CHAPTER 12

Search and Rescue Activities in Disasters

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The objective of this chapter is to review what is known about search and rescue activities in disasters, including heavy urban search and rescue teams. The accumulation of scientific knowledge about search and rescue (SAR), which is, as reflected in this chapter, disproportionately centered on disasters in the United States, allows us to identify certain recurrent patterns that should be considered in the development of an effective plan for national emergency response. The following sections present what is known about SAR, factors affecting survival, the behavior of victims, the impact of social and cultural arrangements, and ecological aspects of SAR in constrained and unconstrained spaces. This is followed by brief discussions of the search and recovery activities in the Columbia Shuttle Accident as well as by examinations of the World Trade Center (WTC) and Pentagon 9/11 SAR operations. The chapter concludes with an acknowledgment of the remaining research gaps in our understanding of SAR and with a summary of what needs to be done to improve SAR operations worldwide.

INTRODUCTION

There is widespread consensus among specialists that: (1) SAR is social, collective behavior of volunteers who share a culture and act as socialized human beings and are members of a human community; (2) Preexisting and emergent organizations, social statuses and social identities, such as neighborhood and work place relationships and family and neighborhood social identities, serve as a basis for the emergence of new SAR groups and constitute the fundamental concepts and categories that are needed to understand and improve SAR activities; (3) SAR activities do not emerge from a vacuum; as an example of the principle of continuity advocated by Quarantelli and Dynes (1977), there are always elements of the traditional social structure embedded within collective behavior entities, and their emergent division of labor, role structure, and activities are also dependent on prior social relationships and forms of social organization in the community or region; (4) "Breakdown" models of

social organizational patterns in disaster are not useful to understand SAR. Television reports and misinformed reporters often misinterpret throngs of people moving seemingly at random at the sites destroyed by various hazards, and assume that the people were disoriented immediately after impact and had lost their ability to enact social roles. Despite these reports, scientific research shows the absence of widespread confusion, lack of coordination, and "panic" (Aguirre, 2005). The seeming disorganization and aimless movement of people is the result of their individual and collective acts as they try to accomplish multiple individual and collective goals under severe time constraints (c.f. Fritz & Mathewson, 1957). Creative problem-solving and rationality is a more accurate way of understanding their actions (Aroni & Durkin, n.d., p. 30); and (5) Advances in our understanding of SAR depends on multidisciplinary scientific collaboration involving, among others, structural engineers, emergency medical personnel, and social scientists. We next provide some of the reasons for these conclusions by reviewing what is known about search and rescue in the scientific literature.

WHAT IS KNOWN ABOUT SEARCH AND RESCUE

Search and rescue (SAR) activities are part of a complex emergency system that emerges to respond to disasters, what has been termed "helpful behavior in emergencies" (Dynes & Quarantelli, 1980). During more than 40 years, disaster researchers (for information on SAR during the Kobe, Japan earthquake of 1995 see Kunii, Akagi, & Kita, 1995; for the Kocaeli Turkey earthquake of August of 1999 see Mitchell, 1999; for the Bam, Iran earthquake of December 2003 see Editorial, 2004; near-exhaustive literature reviews are available in Poteyeva, 2005; Prater et al., 1993) have endeavored to understand what accounts for the relative success of SAR activities in disasters, to include factors such as the nature of structural and nonstructural damage to the built environment (Anagnostopoulos & Whitman, 1977; Culver, Lew, Hart, & Pinkham, 1975; Hart, 1976; Hasselman, Equchi, & Wiggins, 1980; Lechat, 1989; Stubbs, Sikorsky, Lipnick, & Lombard, 1989; Tiedemann, 1989), the epidemiology of SAR events (De Bruycker, Greco, & Lechat, 1985; Glass et al., 1977; Glass, O'Hare, & Conrad, 1979; Lechat, 1976), and the effectiveness of medical services (Quarantelli, 1983a). Aguirre, Wenger, Glass, Diaz-Murillo, and Vigo (1995) have also argued for the importance of social organization in SAR in disasters.

The most extensive study of SAR activity was undertaken during the late 1970s by Drabek, Tamminga, Kilijanek, and Adams (1981), who conceptually recast the study of search and rescue into an emergent, interorganizational, systemic approach. While reaffirming a number of the previous observations made in the literature up to that time, their study highlighted the interorganizational managerial difficulties inherent in SAR. They found four common operational problems: (1) difficulties in interagency communications, (2) ambiguity of authority, (3) poor utilization of special resources, and (4) unplanned media relations. Quarantelli (1983a) analyzed the problem of locating victims and managing their entrance into the emergency medical system. Glass et al. (1977, 1979) provided epidemiological evidence on the etiology of injuries and deaths that had obvious implications for SAR behavior.

To restate the disciplinary consensus (see an earlier summary by Wenger 1990 and literature cited therein):

1. Volunteer and emergent group response is of critical importance.
2. The initial SAR activity is accomplished by volunteers and emergent groups.

3. Since most survivors are rescued within the first 2 days, this emergent and volunteer activity is critically important to the rescue effort, especially because buried and entrapped victims are likely to suffer from injuries that require rapid life-sustaining intervention including compromised access to air, severe loss of blood and body fluid, crushing injury, and internal damage to essential organ systems.
4. Despite the massive attention they usually receive from the mass media (Quarantelli, 1991c), most of the time urban search and heavy rescue (US&R) teams arrive too late to rescue anyone; instead, they undertake highly specialized recovery activities requiring sophisticated skills and equipment. This is due in large part to the particular nature of the sociogeography of disasters in which US&R teams are hampered by problems of timely access.
5. The integration of volunteer and established organizational activities is seldom efficiently achieved; many official responding organizations, particularly those from national governments, usually do not appreciate the work of the volunteers in SAR operations since they are often perceived as lacking sufficient credentialing, specialized training, and tools. In turn, the absence of disaster planning about how to use volunteers creates problems of its own as large number of volunteers converge on disaster sites (Quarantelli, 1996c). Problems of management of rescue activities are serious and include difficulties in coordinating activities across independent, autonomous organizations, disagreement over rescue strategy, and ambiguous authority relationships.

SOCIAL ACTORS

Dynes and Quarantelli (1980) identified four types of disaster volunteers, whom they term organizational volunteers, group volunteers, volunteers in expanded roles, and volunteers in new roles. As Dynes (1970) had theorized earlier, in the typical SAR site these types of volunteers become part of the process of organizational emergence involving extending, expanding, and emergent organizations, the last one often playing key roles in SAR activities (Quarantelli, 1999a). Preexisting networks of human relationships are used to alleviate novel and unexpected collective problems that demand immediate attention. People expand their sense of responsibility toward each other, and often do so by becoming members of new emergent groups that carry out SAR activities. Afterwards, there may be the institutionalization of these groups.

SAR activities are part of the mass assault phase of disaster. As such, multiple individual and collective actors participate in it. Many trapped victims are rescued by the uninjured bystanders and surviving local emergency responders (Aguirre et al., 1995; Auf der Heide, 2004; Durkin, Coulson, Hijar, Kraus, & Ohashi, 1987; Durkin & Murakami, 1988; Kunkle, 1989; Noji, 2003; see other literature in Poteyeva, 2005; Prater et al., 1993). For example, in southern Italy, in 1980, 90% of the survived trapped victims were extricated by untrained, uninjured survivors who used their bare hands and simple tools such as shovels and axes (Noji, 2003). Following the 1976 Tangshan earthquake, about 200,000 to 300,000 entrapped people crawled out of the debris and went on to rescue others (Noji, 2003). These volunteers became the backbone of the rescue teams. Durkin and colleagues (1987, 1988) specified that the primary rescue technique used by the SAR teams and volunteers was a human voice—the victims reacted to the rescuers calling out, and cried for help or made noise with available objects themselves.

The aforementioned institutionalization process can be observed in the thousands of local volunteer organizations that carry out SAR activities throughout the United States. The

majority of these volunteer organizations came about soon after there was a mass emergency, a disaster, or there were cases of missing persons in their communities for which there was no organization in the communities to assist in the response. In a recent ongoing attempt to quantify this activity, we found that the earliest team in our nonrepresentative sample of teams (sampling frame included only those with Web sites during August 2004 to September 1, 2005) was the Hood River Crag Rats Mountain SAR, from Hood River, Oregon founded in 1926. We have identified more than 1000 SAR voluntary organizations in all 50 states, with more than 50 organizations in some states. Initially, most of these organizations were involved in mountain and wilderness search and rescue activities, although nowadays they engage in water rescue as well as a host of other response activities in the aftermath of mass emergencies and disasters. The most frequent team capabilities are: K-9 teams—31% of the teams had them; water rescue—26%; technical rescue— 22%; wilderness—21%; mine rescue—17%. Seventy-one percent of the organizations are supported by public donations, fund raising, and membership support; the breakdown for main sources of support mentioned by our respondents is: donations—56% of the teams mentioned it; sponsors—41%; fundraising—21%; member support—13%; private grants—8%; city, county, state governments—15%; others—6%. They compose a nascent industry in which, despite the recent effort by the Federal Emergency Management Agency (FEMA) to create a National Mutual Aid and Resource Management Initiative, there are at present no uniformed training standards or certification. Instead, these organizations follow various professional standards such as those of the National Association of Search and Rescue (NASAR) and FEMA, although many are not certified by these national organizations; most have developed their own regulations: 6% of the teams in our sample train to NASAR standards and 2% to FEMA standards. NASAR estimates more than 50,000 SAR missions annually—more than 90% carried out by unpaid professionals—missions that, while not all associated with mass emergencies and disasters, still give a sense of the importance of these voluntary organizations.

In contrast, another type of social actor, the urban search and rescue taskforces, has received a great deal of financial support and public attention. In the United States, the Urban Search and Rescue System (US&R) is a collection of multidisciplinary taskforces created from local emergency responders organized under a federal framework for response in the aftermath of structural collapses. These task forces arrive at the site complete with the necessary tools, equipment, specialized training, and skills. They were created to be deployed by FEMA at times of catastrophic structural collapse to engage in such varied activities as structural shoring, canine searches, complex rope systems, confined space entry, and technically assisted void search procedures, although for a number of reasons explored elsewhere (Trainor & Aguirre, 2005) they are now being used to do many other things not initially contemplated when the system was formed. In parallel, other taskforces are being formed by state governments in the United States and by national governments.

FEMA's US&R System is of fairly recent origin, with the first US&R taskforce certified in 1991. The development of heavy rescue search capability was initiated in California, particularly after the 1971 San Fernando Earthquake (Naum, 1993). In 1990, FEMA, fresh from the problems created by Hurricane Hugo and the Loma Prieta Earthquake, organized a week-long meeting in Seattle, Washington where more than 90 specialists representing various constituencies met and developed the outlines of the program. They set up a system of local US&R taskforces that would be made up of personnel from local agencies and who would be federalized and deployed nationwide at the request of FEMA. State emergency management agencies were only marginally involved in the organization, which instead instituted an

organizational link between the taskforces and FEMA. The taskforces have structural engineers to assess risks created by the configuration of collapsed structures, medical and hazardous material personnel, canine units, and very extensive cache of sophisticated tools and equipment for use in heavy rescue environments. When fully implemented each has more than 200 people. Today there are 28 US&R taskforces.

One of the great paradoxes of the present system is that U.S. federal and state funding is directed to these taskforces even though they too often arrive too late to save anyone, and that this is done to the near exclusion of the thousands of voluntary SAR organizations that do most of the rescuing and savings of lives in the United States.

The effectiveness of local SAR voluntary organizations and formal organizations such as fire departments in locating and rescuing victims is in part a result of the interaction of ecological characteristics of the site of the disaster with other factors such as the (1) the social, cultural, and behavioral patterns and social relationships between victims and responders; (2) behavior of victims during entrapment; and (3) nature of the buildings and other structures and their collapse configuration. The morbidity and mortality patterns associated with disasters depend on these other matters, to which we now turn.

CULTURAL AND SOCIAL ARRANGEMENTS

Cultural and social arrangements are often of primary importance (Pomonis, Sakai, Coburn, & Spence, 1991). Reflecting cultural practices, occupancy of buildings by time of day and season is significant in determining occupant exposure to specific hazards (Durkin et al., 1987; Tiedemann, 1989). Kuwata and Takada (2002), in their study of the 2000 Western Tottori earthquake noted the low occupancy of buildings at the time of the disaster as a major reason for the low number of dead and injured; the earthquake occurred at 1:30 P.M. on a weekday, meaning that the inhabitants of the building were awake and at once perceived the dangers of the earthquake. In addition, the most important factor was that the majority of people were not at home—the inhabitant occupancy was estimated at 27%. Knowing the time of the disaster helped Michael Durkin (Durkin et al., 1987) to reconstruct the location of his study's subjects during the 1985 Mexico earthquake: the impact had occurred at 7:17 A.M., when most of the medical students were in their dorm rooms preparing for the day, or on their way to the cafeteria for breakfast. Those who had morning shifts were already at work when the hospital collapsed.

Another issue directly related to community's culture and social relationships is the increased vulnerability to disasters of minority group members and residents of low-income households. These categories of people have lower ability to protect themselves from disaster. Income is positively related to access to better and safer housing and location. Older, unreinforced masonry buildings and mobile homes, which are highly susceptible to collapse in earthquakes, constitute an important source of affordable housing for lower-income residents in earthquake-prone cities such as San Francisco and Los Angeles.

Religious and ethnic minorities are often impacted by a number of erroneous assumptions about the management of the dead in the aftermath of major disasters which are often used to guide SAR activities. In Nicaragua, in 1998, because of an avalanche at the Casitas Volcano brought about by heavy rains from Hurricane Mitch, more than 2000 people died. Acting under the erroneous belief that human bodies are public health risks, and violating the rights of victims and their relatives to a burial in accordance to religious beliefs and local cultural practices governing the handling of the dead, the army incinerated more than 1000 victims;

the rest were buried. None were identified. To this day they are listed as "persons that are missing," an ambiguous status that creates legal and other difficulties for their surviving kin (Pan American Health Organization, 2004, pp. 163–170).

SURVIVAL

Several studies examine the relationship between changes in response time and the saving of trapped victims (Coburn & Hughes, 1987; Kunkle, 1989; Pomonis et al., 1991; Quon & Laube, 1991). Kunkle claims that 80% to 90% of entrapped victims who survive are recovered in the first 48 hours after the disaster impact, and that many more entrapped victims could survive with timely delivery of appropriate medical care. Comfort (1996, p. 134) reports that in the 1995 Kobe, Japan earthquake the percentage of those rescued who survived was 80.5% for the first day after the earthquake, 28.5% for the second day, 21.8% for the third, 5.9% for the fourth, and 5.8% for the fifth day. Quon and Laube developed a predictive model that suggests that a 10% to 20% reduction in response time would yield a 1% to 2.5% reduction in fatalities. In the 1988 Armenia earthquake, 89% of those rescued alive from collapsed buildings were extricated during the first 24 hours. Noji et al. (1990; see also Olson & Olson, 1987) documented that most lives are saved and victims rescued during this immediate post-impact period. The probability of being extricated alive from the debris declined sharply over time, with no rescues after day 6. Noji (1991) points out that people have been rescued alive after 5, 10, and even 14 days of entrapment, but these constitute rare events.

Pomonis et al. (1991) stress the importance of a victim's health condition inside a collapsed building at any given time; surviving entrapment can be expressed as a function of time and the injury level sustained at the moment of entrapment. Other factors need to be accounted for as well, such as exposure; dehydration or starvation after a long period of time; weather conditions and the amount of air voids that are created within the rubble; the weight of the rubble above the victim; and the victim's preentrapment health condition. Pomonis et al.'s study provides a number of empirical illustrations of the potential interplay among the mentioned factors. Thus, the collapse of the Juarez Hospital (a reinforced concrete frame building) in the 1985 Mexico earthquake trapped 740 people within the building. SAR operations lasted more than 10 days, but only 179 persons were extricated alive; 76% died. On day 1 the survival rate was 70% and this level was maintained until day 5. After that it dropped to 20% by day 9. The implication is that 30% of trapped victims were killed instantly or injured too seriously to survive more than one day while the rest of the victims suffered relatively slight injury and survived for a while but began to die after day 5 because of bleeding, exposure, compression, or some other reason.

Entrapment is the single most important factor associated with death or injury (Durkin & Murakami, 1988). As Noji (2003) states, in the 1988 Armenia earthquake, death rates were 67 times higher and injury rates more than 11 times higher for people who were trapped than for those who were not. Certain age groups are more vulnerable and have an increased risk for death and injury in disasters and others. People older than 60 years of age have a death rate that can be five times higher than that of the rest of the population during earthquakes. Children between 5 and 9 years of age, women, and the chronically ill also have an elevated risk for injury and death (Glass et al., 1977). As Noji (2003) points out, limited mobility to flee from collapsing structures, inability to withstand trauma, and exacerbation of underlying disease are factors that may contribute to the vulnerability of these groups. He also stressed the effect that certain social attitudes and habits of different communities may have on mortality

distribution by age. For example, in some societies young children sleep close to their mothers and may be more easily protected by them.

BEHAVIOR OF VICTIMS

Scientific studies of the behavior of victims in disasters are infrequent (see Bourque et al., in this volume). While in need of replication, the few studies that have examined issues ranging from general behavioral patterns of communities during disasters to what building occupants did during the actual period of a disaster and experiences of trapped victims during SAR operations show that the much-feared social disorganization during the disaster periods is extremely rare (Aguirre, 2005; Durkin, 1989; Dynes, 1970), although conditions under which panic does occur have been identified in the literature (Dynes, 1970; Johnson, 1988). An atmosphere of human solidarity and cooperation characterizes the behavioral processes during and in the aftermath of a disaster. Residents of disaster-stricken areas are proactive and willing to assist one another. Research findings show that volunteer activity increases at the time of disaster impact and remains widespread during the emergency period (Dynes, Quarantelli, & Wenger, 1990). In the Guadalajara Gas explosion community residents who were not trapped or freed themselves from entrapment went to great lengths to search for their kin and neighbors (Aguirre et al., 1995). There were instances when individuals would call attention to other victims who were trapped nearby and could not free themselves; they would also speculate about the possible location of other victims, provided rescuers with information about the inner settings of the house, and reconstructed the architectural topography of the streets turned to rubble. Sometimes the victims, when trapped, were able to hear what was going on above or next door and thus maintained social ties with the world around them. They also engaged in imaginary interaction with significant others and saints, seeking spiritual and psychological support, which is so important for survival. More recently, Scanlon's recent observations (2005) of the London Underground's July 7th 2005 terrorist explosion also shows that victims helped fellow victims, that staff operating the trains helped the passengers, and that the first responders were not emergency personnel but people nearby, among them medical doctors who worked at the British Medical Association as well as workers from other commercial establishments.

Studies have paid particular attention to the importance of family as an institution during mass emergencies and disasters (Form & Nosow, 1958; see also Aguirre et al., 1995; Alexander, 1990; Quarantelli, 1988d). Family is a very powerful unifying factor for disaster victims, and, as Alexander points out, its influence could immediately dissolve other groupings such as friends. Family members are the first to be rescued by their kin. As soon as the nuclear family is reunited they concern themselves with other relatives. Second in importance is the concern for immediate neighbors and other nearby residents, and then other people farther removed from the spheres of everyday interactions (Aguirre et al., 1995). While in need of replication, a research finding is that the chances of people surviving the Guadalajara explosion were directly proportional to the presence among the searchers of a person or persons who cared for the victim and who knew the victim's possible location at the time of the explosion. Another important related pattern is that significant others acted as proxies for the victims, reminding the searchers that the family member was missing, and supplying information about their possible location.

Preliminary results from studies of occupant actions during disasters and trapped victims' behavior suggest that victims behave actively and assume responsibility over their rescue to

the extent that they can do so. Thus victims trapped as a result of the Guadalajara gas explosion moved their bodies ever so slowly to create more room in the rubble; others called attention to themselves by screaming and making noise on the nearby debris (Aguirre et al., 1995). Seven of the eighteen victims trapped in the dormitory after the 1985 Mexico earthquake attempted to escape (Durkin et al., 1987).

Prior training and expectations play a significant role in the way that people respond to disasters (Durkin et al., 1987), but these beliefs and expectations have to be reevaluated depending on the physical setting of each particular case, for they may prove to be dangerous. Many beliefs about appropriate response can endanger rather then protect building occupants (Durkin & Murakami, 1988; Kunii et al, 1995). Thus, a significant number of respondents in Durkin's 1985 Mexico earthquake study reported that they chose to "stay where they were" once the shaking began, because they believed it was the right thing to do. As a result they were trapped in individual dorm rooms rather than trying to escape the building. A different example involves a person who moved into the doorway as the shaking began (as she was advised to do during earthquakes), and was hurt by the door being slammed shut. Another person was hurt trying to hide under a desk. Damage done to the General Hospital building by the 1985 Mexico City earthquake made the drills and bomb-threat evacuation routes inoperative, and the nursing staff had to find alternate ways out, demonstrating the ad hoc resourcefulness of disaster victims.

Traditionally criteria for evaluating structural safety have been tied to the structure itself (Stubbs & Sichorsky, 1987). However, nonstructural failures such as collapsing of cladding or partitions, ceilings, windows, equipment, fixtures, piping, ducts, and roof tile can also cause substantial harm. They should be physically connected to the structure (Cole, 1991; Jones, Noji, Smith, & Krimgold, 1990). Study of the Loma Prieta earthquake (Cole, 1991) documented many instances of overturned files and bookshelves that were not properly braced and anchored. These building contents caused a large number of injuries, with the ratio of injuries from building contents to those from structural elements being 3 to 1. People were hurt mostly by moving desks, filing cabinets, and furniture situated in the immediate vicinity of where those people were located. Therefore, building elements and contents play a clear role in endangering occupants' lives (Durkin & Murakami, 1988) when they are not appropriately braced and secured to the walls and floors of buildings. The 1979 El Centro, California earthquake study (Durkin, 1985) showed that 36% of office workers in the Imperial county services building that sustained considerable nonstructural damage, reported getting under their desks. The sort of evasive action that will prove effective depends not only on the nature of building collapse and the nonstructural failures associated with it, but also on whether the contents of the building are secured to the structure of the building. At the present time, knowledge of building collapse configurations is insufficient to provide valid answers to these matters (see below).

ECOLOGICAL FACTORS

Timely arrival of rescuers, proper behavior of victims, and propitious cultural and social arrangements impact the effectiveness of SAR operations in saving lives. Yet, it is also the case that the environment as it is impacted by human adaptation, what we call the ecological factor, is important as well. The next section reviews what is known about SAR in buildings and other enclosed structures. It is followed by the examination of the Columbia Shuttle Accident, in which SAR took place in a rural environment that presented very different challenges to responders.

SAR in Buildings

A number of studies explore structural vulnerability of buildings to earthquakes, taking into account a multitude of factors—for example, the variety of construction types, material and quality, the geology of the area, and the distribution of shaking intensity. It is possible to only briefly outline the characteristics of various building structures, associated modes of failure, and the consequences of building collapse for search and rescue. The type of building and the collapse patterns are important determinants for morbidity (Glass et al., 1977; Meli, 1989; Noji et al., 1990). Data on earthquakes and other disasters suggest that a relatively small number of damaged structures are the source of the vast majority of the serious casualties (Coburn, Spence, & Pomonis, 1992). For example, 50 of 62 deaths in the Loma Prieta earthquake occurred at the Cypress freeway structure in Oakland and 40 of 64 deaths in the 1971 San Fernando earthquake occurred as a result of a collapse of a Veterans Hospital (Noji, 2003). There is also information on the vulnerability of particular building structures. Noji (2003) states that by far the greatest proportion of earthquake victims have died in the collapse of unreinforced masonry buildings or unreinforced fired-brick and concrete-block masonry buildings that can collapse even at low intensities of ground shaking and will collapse very rapidly at high intensities. Other studies also support this conclusion (Sparks, 1985). Un-reinforced masonry buildings are from one to six stories in high and may be residential, commercial, and industrial. Their primary weakness is in the lateral strength of the walls and the connections between the walls and the floor or roof assemblies. Collapses are usually partial and are caused by the heavy, weakened walls falling away from the floors. Falling hazards are very widespread at these buildings because of the amount of small, loose masonry components that results from the collapse. At the same time large angular voids form, because large sections of floor or roof often stay together as a plane. Adobe structures have performed very poorly in many highly seismic parts of the world—for example, eastern Turkey, Iran, Pakistan, Latin America (see Ceciliano, Pretto, Watoh, Angus, & Abrams, 1993; Noji, 2003). These buildings not only have collapse-prone walls but also very heavy roofs that prove to be deadly to people when they collapse. On the other end of the spectrum of building vulnerability are wood-frame buildings, which usually comprise residential housing. They are one of the safest structures during an earthquake, because, despite their weakness to resist lateral forces and consequent collapse, they are constructed of light wood elements, and their potential to cause injury is much less serious than that of unresistant old stone buildings (Noji, 2003). A study of the 1995 Hanshin-Awaji earthquake in Nishinomia City (Hengjian et al., 2000) has concluded that most casualties occurred in relatively old two-story wooden buildings in which the ground floor collapsed completely without survival space. More than 84 percent of casualties occurred in buildings that collapsed without survival space.

Concrete-framed houses are generally safer in terms of their resistance to collapse, but they are also significantly more lethal than masonry or wooden buildings. Reinforced concrete requires sophisticated construction techniques; however, it is often used in communities around the world where either technical competence is insufficient or inspection and control are inadequate (Noji, 2003). Catastrophic failures of modern reinforced, concrete-slab buildings have been described in Mexico City (1985), El Salvador (1986), and Armenia (1988) (Bommer & Ledbetter, 1987; Wyllie & Lew, 1989). The principal weakness of concrete frame building (heavy floor) is the poor column reinforcement and inadequate connections between floor slabs and columns. Collapse from the failure of these parts can be partial or complete. These structures often fall down on themselves, or they may fall laterally if the columns are strong enough. Meli (1989) states that the failure of vertical members is worse than the failure

of horizontal components and that to avoid a catastrophic collapse it is necessary to preserve the "main vertical load-resisting elements." Whereas the debris of buildings of adobe, rubble masonry, and brick can be cleared with primitive tools, reinforced concrete represents serious problems for rescuers, and requires special equipment. Other types of buildings discussed are pre-cast concrete buildings, which fail because of the weakness of the connectors between building parts such as floors, walls and roof; and heavy wall tilt-up/reinforced masonry. The latter have received mixed reviews as to their resistance to earthquakes (Cole, 1991). Walls in these structures usually fall away from the roof or floor edge, but because they are very strong panels, the top of the wall will fall far away from the building.

Empirical studies have evaluated the comparative performance during disasters of buildings of older and newer construction (Cole, 1991; Hengjian et al., 2000). Thus, during the Loma Prieta earthquake relatively modern buildings performed much better than buildings of pre-1973 construction. Most of the significant structural damage suffered by modern residences was due to the collateral effects of earth movement, that is, land sliding and soil rupture, although this particular earthquake was not a good test of the buildings because of its moderate intensity. Cole speculates that buildings designed and constructed to current codes would have fared well during a stronger, longer duration earthquake. On the other hand, residential buildings of older "archaic" construction suffered extensive damage.

Tiedemann (1989) lists the factors that impact the behavior of buildings during earthquakes and, therefore, affect the number of casualties: resonance between predominant frequencies of the foundation material and of the building structure; quality, that is, predominantly hardness of the foundation material; shear strength of the building resulting from the combined strength of structural and nonstructural parts; compatibility of behavior of building materials and components under dynamic loads; regularity and symmetry as regards floor plans, elevations, shear strength, distribution of masses and damping; type and behavior of nonstructural elements—their design, quality arrangement, and fastening; hammering between buildings; orientation sensitivity; and liquefaction. These factors determine the vulnerability of buildings to collapse during disasters as well as provide clues as to where void spaces might occur, and thus where surviving victims might be found during SAR.

The types of collapse generate known patterns of void spaces in the rubble which are very important to search and rescuers. The SAR literature discusses several types of collapse voids. For example, the Manual for the International Fire Service Training Association (Murnane, 2003) outlines five types of collapses (paraphrasing): (1) Lean-to collapse occurs when one exterior wall collapses, leaving the floor supported at one end only; the victims are likely to be found in the lower portion of the lean-to or positioned on the floor below the unsupported lean-to. Removal of debris that is supporting the "base" of the lean-to collapse can cause the floor to slide, collapsing the void. In the case of a supported lean-to collapse, most likely the victims will be located at the bottom of the lean-to near the wall surrounded by rubble, or they could be on the floor below the collapsed floor under the large void created at the opposite end of the failed construction. Victim survival profile is low to medium. (2) V-shape collapse occurs when an interior supporting wall or column fails. Victims are typically found on the floor below. They usually have a higher survival rate because of the sheltering effect of the collapse floor (prevents rubble landing on them). Victims on the top of the collapsed floor usually are at the bottom or near the center of the V, or trapped in the debris in various places. Because of large amount of debris concentrated in one area, survival rate for victims in this area is low. (3) Pancake collapse occurs when all vertical supporting members fail and most of the floors collapse on top of one another. This is more probable in heavy-floor buildings. This kind of collapse might not move the victim horizontally but drop the victim straight down

in the collapse pile, so that victims may be located on several floors anywhere in the debris. Victim survival rate is very low. (4) Yet another configuration is the cantilever collapse. This type of collapse is similar to the pancake pattern with the additional problem of some of the floor planes extending, unsupported, from the debris pile. Victims might be found under the floor as in the pancake condition. (5) Finally, in A-frame collapse, the highest survival rate is for victims located near the partition wall at the center of the collapse. Victims located on the floor above can be pinned in the debris near both exterior walls, which results in a lower survival rate.

The location of people in the building at the time of the disaster is an important determinant of morbidity (Noji, 2003). For example, occupants of upper floors of multi-story buildings have been observed to fare less well than ground-floor occupants. In Armenia, there was a significant increase in risk for injury associated with the floor people were on at the moment of the earthquake. People inside buildings with five or more floors were 3.65 times more likely to be injured compared to those inside buildings less than five floors in height (Armenian, Noji, & Oganessian, 1992), and in the 1990 Philippine earthquake, people inside buildings with seven or more floors were 34.7 times more likely to be injured (Roces, White, Dayrit, & Durkin,1992). As Coburn et al. (1992) point out, in a high-rise building escape from upper floors is improbable before the building collapses, and if it collapses completely, nearly 70% of the building occupants are likely to be trapped inside. In a low-rise building that takes perhaps 20 or 30 seconds to collapse, more than three quarters of the building's occupants may be able to escape before the collapse. In general, however, as Kunii et al. (1995) point out, needed are studies of behavior of individuals in disasters that protects them. Furthermore, developing scientific knowledge about the circumstances of entrapment and location of voids will contribute to the development of effective SAR techniques and effective injury-prevention strategies.

Very different ecological settings operated in the Columbia Shuttle Accident and in the WTC and Pentagon terrorist attack of 9/11, a matter to which we now turn.

The Columbia Shuttle Accident

In contrast to SAR in well defined and circumscribed ecological areas, the search and recovery effort that took place in the aftermath of the Columbia Discovery space shuttle accident of February 1, 2003 involved the simultaneous presence of local search and recovery groups and US&R taskforces working over a very large geographic area in central Texas, a region estimated to be 160 miles long and 35 miles wide. The incident was a federalized activity but it could not be done without the assistance of agencies from local and state governments and voluntary firefighters and SAR teams and other types of volunteers who were coordinated using a grill pattern map and geographic information system (GIS) that was initiated by Texas Forest Service (TFS), FEMA, and the National Aeronautic and Space Administration (NASA). The response was a mass assault in which the coordination function emerged over time. During the first 13 days, a great deal of the work of recovery was done by neighbors of the towns of Kerens and Rice in Navarro County, Texas and other towns in which the debris fell and by other local and state organizations who worked to secure the pieces of debris until these could be removed by NASA; in Hemphill and other towns, the churches got together and fed the volunteers and responders who came into the community to participate in the search and recovery. There were many individual and organizational participants. Interagency coordination problems that were eventually alleviated once an interorganizational managing group was set up and an

understanding of agencies' capabilities, division of labor, and decision making system were established among the participants.

In this instance of a very large scale response operation involving a mass assault in which SAR volunteers and US&R FEMA taskforces operated simultaneously over a large geographic area, the official disaster response system as it was set up on paper had limited use. While outside this official system, neighbors, SAR groups, other organizational volunteers, and community institutions such as churches became critical although largely unrecognized actors in the federal effort. The large extension of terrain meant that it was not possible to establish a perimeter or control over the site. Instead, the mass media and existing emergency management and police systems were used to alert the public and instruct it in the ways it could assist the efforts of the federal government in securing and recovering the parts. Rather than entire US&R taskforces, only elements of some of these taskforces such as canine specialists and hazardous material specialists participated in the operation, again, a marked departure from their common pattern of operation; there was no need for a good portion of their equipment and trained personnel. This case study reaffirms earlier findings in the social sciences of disasters. It shows that SAR operations are, to a significant degree, impacted by the ecological settings in which they take place. Most of what we know about SAR applies to what take place in buildings and other well delimited areas, which is unrepresentative of the diversity of ecological contexts in which SAR takes place and the various challenges these contexts create for responders. US&R taskforces and other SAR groups had to adjust to the needs of the other organizational partners in what became an emergent multiorganizational coordinating search and recovery effort.

WTC AND THE PENTAGON

The nature of the structural collapses that rescuers had to deal with at the World Trade Center (WTC) and the Pentagon were very different from collapses caused by natural disasters, and represented a serious challenge for the US&R Task Forces (Hearing before the Committee on Science, 2002; Titan Systems Corporation, 2002). Typically, in case of a structural collapse caused by an earthquake, large pieces of the structure create void spaces in which live victims may be found (Murnane et al., 2003). The bomb explosion outside of the Murrah building in Oklahoma City "essentially pulverized" the structure (Comeau, 1996) and made it very difficult to shore up and stabilize the building. The destruction and fires from the plane explosion within the WTC Towers weakened the infrastructure of the buildings, collapsing the upper floors and creating too heavy of a load for the lower floors to bear. Heavy concrete and steel structure and massive fires impeded the survival of any victims after the collapse (Hearing before the Committee on Science, 2002).

WTC

After the September 11 terrorist attack on the World Trade Center "the very first rescue and evacuation activities were initiated and performed to a great extent by civilians who worked in the World Trade Center" (Petrescu-Prahova & Butts, 2005). Thousands of volunteers formed several staging areas close to Ground Zero. Community and religious organizations, charitable agencies, local businesses, and concerned citizens established and helped operate ad hoc catering, rest, and comfort stations near the disaster sites. Many off-duty emergency medical service (EMS), police, and fire personnel reported directly to the collapse, often

traveling hours to reach the site. This phenomena of self-dispatching, also present after the Oklahoma City bombing and the Pentagon attack, was later criticized as adding to the confusion and disarray of the response scene, complicating a coordinate response effort. Unfortunately, it does not address the problem of how to incorporate the helping behavior of volunteers in disaster response planning. By 9:57 P.M. on the day of the attack, New York City Mayor Rudolf Giuliani made an announcement that no more volunteers were needed to help with the WTC rescue efforts.

What makes SAR at the WTC so different from other events of its type is the paucity in reestablishing command and control at the site. While still a subject of research, every indication we have is that perimeter control and a workable division of labor and cooperation among various responding official agencies were not accomplished until after the first 5 or 7 days after the terrorist attack. This was in part due to the impact of the attack on key organizations in charge of disaster response for the city. The destruction of New York City's Office of Emergency Management and Interagency Preparedness, the tremendous losses in special operations and command structures of the Fire Department of New York (NYFD) and less so of the New York Police Department (NYPD) and the Port Authority Police Department meant that it would take time and innovation to reconstitute the official response capabilities in the area of impact.

It is not possible to underestimate the impact of these events on the NYFD, the lead local agency in charge of operations at the site. Experienced officers capable of establishing an effective response were lost to NYFD at the start of the operations, which meant that officers with less operational experience and knowledge were placed in positions of responsibility at the site. Furthermore, many established bureaucratic procedures had to be suspended and superseded during the response period, which brought about innovation and adaptation but also a degree of confusion. It is in this context that the US&R taskforces attempted to insert themselves into SAR operations.

Twenty FEMA US&R task forces were present at the collapse site at one point in time. Preliminary findings indicate that they had a very difficult time accessing the site of SAR operations. There were no standard operating procedures understood by all responding organizations providing guidance to this interorganizational effort. Instead, it was an ad hoc process in which US&R taskforces used personal contacts and other ad hoc measures to "negotiate" access to the site from very often suspicious and unwelcoming NYFD officials. There were many reasons for this general attitude, foremost among them ignorance by NYFD personnel operating at the site about who the US&R were and their technical capabilities, in a context in which the site was peopled by many volunteers who made false claims regarding their technical competence in US&R procedures. The result was that very often US&R taskforces would be left waiting for things to do at the Javitts Center during the critical first days of the response. Eventually, many of them were given fire suppression responsibilities elsewhere in the city to allow NYFD personnel to participate in the WTC operations, in effect acting as regular fire department units, a worthwhile function but not one that reflected the purpose of the taskforces.

WTC illustrates the effects on SAR operations of the relative sophistication and resources of local fire departments. Before 9/11, the NYFD, probably the largest and most technically sophisticated and admired fire department in the world, was not accustomed to receiving assistance from any organization. Instead, it gave assistance to others. Thus, with its special operations unit decimated, it lacked the personnel who had participated in the development of the US&R system and who could have acted as a link between it and the taskforces. It also lacked the tradition of interagency coordination that would have facilitated the integration of

the various organizational actors. Thus, the effects of the disasters were multiplied by matters of organizational culture.

The Pentagon

The severity of attack on the Pentagon—the force of the plane crash, which penetrated the inner wall of the complex, and massive fires from the explosion— reduced the chances of survival. Victims who were able to escape did so within the first minutes after the impact (Titan Systems Corporation, 2002). Partly because of the Pentagon being a U.S. military facility under the direct control of the Secretary of Defense, the emergency response to the incident was more tightly controlled and better organized. The Arlington County Fire Department (ACFD) dominated the response from the first minutes after the impact (Collins, 2002).

There is official secrecy about what happened during the evacuation and SAR that took place inside the buildings of the Pentagon impacted by the airplane and about the use and relative effectiveness during the emergency of cameras and other electronic censors that are placed in the buildings for security purposes. There is some indication that the monitoring and visualization systems in the Pentagon facilities worked quite well in identifying the danger zone, establishing the extent of the hazard, and isolating it through pressurization and movable doors/gates that delayed fire progress. Still, a few people died of smoke inhalation. Unconfirmed information indicates that people evacuated in an orderly manner both to outside and to other parts of the buildings, and that some Navy personnel doused themselves with bottled water prior to attempting to reenter the facility to rescue people. Volunteers participated in rescue efforts and in searches, forming human chains to remove rubble to create egress pathways, and developing a rough division of labor while doing so; exhausted rescuers, typically at the top of the chain, would be replaced by rested ones in the back of the chain. There is also indication that construction workers at the site on the day of the attack were very helpful in the evacuation of the impacted area (Natasha Thomas, personal communication).

In comparison to WTC, the SAR procedures in the Pentagon were in many ways a textbook example of high interorganizational effectiveness and cooperation (Collins, 2002). The primary reasons are that they took place in a federal facility that had a very secure campus and a system of safeguards and military discipline. Most of the responding organizations were part of the federal government, which eliminated many jurisdictional problems that are often seen in this type of operation. It also took place in a region that had experienced an important transformation in its readiness posture. There had been a two decades-long regional tradition of preplanning and coordination among fire and rescue units of Arlington County, Fairfax County, Montgomery County, Alexandria, and the District of Columbia (ICDRM, 2002). The need for such levels of cooperation became apparent after the Air Florida Flight 90 crash of January 13, 1982.

This set of ongoing planning tools and the social relationships and trust they propitiated increased the resilience of the inter-organizational system for disaster response in the region and provides the background to what has become an example of how it should be done. In contrast, there was no similar interorganizational system operating in the NYC region that would have provided the capability to respond more effectively to the enormous destruction that took place in lower Manhattan. Instead, there was the NYFD, and when it was weakened by the WTC collapses there were no preestablished alternative arrangements and a tradition of interorganizational coordination in place. Comparing these SAR case studies provides some

understanding of the capacities and limitations of the US&R taskforce system and of the importance of disaster planning.

REMAINING RESEARCH GAPS

The foregoing is intended to convey the range of topics that have been addressed in the SAR scientific literature. We are painfully aware of its shortcomings. The majority of the existing research results reviewed here are in need of replication and expansion, while other needed research has not been carried out. For example, while information on the circumstances of entrapment and location of voids can contribute to the development of effective SAR techniques and effective injury-prevention strategies as well as national programs of response, to this day there have been no efforts to construct simulation models of building collapse configurations, develop a typology of building collapse, and ascertain empirically where the voids are in fact located in these types of collapsed structures which would then enrich and perhaps correct the practical knowledge of the practitioner community reviewed earlier.[1]

Moreover, there is little information about survival rates in reinforced concrete and in steel frame buildings, which are common on the West Coast region of the United States and elsewhere in the world. While common steel frame buildings perform relatively well in an earthquake, it is not known how they will respond to explosions caused by terrorists and accidents. An area that is almost untouched by research is the impact of different national and regional building codes and building practices on SAR. For example, a great many of the houses in Mexico are made of concrete, which presents very different challenges to SAR than is the case of the typical construction used in the United States. Most of the research conclusions in this area of study stem from events that occurred in foreign countries, where the building codes differ from the U.S. codes of practice. These differences in building codes and practices might lead to substantially different failure modes and survival rates in the United States.

There is also conflicting information on what is in fact the best behavior pattern for victims to follow during the actual occurrence of earthquakes and floods as well as immediately afterwards. A number of important research questions are still unanswered related to the entrapment of victims in the aftermath of disasters. Some of the most obvious of these are: What are the factors responsible for the survival of building occupants? How do the location of the occupants, actions of the occupants, nonstructural elements and building contents, nature and time of entrapment, and method of rescue play a role in survival? Most of the SAR literature is related to seismic disasters, with relatively little information about other types of hazardous events such as floods and blasts or explosions. In light of the new international focus on terrorism, there appears to be a gap in knowledge in this area. Our impression is that despite its obvious importance as part of the emergency response phase of disasters, SAR as a topic of scientific research has experienced a lull in interest; most of the scientific contributions included in this chapter, few as they are, are more than a decade old. The dearth of scientific research in SAR is such that it is not possible to establish findings using an international, intercultural comparative frame of reference (Dynes, 1993). Most of what is known is based on the United States and research is needed to establish the cross-cultural validity of what is known. A comprehensive and systematic research agenda for SAR would involve a multi disciplinary

[1] A partial answer to some of these questions, involving computer simulation of building collapse and behavior of victims is now being done by Sherif El-Tawil and B. E. Aguirre with partial financial support from the National Science Foundation, Grant no. 0408363.

effort by structural engineers, epidemiologists, emergency medical personnel, social scientists, and emergency planners using an international, comparative scientific research design. This research agenda will include understanding the social and cultural factors that (1) facilitate the development of emergent SAR groups, (2) are implicated in their institutionalization, (3) facilitate the upgrading of technical capacities of these voluntary organizations, and (4) facilitate their operational coordination with local and state, formal SAR responders as well as with other state organizations. It would also involve research on the victim–rescuer relationship and on the ways that the presence or absence of social relationships between them and the social visibility of the victims impact SAR activities and chances of survival. Another research goal would be to develop scientific knowledge of ways to increase the effectiveness of the interphase between emergency medical services and SAR by emergent groups and other volunteers.

CONCLUSION

US&R doctrine assumes that the main players in response are the local emergency management authorities, usually the local fire departments, that the federal taskforces are mobilized to assist them, and that the site of operations has been cordoned off so that only the "right" people are allowed in it. These assumptions are contradicted by the evidence we have presented from the incidents in the WTC and the Columbia Shuttle accident. These operations were so complex that not only is SAR in them an activity dominated by local volunteers and organizations, but the recovery of bodies is also a multiorganizational effort in which US&R taskforces had to share the site with multiple social actors. Greater importance should be placed on the social complexity of these sites of massive disasters, and on what this complexity implies for the operation of US&R taskforces. More attention should be given to the implications of the Pentagon response. It was a success that can be used to rethink the operation of these taskforces, particularly the ways in which they can become part of state-level systems of disaster response that would be linked to regional level capabilities through mutual aid agreements. Such a state level system would help ameliorate if not solve two of the seemingly intractable problems they now face—lateness in arriving at disaster sites and lack of previous interaction and a tradition of training and coordination with local responders that is key to effective response operations. More broadly, there is a need to rethink the distribution of public moneys spent in SAR, since so many of the rescues are made by emergent groups, neighbors, and volunteers who do not receive much assistance at present.

Needed is an international program of public education on first aid and emergency medicine, and programs to teach people what to do if they are victims and the right ways to conduct search and rescue in various types of terrains and the many other technical matters that they would need to improve their safety and their chances of rescuing victims. Associated with it is the pressing need to create government programs to make readily available the appropriate hand tools such as metal buckets, hand gloves, ropes, hydraulic arms, jacks, and drills that are needed by volunteers to carry out SAR activities during the mass assault phase of disasters. There is also a pressing worldwide need to give more attention and support to the emerging social organizations that SAR volunteers create in the aftermath of disasters (Drabek, 1987a; Forrest, 1978). This mass assault phase of disaster, if properly channeled and understood, constitutes the most important societal resource available for response in the immediate aftermath of disasters. It should become a key aspect of disaster preparedness planning. Unfortunately, at present, perhaps with the exception of the Community Emergency Response Team (CERT)

Program in California (Borden, 1991) and a few other states in the United States (Franke & Simpson, 2004) they are not so recognized, and instead SAR emergent actors and volunteers are typically seen as appendages to the work of state agencies or as impediments to the work of these agencies. Under the emphasis of professional ideologies emphasizing technology and specialization, the emergent features of the mass assault go unrecognized as key resources in improving the effectiveness of disaster response and the safety of people throughout the world. Change in this inappropriate approach to SAR is perhaps the most important factor that is needed in improving the public administration of SAR as a disaster preparedness and response function.