minister's Office and relevant national agencies in New Delhi. State agencies also used standard telephone communications as soon as they were available in the earthquake-affected areas, as well as fax and radio communications.

In a technical initiative to support economic development, RESECO had initiated a geographic information system (GIS) for the State of Gujarat in 1999, and had an basic framework in place when the earthquake struck. These data served as a baseline for assessing damage to the villages, cities, and towns. On January 29, 2001, three days after the earthquake, the Indian satellite passed over the state of Gujarat and took satellite images of the damaged area. When compared to the images taken prior to January 26, 2001, these post-earthquake images provided a critical means of detecting changes in the landscape, as well as assessing damage to villages and infrastructure in the area. The images revealed information that would have been invaluable to guiding search and rescue efforts, as well as the longer term recovery programs. The difficulty, however, lay in transmitting the data and interpreting the results to managers at the local district and village levels to inform field operations in a timely manner.

At the national level, a sophisticated array of advanced means of information technology and telecommunications were available, including satellite communications, GIS, remote sensing imagery and analysis, as well as radio, telephone, fax, and e-mail communications. This technology facilitated near-instantaneous communication between the Gujarat state agencies in Gandhinagar and the Central Government agencies in New Delhi, and facilitated the exchange of information among national agencies.

At the international level, innovative inter-organizational approaches were developed and supported by existing organizational networks that linked Indian agencies with relevant groups and agencies in other parts of the world. News of the Gujarat Earthquake and reports from the Government of India were telecast live on CNN, BBC and other international news channels. These news reports elicited sympathetic and generous responses from international charitable organizations as well as individual donations of money, time and goods, especially among the large Gujarati diaspora in the U.S., United Kingdom, France, Germany, Japan, and many other countries. In Silicon Valley, California alone, the Gujarati diaspora raised $2 million for relief and took an active role in contacting not only the Gujarat State Government but also families, friends, and non-governmental organizations that were active in relief work in the damaged communities. Much of this exchange was done through e-mail and supported by news reports and official reports from government agencies that were posted on Web pages and accessed around the world via the Internet.

A second and important innovation at the international level was the response of a multi-national company to the information needs of Gujarat in managing this disaster. IBM, a multi-national company with headquarters in the United States but branch offices in India, immediately responded to the devastation in Gujarat by offering to assist in managing the information needed for multi-organizational response in disaster operations.[2] IBM, perhaps

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[2] This account is based on reports provided by Brent Woodworth, Worldwide Segment Manager, IBM Crisis Response Team, Los Angeles, California.

unique among multi-national companies, has established a Crisis Response Team to assist nations and communities stricken by natural disasters. Since IBM has a global clientele, its business interests and the welfare of its international employees are adversely affected by major disasters in their respective nations. Accepting responsibility for contributing substantively to meet the needs of the communities and nations in which it does business, IBM falls into a select group of private firms that provides expertise, skills and material assistance in managing the complex, urgent tasks of disaster operations.

IBM's design for a crisis management strategy in the Gujarat case represents an effective model for multi-national organizations. First, IBM sent an experienced Crisis Management Team from Los Angeles, CA to Gujarat within hours after the earthquake to assess the situation, identify needs that IBM could fill, and develop a strategy for doing so. Given its strengths in network operations and software development, IBM focused on information management for field operations and the development of a database for inventory control and decision support. Second, the IBM Country Manager for India sent an e-mail request to IBM employees working in India for volunteers to work in Gujarat. This step was crucial, because of the need for personnel to speak the local language of Gujarati or the national language of Hindi. Approximately 50 young IBM employees from Bangalore and other cities volunteered to go to Gujarat. Third, IBM sought and received approval from the Gujarat State Government to establish a working information system that would provide timely, accurate decision support for disaster assistance, and identified an Indian Administrative Service officer who served as their point of.contact. Fourth, the IBM group established and maintained the information system at no cost to the Gujarat State Government. The IBM group identified nine cities in the earthquake-affected region that served as nodes for the receipt and distribution of disaster relief materials and supplies. Two-member teams with computers were established at each location to create an inventory of relief supplies as they came in. The reports from the nine locations were cumulatively integrated to provide a regional database so that administrators at any one location could access information on the status of relief supplies at each of the nine sites, and assess their needs against the supplies available for the region [Gupta 2001].

Ordinarily, this would be a networked system, and in some locations, telephone connections were working, so that data could be transmitted via modem. In other locations, however, telephone service was disrupted and the computers were used as stand-alone machines. In order to update the records, an IBM team would load its computer onto a truck and drive to the next location to upload data on incoming supplies. As the incoming shipments of relief materials began to decline, the IBM site teams turned to monitoring the distribution of those materials. The IBM information management system operated for 20 days, from February 8 - 28, 2001. After the operations were concluded, the cumulative records were turned over to the Gujarat State Government at no cost for their continued use in disaster recovery operations.[3]

4.2 Information processes, using different types of information technology, produced different results.

Information processes developed at each jurisdictional level to support disaster operations. These processes reflected the different technologies available to public managers, agency

[3] Personal communication, Brent Woodworth, Worldwide Segment Manager, IBM Crisis Response Team, October 15, 2002.

personnel, and the affected communities. At the village level, families, friends, and neighbors helped one another, sharing information and resources as it became available. Upon learning of the disaster from public news sources, non-governmental organizations rushed teams to the disaster- affected areas, and worked directly with the residents of the damaged villages to provide shelter, food, and medical assistance. Information was shared among different groups and reached damaged villages, but there were significant gaps. In severely damaged Bachau, for example, 100 out of 180 registered buildings were destroyed, and virtually all of the remaining buildings were uninhabitable. Many of the surviving families sent their women and children to live with relatives in other cities, while the men stayed in Bachau to protect what little remained of their homes and businesses. They were determined to rebuild their communities, but a month after the earthquake, they remained waiting in the rubble, without reliable means of communication or a clear strategy for action, with no resources and dwindling hopes. Frustration and despair were mounting by the day, as they lacked any consistent or reliable means of interaction with public or other sources of assistance.

At the District level, the Collectors' offices had satellite telephones, but they were not always used. In Rajkot, for example, the District Collector found the satellite phone inconvenient and impractical, as he had to go outside to use it. Consequently, his district relied on standard means of telephone communication as soon as it was available. Fortunately, Rajkot District did not suffer severe damage to its communications lines, but it was not possible to communicate easily with outlying villages or with cities and towns in the more severely damaged Kachch District. In Bhuj, however, the District Collector was more familiar with this technology, and used his satellite phone readily in regular communications with the state offices in Gandhinagar and other organizations engaged in disaster operations. The result was a differential pattern of communications among the four districts that were most heavily damaged, with areas that were not reporting regularly regarding their status in disaster response and recovery operations.

In the larger cities and towns of the damaged districts, the Indian Administrative Service (IAS) officers instituted information processes to survey the damaged areas and to tally the losses in lives, property and infrastructure. The surveys also collected data regarding the number of requests for assistance in each town, and the collectors used these data to document existing needs against available resources. But villages without ready means of communication were unable to give accurate or timely reports, which served the primary basis for governmental decisions on the allocation of disaster assistance. Consequently, the distribution of relief varied in many instances according to the functionality of the reporting system.

Further, RESECO had been planning a Geographic Information System (GIS) for the State of Gujarat since September 1999, seventeen months prior to the earthquake, with financial support from the United Nations Development Program (UNDP). The GIS was intended to support economic development of the region, and RESECO had an initial framework in place. On 27/01/01, the day after the earthquake, RESECO staff made a map of the damaged area at the taluka level. RESECO identified approximately 30 talukas that were the worst affected. These talukas required every type of assistance. For each village, the GIS provided information regarding population, number of households, number of persons in each household, education and drinking water facilities in the community. The data came from the census that was taken in 2000. The new census information was just released in January 2001. The GIS included 79 layers of information. However, this was a new technology to most of the officials working at the district level, and it was not evident that staff at district offices had the equipment or training to use this technology. In none of the four districts were GIS maps visible in district offices. When asked, none of the managers in public or nonprofit organizations at the district level had seen the GIS maps in the field. The same situation was likely true at the taluka level, where managers had even less access to technical equipment and training.

At the national level, India has an advanced information infrastructure that includes the Indian Satellite System and the Indian Space Research Agency. The technical information infrastructure at the national level exceeds the capacity of the organizational infrastructure to use it effectively for disaster operations at the state, district, and taluka levels. The technical information infrastructure is further hampered by weak components of the general infrastructure of the society, for example, the electrical power network which suffers outages with regrettable regularity.

4.3 Differences in information management created major obstacles for effective crisis operations

Gaps in information processes within and between the jurisdictional levels of government hindered the effective management of disaster operations for the response system as a whole. The source of these gaps was sometimes technical, but not always. A major difficulty for the full implementation of an effective information infrastructure is the lack of education, training, and systematic planning for disaster reduction at the district and taluka levels of government. Yet, even at local levels, there was evidence that people can and do learn to use new technologies and to develop the skills needed to manage risk and act on the basis of incoming information. This willingness to learn clearly represents a major resource that can be activated in Gujarat to strengthen the capacity of communities to manage their own risk

These three sets of findings lead to the formation of a conceptual model regarding the relationship between information technology and efficiency in disaster operations. This model is stated briefly in three hypotheses that can be tested empirically with data collected from organizational performance in disaster operations.

Conceptual model of the relationship between information processes and efficiency in disaster management

As organizations increase their interactions, they share information
As organizations share information, they increase coordination
As coordination among organizations increases, efficiency increases.

A converse model that acknowledges the limits placed on organizational action by restricted information sharing is also proposed.

Converse model of the relationship between limits on information processes and efficiency in disaster management

As organizations limit their interactions, they also limit information sharing
As information sharing is limited among organizations, coordination is also limited
As coordination among organizations is limited, efficiency decreases

The two models reflect different consequences for multi-organizational response systems that adopt different strategies for information management. The first model, assuming organizational capacity to learn, leads to increased efficiency in response and recovery operations over time. The second model, based on the premise of organizational control, leads to the opposite outcome, decreased efficiency in multi-organizational response over time.

5. Conclusions

The three findings stated above, and the conceptual models they suggest, lead to a basic conclusion regarding a constructive role for international research and action in countries that are exposed to severe seismic risk and have experienced destructive seismic events. By partnering with practicing organizations in nations prone to seismic risk, members of the international research community can support the larger goal of understanding the dynamics of risk reduction and, specifically, the contribution that advanced information technology can make to organizational policies, procedures, and practice by enabling responsible managers to take timely, informed action to reduce risk and increase efficiency in response. Four tasks are especially needed, and would benefit from collaboration among local agencies and researchers and experienced researchers in the international community. These tasks include:

- Develop models based on empirical data, using actual events as case studies that illustrate specific hazards and the interaction among types of conditions that occur in other locations
- Test the models based on empirical data in simulated operations environments to explore alternative methods of risk reduction and response
- Use the results from the simulated operations tests to inform designs for improved policy and procedures in inter-jurisdictional practice
- Create knowledge bases for interdisciplinary, inter-jurisdictional training and education in disaster reduction and risk management

These four steps, taken in partnership with the international research community, would make a substantial difference in risk reduction and response in practice.

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