The Application of Intelligent Transportation Systems (ITS) and Information Technology Systems to Disaster Response

by

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Submitted to the Department of Civil & Environmental Engineering
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ABSTRACT

Disaster response operations during recent terrorist attacks and natural disasters have been a cause for concern. Lack of planning is one source of difficulties with these operations, but even if a perfect plan is agreed upon before a disaster occurs, it is unlikely that disaster response operations will be successful without better technological support.

For this thesis, three prominent and recent disaster cases are analyzed in order to better understand current disaster response problems that result from insufficient Information Technology (IT) and Intelligent Transportation Systems (ITS) support. After presenting this analysis, we provide results of a technology review, whose goal was to search for emerging technologies that could perform better during a disaster response than the standard, currently available systems. Using these emerging technologies, a Disaster Response Support System (DRSS) is proposed that would provide improved capability, interoperability, and robustness compared to the currently available support systems. Finally, potential barriers to deployment of a system such as the DRSS are discussed and ways in which these barriers can be overcome are suggested.

Thesis Supervisor: Joseph M. Sussman

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LIST OF ACRONYMS

ACN	Automated Collision Notification
ATIS	Advanced Traveler Information System
ATSAC	Automated Traffic Surveillance and Control System
AVL	Automated Vehicle Location
CAD	Computer-Aided Dispatch
CapWIN	Capital Wireless Integrated Network National
CCTV	Closed-Circuit Television
CTECC	Combined Transportation, Emergency & Communications Center
CUBE/REDI	Caltech USGS Broadcast of Earthquakes/Rapid Earthquake Data Integration
DOD	Department of Defense
DRSS	Disaster Response Support System
EDI	Electronic Data Interchange
EDIS	Emergency Digital Information System
EMS	Emergency Medical Services
FAA	Federal Aviation Administration
FDNY	Fire Department of New York
FEMA	Federal Emergency Management Agency
Field Comm	Field Communications Van
GE	General Electric
GETS	Government Emergency Telecommunications Service
GIS	Geographic Information Systems
GPS	Global Positioning System
HAR	Highway Advisory Radio
HEAR	Hospital Emergency Area Radio
HOV	High-Occupancy Vehicle
IIMS	Integrated Incident Management System
IRRIS	Intelligent Road & Rail Information Server
IRVN	Interagency Remote Video Network
IT	Information Technology
ITS	Intelligent Transportation Systems
LAN	Local Area Network
MERS	Mobile Emergency Response Support
MIVIS	Massachusetts Interagency Video Information System
NCS	National Communications System
NRP	National Response Plan
NYC	New York City
NYPD	New York Police Department
OASIS	Operational Area Satellite Information System
OEM	Office of Emergency Management
P2P	Peer-to-Peer
PAPD	Port Authority Police Department
PDA	Personal Digital Assistants
PSAP	Public Safety Access Point
SOV	Single-Occupancy Vehicle
TMC	Traffic Management Center
TRANSCOM	Transportation Operations Coordinating Committee
TrEPS	Traffic Estimation and Prediction System

VII	Vehicle-Infrastructure Integration
VMS	Variable Message Signs
WAN	Wide Area Network
WIISARD	Wireless Internet Information System for Medical Response in Disasters
WPS	Wireless Priority Service
WTC	World Trade Center

Chapter 1. Introduction.

1.1 Research Motivation

In recent history, both the world and United States communities have had to deal with numerous disaster situations. These include: the terrorist attacks of September 11, 2001, hurricanes on the United States' eastern seacoast during the summer and fall of 2005, a major tsumani in southeast Asia in December of 2004, the terrorist attacks in London in July of 2005, and a devastating earthquake in Pakistan in October of 2005. When such disasters happen, a key, problematic issue is how to best manage the emergency situation. Many metropolitan areas either lack a response plan or have an emergency response plan that is insufficient. In addition, even if a good plan is in place, it appears that, in most cases, emergency situations require better technologies and system support than is currently available. The recent events have made disaster response a significantly more prominent public policy issue for governments around the world, and management plans and supporting systems are currently being revised to become more effective and efficient.

1.2 Main Research Objective and Questions

The research objective of this thesis is to address how emerging technologies and systems could be used to aid with disaster response. In particular, we will focus our attention on Information Technology (IT) and Intelligent Transportation Systems (ITS) as sources of potential solutions to disaster response problems. In our approach, we pose four main research questions that need to be answered, as follows:

1) What are the problems and challenges facing typical disaster response operations in the United States?
2) What currently available and developing IT and ITS technologies and systems have the potential to ameliorate disaster response problems and challenges?
3) How could these IT and ITS technologies be applied to resolve specific challenges and problems of the three disaster cases that we studied?

4) What issues will we be faced with in attempting to implement these IT and ITS technologies to support disaster response operations, and what might be some ways of overcoming them?

We next discuss our basic approach to answering these questions in this thesis.

1.2.1 What are the problems and challenges of typical disaster response operations in the United States?

Before we can propose applications of technology to response problems, we must understand these problems. To do this, we study three prominent and recent disasters that have occurred in the United States. In extracting the problems and challenges, we particularly focus on problems that arose as a result of functionality issues of available IT and ITS systems, or often, as a result of a complete lack of such support systems. The cases were chosen carefully so as to study disasters of various varieties and to include cases from different parts of the country. The three chosen disasters to study are as follows:

- The 1994 Northridge, CA Earthquake
- The September 11, 2001 Terrorist Attacks on the World Trade Center
- The 2005 Landfall in New Orleans, LA of Hurricane Katrina

1.2.2 What currently available and developing IT and ITS technologies and systems have the potential to ameliorate disaster response problems and challenges?

Based on the lessons learned from the case analyses, the next step is to begin investigating how these types of disaster response operations could be improved. To initiate this investigation, an emerging technology review was performed. The technologies that were sought were those that were judged to have the potential to provide better disaster response support than those that were available during the disaster cases.

1.2.3 How could these IT and ITS technologies be applied to resolve specific challenges and problems of the three disaster cases that we studied?

After we have determined what were the disaster response problems and challenges of the three disasters as a result of the lack of sufficient IT/ITS systems and have also performed the technology review, we can then propose how emerging IT and ITS technologies could be used to ameliorate these challenges and problems. In doing so, we will propose a Disaster Response Support System (DRSS) that is comprised of technologies that were considered in the technology review. Then, we will suggest how such a system as the DRSS could have been used to improve disaster response capabilities for each of our three disaster cases.

1.2.4 What issues will we be faced with in attempting to implement these IT and ITS technologies to support disaster response operations, and what might be some ways of overcoming them?

Before the successful deployment of a system such as our proposed DRSS can occur, some institutional and technological barriers will need to be overcome. We will include discussion of the main issues that are anticipated. Additionally, suggestions regarding how these issues could be overcome are presented.

1.3 Thesis Structure

Four main chapters, Chapter 2 through 5, comprise the core of this thesis. Each of these chapters corresponds to one of the four questions above, in that order. After these four core chapters, we will summarize and conclude this thesis in the final chapter, Chapter 6. Appendices are also provided after the six chapters. These appendices, Appendices A-C, are chronologies of the three disaster cases that were investigated.

Chapter 2. The Value of IT/ITS Technologies for Three Disaster Case Studies

2.1 Introduction to Disasters and Disaster Response

A disaster is a very general term that refers to many different types of catastrophic events. In general, a disaster occurs in an area where people live and their livelihood and health is influenced in ways that are not typically encountered. Disasters vary by extremity, types of consequences, size of the area affected, warning time, and many other factors. According to the Federal Emergency Management Agency (FEMA) (1), the following are different types of disasters:

- Chemical Emergencies
- Dam Failure
- Earthquake
- Fire or Wildfire
- Flood
- Hazardous Material
- Heat
- Hurricane
- Landslide
- Nuclear Power Plant Emergency
- Terrorism
- Thunderstorm
- Tornado
- Tsunami
- Volcano
- Wildfire
- Winter Storm

Although this list covers many different disaster types, we would also add Power Failures as another important type of disaster. An example of this was the Northeast U.S. and Canada power outage of August, 2003.

A typical disaster response is also hard to characterize specifically, since disasters come in such varied forms. A key characteristic of the disaster response process in the United States is decentralization, since much of the responsibility to deal with a disaster is assumed by local governments. Particularly during major disasters, many different agencies from different levels of government participate in the response efforts, as the state and federal governments come to the aid of local governments. The assistance is usually welcome but coordinating all of the response personnel, equipment, and supplies can become extremely difficult. Although, for example, the federal government has been pushing for a nation-wide disaster response plan, including its efforts to develop the "National Response Plan" and the "National Incident Management System" (2, 3), much work remains to establish a coordinated and efficient disaster response process in the United States.

2.2 Framework for Analysis

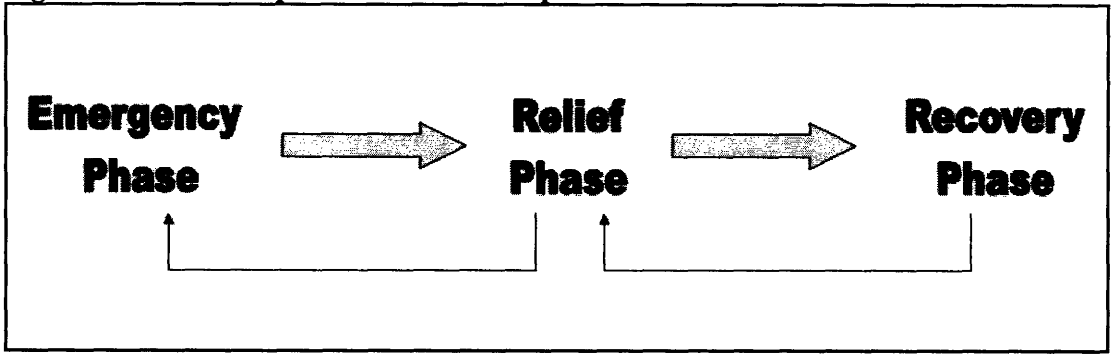
A disaster response has three primary phases: *emergency, relief,* and *recovery.* Our analysis in this report will be structured based on these three phases, while recognizing that other possibilities exist. Descriptions of the phases follow.

The *emergency* phase is when such activity as search and rescue and life preservation, injury treatment, and emergency infrastructure inspections and repairs occur. This is usually in the immediate wake of the disaster.

The *relief* phase follows the emergency phase and is a time when temporary solutions are sought to assist the community.

The *recovery* phase is when the primary objective is to bring the effected community back to their original, or even improved, quality of life level. The recovery phase generally follows the relief phase.

Figure 2.1. The three phases of disaster response.



While the three phases of disaster response generally occur sequentially, it is important to mention that the transition from one phase to another will typically be "fluid". For example, at a time when certain aspects of a disaster response are still in the emergency phase, other aspects may simultaneously already be considered as relief activities. Additionally, it is possible for a disaster to revert backwards, for example, from the relief phase back into emergency phase status.

When studying the disaster response cases, we will consider three primary categories of disaster response functions. The first category will focus on *sensing and assessment* of the disaster situation. The second category will focus on *communication and coordination* of the disaster response process. The third category will focus on *transportation operations* in the effected areas and critical premises.

Although there are other categories of disaster response functions that we could also focus on, we choose to concentrate on these three as a way of focusing the thesis and since IT and ITS solutions are most likely to help in these areas.

More specifically, each category can be broken down into specific functions by the phase of disaster response. Within each phase, we can identify the most important disaster response functions. These functions are shown in Table 2.1. Following the table, brief descriptions of each function will be given. All functions are those where emerging technology have a potential application. These applications will be described in Chapter 4. In this chapter, for each of our three case studies, we will present some background information for each function as well as information concerning the use and value of available IT/ITS technologies.

Table 2.1 Important Disaster Response Technology-Related Functions.

	Sensing and Assessment	Communications and Coordination	Transportation Operations
Emergency Phase	Disaster sensing and assessment	Communication and coordination between response agencies for emergency operations	Movement/evacuation of victims/general public
	Critical infrastructure sensing and assessment	Communication and coordination between response agencies and emergency responders	Mobility of responders
	Victim location/tracking	Communication and coordination between emergency responders	
	Responder / emergency response activity tracking	Communication and coordination between victims/general public and response agencies	
Relief Phase	Relief activity tracking	Communication and coordination between response agencies to coordinate relief	Support of temporary transportation movements
	Resource tracking	Communication and coordination between response agencies and responders during relief	
Recovery Phase	Recovery activity tracking	Communication and coordination between all relevant agencies to coordinate recovery	Support of new (or original) transportation movements

Brief descriptions of each of the functions follow.

2.2.1 Sensing and Assessment

EMERGENCY PHASE

Disaster sensing and assessment

This function involves sensing the environment to assess the approach (if applicable), potential, and actual extent of a disaster. Examples of this type of sensing and assessment would include hurricane tracking systems, earthquake location and magnitude sensing, and sensing and assessment of biological or chemical agents in the air.

Critical infrastructure sensing and assessment

This function involves sensing and assessment of critical infrastructure after the effects of the disaster have been felt. Critical infrastructure includes energy systems, information technology systems (now including the internet), telecommunications systems, housing, transportation systems, health care systems, water systems, and the public administration facilities.

Victim location / tracking

This function involves determining the locations of victims and their status and tracking their location and status throughout the treatment and assistance processes.

Responder / emergency response activity tracking

This function involves determining the locations of responders and their status and tracking their location and status throughout the emergency response process. The responders' agencies' overall activity tracking can be associated with responder tracking.

RELIEF PHASE

Relief activity tracking

This function involves tracking the relief activities of the various agencies involved in the relief effort. Relief activities include food and water distribution and shelter provision.

Resource tracking

This function involves tracking of relief resources such as goods and supplies that are being distributed.

RECOVERY PHASE

Recovery activity tracking

This function involves tracking the recovery activities of the various agencies involved in the recovery effort. Recovery activities include damaged highway reconstruction, telecommunications repair, and other activities that seek to bring the effected area back to a normal status.

2.2.2 Communications and Coordination

EMERGENCY PHASE

Communication and coordination between response agencies for emergency operations

This function involves communication and coordination between response agencies to implement the most effective emergency response possible. This is necessary so that the managers of each agency are aware, in general, of what other response agencies are doing.

Communication and coordination between response agencies and emergency responders

This function involves communication and coordination between response agencies and their emergency responders that are in the field. Primarily, this function includes communication between agency managers and in-the-field responders to disseminate orders.

Communication and coordination between emergency responders

This function involves communication and coordination between emergency responders, including those from different agencies. This would include, for example, coordination of medical care on a mass scale where responders need to talk with other responders, from their own and other agencies, to seek assistance or offer help in providing care.

Communication and coordination between victims/general public and response agencies
This function involves communication and coordination between victims/general public and response agencies. The communication is necessary for response agencies to locate the victims / general public that need assistance and so that victims can get critical information about the disaster.

RELIEF PHASE

Communication and coordination between response agencies to coordinate relief
This function involves communication and coordination between response agencies to implement the most effective relief effort possible. Communication and coordination would include, for example, passing of information about goods and supplies shipments.

Communication and coordination between response agencies and responders during relief
This function involves communication and coordination between response agencies and their responders that are in the field. Communication and coordination between agencies and responders is necessary for some disasters, such as Katrina, for example, since many responders are still deployed in the effected area during the relief phase.

RECOVERY PHASE

Communication and coordination between all relevant agencies to coordinate recovery
This function involves communication and coordination between response agencies to implement the most effective recovery effort possible. Information to pass would include, for example, recovery progress of critical infrastructure. Passing such information in real-time becomes less important during this stage.

2.2.3 Transportation Operations

EMERGENCY PHASE

Mobility/evacuation of victims/general public

This function involves providing maximum feasible mobility and evacuation efficiency to the victims of a disaster and the otherwise effected general public. Aside from evacuation, the general public would need mobility to, for example, seek emergency medical assistance.

Mobility of emergency responders

This function involves providing maximum mobility to emergency responders. Mobility includes transport of responders to scenes where their assistance is needed and from incident scenes to hospitals and other places where victims need to be taken for any further assistance.

RELIEF PHASE

Support of temporary transportation movements

This function involves the support of temporary transportation movement patterns while the recovery phase is still being awaited. Such support would include management of early-term detours, for example.

RECOVERY PHASE

Support of new (or original) transportation movements

This function involves the support of new (or original) transportation movement patterns, if they result from the recovery/rebuilding process. This support would include longer-term detour management and provision of alternative transportation modes, such as expanded transit availability. A re-education campaign of the general public regarding prominent modifications to the transportation network may be necessary.

2.3 Case Analyses

Now that we have started to define just what a disaster is, what a typical disaster response might involve, and what some disaster response functions are, we will now turn our attention to the actual findings about how the functions were performed in our disaster response cases and details about the IT/ITS technologies and systems that were available and used in those cases. As mentioned in the introduction, we have chosen the following three cases to study:

- The 1994 Northridge, CA Earthquake
- The September 11, 2001 Terrorist Attacks on the World Trade Center
- The 2005 Landfall in New Orleans, LA of Hurricane Katrina

These cases were chosen so that a variety of disaster types were included, but also, so that the disasters were prominent, recent occurrences. All three of the chosen cases are fairly recent, and all were disasters that had at least some substantial difficulties with disaster response. These three cases also had good variety. Northridge and Katrina, were of course, natural disasters, while the September 11 attacks, or "9/11", was a man-made (terrorist) disaster. On the other hand, 9/11 and Northridge were disasters that offered no warning to the community, while Katrina offered several days of warning.

In the analysis that follows, for each function, we will first present some background information that is specific to the disaster case being analyzed. Second, for each function, we will summarize the IT/ITS technology that was available for use, again in the context of the disaster case being analyzed.

Finally, Appendices A, B, and C contain chronologies for the three disaster cases: Northridge, 9/11, and Katrina, respectively. The reader may find it useful to refer to the chronologies to get a better sense for the order of events for each disaster case.

2.3.1 Northridge Case Analysis

On Monday, January 17, 1994, at 4:30 AM, the Northridge earthquake with magnitude 6.8 shook the Los Angeles metropolitan area. The epicenter of the earthquake was in Northridge, CA, about 25 miles northwest of Los Angeles' downtown. The event caused substantial damage to the region. Damage was incurred to 114,000 residential and commercial structures over an area of about 2,100 square miles. About 33,000 people reported damage to their homes and had immediate shelter and welfare needs. (4) Depending on the source, it appears that 60-70 fatalities were also caused by the earthquake. 19 deaths occurred as a result of heart attacks and 33 as a direct result of collapsed buildings. Moreover, according to one source, 9,000 people were injured. Injuries ranged from cuts and bruises to serious injuries or ailments which required immediate hospitalization. Area hospitals reported treating 2,800 patients and hospitalizing about 530 of them within the first 72 hour period following Northridge. (4)

In addition, the earthquake also caused widespread power outages, impaired communications, ruptured water and natural gas lines, widespread fires caused by the combination of broken gas lines and electrical lines, landslides, and devastating damage to the road network, including some of the most important highways in the Los Angeles area. (4, 12) Structural damage, although typically minor in many cases, rendered many freeways impassible. Landslides were also a huge cause of freeway closures. Flooding from water main breaks blocked some roads and fire was a damaging factor as well. Some roads were also blocked by fallen structures, including buildings and bridges. (5) Overall, shortly after it occurred, FEMA reported the Northridge earthquake as one of the largest and most costly disasters in U.S. history, with the total cost of the disaster estimated at $25 billion.

We next discuss more specifically the Northridge disaster response, based on the framework presented in the beginning of this chapter.

2.3.1.1 Sensing and Assessment

EMERGENCY PHASE

2.3.1.1.1 Disaster sensing and assessment

FUNCTION BACKBROUND: Sensing and assessment of the earthquake's epicenter, magnitude, and duration was an important emergency function. The type of information that would have been critical to collect immediately after the Northridge earthquake struck would be that it occurred on Monday, January 17, 1994, at 4:30 AM, with a magnitude 6.8 on the Richter scale, and epicenter in Northridge, CA.

TECHNOLOGY: Several technologies, just being developed at the time Northridge struck, were instrumental in the initial stages of the response process. The first is Caltech USGS Broadcast of Earthquakes/Rapid Earthquake Data Integration (CUBE/REDI) system. This system provides to its subscribers almost instantaneous data about the location, magnitude, and duration of an earthquake. This information can be very instrumental in mobilizing immediate disaster response operations, since the CUBE/REDI data can be processed along with data about housing and transportation structures in the area to aid in the decisions regarding where to deploy the scarce personnel and supplies involved in the response. (4) The CUBE/REDI system received information from seismometers and strong ground motion instruments placed in approximately 250 sites and altogether known as the Southern California Seismic Network (SCSN). Once the system recognizes an earthquake that was likely damaging, an alert is sent out to subscribers of the system within 4 minutes via commercial pagers or electronic mail. Subscribers include primarily managers of physical infrastructure in Southern California, including the Office of Emergency Management, Pacific Bell, Caltrans, and Southern Pacific Transportation. Before this system was available, information about the earthquake would have to be received by radio or television news broadcast. (6, 7)

The CUBE/REDI was operational after the Northridge earthquake. Additionally, it appears that they were quite instrumental for success for this function.

2.3.1.1.2 Critical infrastructure sensing and assessment

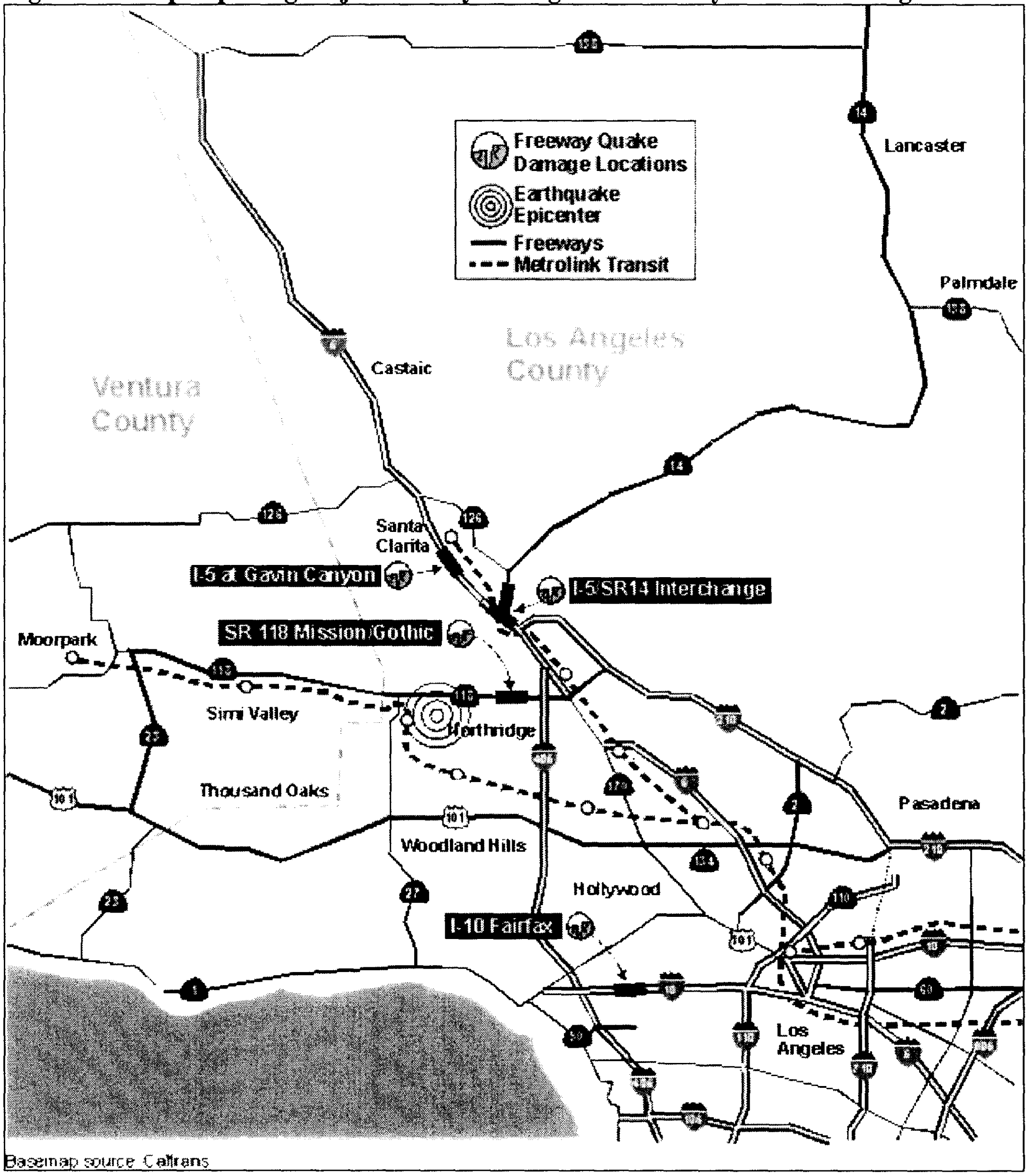
FUNCTION BACKGROUND: This function involved sensing and assessment of the critical infrastructure after the Northridge earthquake. The earthquake caused a great amount of damage to the region that included damage to residential and commercial areas, power outages, impaired communications, ruptured water and natural gas lines, fires, and landslides. (12)

The Northridge earthquake damaged the road network extensively in the area, including damaging several of the most important highways in the Los Angeles area. The road network, in general, suffered from widespread impediments to use as a result of structural damage, landslides, flooding, fires, and debris. (5) Although such damage would have been problematic for any urban community, it must have been particularly so for the automobile centered society in this region.

There were additional causes of road closures during the Northridge disaster. Sometimes damage to freeways does not immediately cause collapse or failure, but there is enough damage that there will be an increased potential for collapse, especially if the road continues to be used. If this type of situation can be identified, then this road would need to be closed. Finally, there are some less common circumstances that result in road closures after a disaster such as Northridge like snapped electrical cables or train derailments that block the road path. (5)

A US DOT comprehensive study on the event concluded that there were four main highway infrastructure damage points. The four main points of damage were on I-5, SR-14, I-10, and SR-118. (12) The damage to I-5 and I-10 was particularly disruptive, since I-5 is a main north-south artery in Southern California, while I-10 is one of the main east-west corridors in the Los Angeles area. While SR-14 suffered damage only at one location, I-5, I-10, and SR-118 all experienced collapses and other forms of damage in multiple locations. (12) Minor damage to the Pacific Coast Highway, or SR-1, was also noted. (8) Figure 2.2 shows these major freeway damage locations on a map.

Figure 2.2 Map depicting major freeway damage immediately after Northridge.



Source: 12

Hospitals in the Los Angeles areas suffered damage after the Northridge earthquake. According to one source, four hospitals in the Los Angeles area were damaged severely enough by Northridge to require closing the facility. This is considered fairly light damage to the hospital community by large earthquake standards. (9) Information about the status of hospitals was important because thousands of patients needed treatment.

TECHNOLOGY: Comprehensive sensing and assessment of critical infrastructure was impossible. No technology was present specifically for sensing and assessment of the critical infrastructure. Data collection was done manually. For example, we know that Caltrans had to send out a team of surveyors to assess the state of the transportation network. (12)

2.3.1.1.3 Victim location / tracking

FUNCTION BACKGROUND: This function involved quickly locating victims in need of assistance. Also, the function would include tracking victims throughout the emergency response process.

Immediate medical treatment was needed throughout the affected area of the earthquake. Urban Search and Rescue teams led the effort to search for trapped or injured survivors and attempted to rescue them. A key difficulty with any earthquake search and rescue operation is that victims are typically spread across a large geographic area, which was the case for Northridge.

TECHNOLOGY: A victim location and tracking system was not present. Thus, victim location and tracking functionality was very limited. Victim location and tracking information would only be available via the limited communication mediums that were available. These media will be discussed further in the communication and coordination section.

2.3.1.1.4 Responder / emergency response activity tracking

FUNCTION BACKGROUND: This function involved determining the locations of responders and their status and tracking their location and status throughout the Northridge emergency response process. The responders' affiliated agency overall activities also are included in this function. Status information would include such information as available capabilities and tools of specific responders.

TECHNOLOGY: No specific responder tracking technology was available during the Northridge earthquake emergency response. Limited communications, described in the communications and coordination section, allowed for some information gathering about in-the-field activity.

RELIEF PHASE

2.3.1.1.5 Relief activity tracking

FUNCTION BACKGROUND: This function involved tracking the relief activities of the various agencies involved in the relief effort. Relief activities included, for example, efforts to provide shelter to those that lost their homes. Another example of relief activities dealt with setting up traffic detours and providing new transit services for the public.

TECHNOLOGY: Some technology support was available for this function. Geographic Information Systems (GIS) were used by the Office of Emergency Management (OEM). GIS tools were used to track assistance activity to the general public. Disaster Assistance Centers locations were plotted, for example. (4)

2.3.1.1.6 Resource tracking

FUNCTION BACKGROUND: This function involved tracking of relief resources such as goods and supplies that were being distributed. Those citizens that were left without a home would need various goods and supplies to sustain themselves.

TECHNOLOGY: Some technology support was also available for this function. As for the previous function, Geographic Information Systems (GIS) were used by the Office of Emergency Management. GIS tools were used to track the flow of resources to the general public. (4)

RECOVERY PHASE

2.3.1.1.7 Recovery activity tracking

FUNCTION BACKGROUND: This function involved tracking the recovery activities of the various agencies involved in the recovery effort. Recovery activities involved residence rebuilding and transportation network recovery.

TECHNOLOGY: As was the case for relief activity tracking and resource tracking, GIS tools were also used to during the recovery phase to track recovery activity. In fact, these tools were used more extensive during the recovery phase than the relief phase. (4)

2.3.1.2 Communications and Coordination

EMERGENCY PHASE

2.3.1.2.1 Communication and coordination between response agencies for emergency operations

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies to implement the most effective emergency response possible. First, responder dispatch logic would be necessary. Second, coordination of medical care would also be needed. Additionally, debris blocking the roadways needed to be cleared.

Although we could not find it explicitly stated, we presume that a coordinated search and rescue operation would have been difficult. For example, if a particular area needed responder presence, deciding which deployed or not yet deployed response team to send there, based on required training or skills or just proximity to the area, would be important to ensure an effective response.

Once at a rescue scene, responders were responsible for administering the best possible medical care to those that needed it. Many of the people rescued would need treatment at a hospital or temporary medical aid centers set up after the disaster struck, preferably at predesignated locations. Reliance on temporary medical care facilities appeared to have been important, even in the case of Northridge, where many hospitals remained operational. Given the large number of victims that needed care, some of these hospitals may have been overwhelmed with patients. Thus, communication and coordination was important within the medical response community to make efficient decisions regarding to which hospitals or medical aid centers to take victims.

All sorts of debris and travel impediments were reported to be on the area's road network. Prompt clearance of this debris was important, as was recognized by authorities, since contracts were in place to clear debris and demolish ruined highways within hours of the earthquake. However, it seems that coordinating this effort would have been important.

TECHNOLOGY: It appears that some technology was present and used to support inter-agency communication. The Operational Area Satellite Information System (OASIS) provided a channel of communications transmission. OASIS is a FEMA-sponsored system that was just in its implementation stages when Northridge struck; it uses a dedicated satellite to provide disaster resilient communications between Emergency Operations Centers (EOCs) in California. (10) Another communications system that was in developing stages in January 1994 was the Emergency Digital Information System (EDIS), which served to disseminate vital information simultaneously to responsible public agencies, their target audiences, and the media. EDIS used OASIS as the communications backbone to achieve its purpose. EDIS was also sponsored and implemented by FEMA. (4) Fax machines and electronic data sharing between computers were also used for data exchange. Internet was only sparsely available in 1994. (12)

2.3.1.2.2 Communication and coordination between response agencies and emergency responders

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies and their emergency responders that were in the field. The type of information that would need to be communicated would be dispatch orders, victim location and status, hospital status, and road network conditions.

TECHNOLOGY: Radio communications were used for agency to responder communication, but often did not get a sufficiently strong signal in the areas the earthquake did the most damage. Additionally, and as is typically the case with any disaster response situation, other forms of communication were a major difficulty throughout the emergency response process. Phone lines became unusable after the earthquake as the phone system became overloaded with people trying to make calls or phone lines being clogged up by phones that were knocked off the hook by the tremors. In 1994, cell phones were only starting to be widely used, but were very useful where service was available. Additionally, pagers, fax machines, and electronic data sharing between computers were again used for data exchange. (12)

A specific case of agency to responder communications was the fire department's dispatch system. The Los Angeles County Fire Department had developed, by the time Northridge occurred, a sophisticated computer-aided dispatch (CAD) system. An operator would no longer need to answer the phone and record the incident information. Instead, this process was automated. The location and the nature of the incident would be recorded in their database, and the nearest resource to assist at the incident would be identified based on a computerized resource directory. The fastest route to the incident would also then be calculated, although access to real-time transportation network information was likely difficult. (If the recommended fastest route would have involved travel over some of the damaged part of the transportation network, then some trial-and-error would be required to find an available detour.) The Operations Chief was the key decision maker for this system who would verify the incident and response strategy and transmit the required orders to field personnel via fire radio. (4) Importantly though, according to the Los Angeles Fire Department, this computer system went down for about the first 6 hours after the earthquake due to power failure and subsequent power generator failure, causing the system to go on "manual mode". However, radio communications continued to be operational throughout this time period. (11)

2.3.1.2.3 Communication and coordination between emergency responders

FUNCTION BACKGROUND: This function involved communication and coordination between emergency responders, even if they were from different agencies. This would include coordination of medical care on a mass scale.

In neighborhoods that were hit hardest, a triaging type of system would be necessary to most efficiently deal with a large number of victims of varying degrees of emergency needs. Some victims would need medical attention. Others would be in need of just food and shelter. Coordinating the most efficient assistance effort to these victims would be an important part of this function and would require responders to communicate with each other.

TECHNOLOGY: In order to communicate with each other in the field, responders would need to rely on radios and cell phones. However, radios had difficulties with operability in some incident locations. Moreover, radios were not designed to be interoperable between agencies. (Interoperability of communications technology was a problem for the other disaster case studies as well and usually is a problem as a result of cost and difficulty of implementation.) Cell phones had the same difficulties and not many responders even had them.

2.3.1.2.4 Communication and coordination between victims/general public and response agencies

FUNCTION BACKGROUND: This function involved communication and coordination between victims/general public and Northridge response agencies. The communication was necessary for response agencies to locate the victims / general public that need assistance and so that victims can get critical information about the disaster situation. Initially after the earthquake occurred, there was a broad need for victims to communicate their needs to authorities.

TECHNOLOGY: Regular phones were not in operation immediately after the earthquake. Only limited number of cell phones, and only where service was available, could have been used to call for emergency help and communicate with the response agencies. Thus, this function would have been particularly difficult to perform.

RELIEF PHASE

2.3.1.2.5 Communication and coordination between response agencies to coordinate relief

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies to implement the most effective relief effort possible. Coordinating the mutual efforts of the numerous organizations that became involved in the Northridge disaster response was a challenge. Within days of this earthquake, there were hundreds of organizations represented in the response effort by thousands of personnel. It is apparent that coordination was crucial since, at least initially, managers from different agencies would meet in the morning to establish response activity plans and then would meet in the evening in order to report on their day's activity. However, during the day, there were limited communications between personnel from different agencies. Without real-time communications during the day, the effectiveness of the response suffered.

An important long term relief effort was related to public welfare. In terms of longer-term public welfare, as a result of the extensive damage to residential areas, shelter had to be found for those that were left homeless. In addition, financial assistance would have also likely been an issue for such people. The main problem here was coordinating the quality of life needs of the impacted population with the resources available. By quality of life, we mean anything that has to do with a person's health or general well-being "generated by the significant loss of housing, property, jobs, transportation, and access to other services such as medical care and nutrition." (4)

TECHNOLOGY: For relief related communications, the OASIS and EDIS systems were still available and used. At the same time, as phone system communications were recovered, they could be used once again for agency-to-agency communication and coordination. Fax and electronic data sharing were again available for data exchange. (12)

2.3.1.2.6 Communication and coordination between response agencies and responders during relief

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies and their responders that were in the field. During the relief phase, there were responders from hundreds of different organization assisting with the relief efforts.

TECHNOLOGY: Although phone communications would become gradually fixed, the problems with radio signal coverage would still remain and cell phones still, of course, were sparsely available.

RECOVERY PHASE

2.3.1.2.7 Communication and coordination between all relevant agencies to coordinate recovery

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies to implement the most efficient recovery effort possible. The main efforts of recovery would include bringing back victims of the earthquake to a decent quality of life and finishing the rebuilding of damaged infrastructure.

TECHNOLOGY: OASIS and EDIS were still available for communication between EOCs. As more phone communications became available, standard means of communications could be used as well to coordinate between the agencies involved in the recovery process.

2.3.1.3 Transportation Operations

EMERGENCY PHASE

2.3.1.3.1 Mobility/evacuation of victims/general public

FUNCTION BACKGROUND: This function involved providing maximum mobility to the victims of the Northridge earthquake and the otherwise effected general public. Since many highways were damaged during the Northridge earthquake, travelers on the network would have faced serious mobility issues immediately after the disaster struck. Primarily, the problem was a lack of real-time information to support routing decisions. This would have been a problem for the common traveler trying to seek medical attention or other emergency help. It is known, for example, that not all victims were assisted by official emergency responders. Volunteer members of the general public were instrumental in rescuing victims and providing transportation to hospital or temporary medical care facilities. (9)

Initial detours were set up on the first day following the earthquake. Overall travel needs were lighter than usual, unless for emergency, since the day of the earthquake was a national holiday, Martin Luther King Day.

TECHNOLOGY: In 1994, the media played a key role in traffic information dissemination, with television being the most real-time. However, since immediately after the earthquake, power was out for most of the effected area, television would not have been available. It appears that only a limited number of Variable Message Signs (VMS) could have been used at the time to disseminate real time information. However, these too were vulnerable to the power failures. Highway Advisory Radio (HAR) was used when power was available.

Another more serious problem had to do with the initial gathering of traffic information. As was stated earlier, to gather transportation network status information, Caltrans sent out teams of inspectors to do manual data gathering. This was time consuming and prone to inaccuracies. As a result, initially after the earthquake, there was in fact no information to disseminate, even if the technologies just mentioned had been operational. (12)

2.3.1.3.2 Mobility of emergency responders

FUNCTION BACKGROUND: This function involved providing maximum mobility to emergency responders. Mobility included transport of responders to scenes where their assistance was needed. Additionally, responders would need to have mobility to transfer victims to hospitals or shelters.

The transportation system was critical for the mobility of emergency responders, including search and rescue teams, fire departments, police, and others, in the response to this disaster. In order to respond, responders would need to have mobility in order to get to the scenes where they were needed. However, this mobility would have had to be accomplished over a damaged transportation network where all sorts of obstacles and debris would impede travel. Moreover, some equipment such as vans, buses, trucks was susceptible to being damaged in the earthquake, making mobility even more difficult.

TECHNOLOGY: During the initial stages of emergency response, emergency responders would not have been too much better off than the general public for mobility. It was difficult for them to get real-time information about the road network, particularly early on. Aside from the technologies that the information that the general public had access to, emergency responders could have attempted to access road status information from their agencies via their radios. However, as was discussed in the communication and coordination section, radios were prone to being out of signal range. In addition, their agencies would not necessarily have the information they needed or could have provided information that was inaccurate.

RELIEF PHASE

2.3.1.3.3 Support of temporary transportation movements

FUNCTION BACKGROUND: This function involved the support of temporary transportation movement patterns while the recovery phase is still being awaited. Since many highways and roadways were damaged during the Northridge earthquake, detours had to be established on arterial routes. However, the abnormal traffic load on these arterials would have created difficult conditions on those roadways as well with high levels of congestion spilling into those routes. A method to manage the traffic on these arterials would have been important.

There was a lack of real-time information to support routing decisions. Detour, road closure, and reconstruction information was provided largely through the media and other methods that were incapable of being real-time. This created a problem for the common traveler in the months to come after the earthquake as the region's road network was built back to full operation.

Additionally, after the earthquake, the Los Angeles metropolitan area was forced to come to rely on public transportation more much more than it does typically. Transit ridership increased very significantly in the aftermath of the earthquake and the damage that it caused on the road network. Transit ridership on commuter rail, for example, peaked at over three times the normal usage. At the same time, many commuters were now faced with using a transit system that was not very familiar to them. In addition, transit agencies in the region changed some bus routes to accommodate new travel patterns, increased transit availability, and implemented shuttle service. The combination of unfamiliarity and new transit developments would make riding transit challenging for travelers. Better transit information would have been very useful in assisting all of these new transit commuters. (12)

TECHNOLOGY: There was some ITS technologies to support temporary transportation movement patterns, but they were prone to power failures and inherent limitations. First, it was quickly realized that Caltrans' Traffic Management Center (TMC) could not handle the coordination and data processing load needed to respond to this earthquake. In addition, although some ITS technology was present, operators recognized the need for more sensing and information technology. Thus, plans for the Earthquake Planning and Implementation Center, or EPI-Center, were quickly implemented in order to help coordinate a response and to "maintain and monitor the new field equipment". (12) However, the EPI-Center would not be ready until April 1994, so it would really only have utility during the recovery stages of this disaster.

The Los Angeles TMC was nevertheless used to its maximum capacity in the response to the Northridge earthquake to improve mobility, with ITS technology based from the center. The ITS technology that was available at the time and operated out of the TMC included some

VMS signs, some CCTV camera installations, on-ramp metering, and loop detectors. Most major freeways in the Los Angeles district had these technologies. The TMC also provided a lot of transportation related information such as information on closures, detours, and reconstruction activities to public officials, the media, and other agencies. Of note, during the relief phase, any unresolved power problems would have caused problems with using all of these technologies. (12)

Besides VMS signs, there had to be a way to disseminate transportation information to the public. At the time, internet was still a fairly novel luxury. As a result, in 1994, Los Angeles' media played a big role in information dissemination regarding the state of the transportation system in the L.A. area. They showed images of damaged freeways and passed on messages about detour information or urging civilians to avoid travel at all, if possible. Information was disseminated using newspapers, radio, and television. Information included was bus and rail routes schedules, carpool partner information, vanpool information, and information about park-and-ride lots as well as telecommuting centers. In addition, 1-800-COMMUTE was set up to provide information over the phone. (12)

Since the 1984 Los Angeles Summer Olympics, the city of Los Angeles had a world-class Automated Traffic Surveillance and Control System (ATSAC). The ATSAC "monitors traffic at intersections within Los Angeles City Limits, adjusts signal timing in response to real-time traffic flows, and is responsible for managing the 'Smart Corridor' to divert freeway traffic onto parallel streets." (12) ATSAC used HAR and VMS to detour traffic from I-10 to designated detours.

RECOVERY PHASE

2.3.1.3.4 Support of new (or original) transportation movements

FUNCTION BACKGROUND: This function involved the support of new transportation movement patterns, if they result from the recovery/rebuilding process, which took about 10 months to complete. Lingering problems from the relief phase continued during the recovery phase, although to a lesser extent. As the transportation network was rebuilt to its normal state, the need for transportation information became less imminent. (Of course, transportation information is useful for day-to-day travel as well, but the need for information here refers to its utility as a result of the earthquake damage.) Transit continued to be more heavily used during the recovery stages of the disaster.

TECHNOLOGY: The technologies available were similar to those available for transportation operations during the relief phase. Although power issues should have been resolved by the recovery phase of the Northridge disaster, the inherent limitations of the technology support systems available (e.g. sparse availability) would still result in long-term mobility issues. ITS technologies and capabilities were sub-par to what would be needed to keep travelers informed enough to make intelligent commuting decisions.

2.3.1.4 Northridge Case Summary

EMERGENCY PHASE

Sensing and Assessment

Immediately after the Northridge earthquake occurred, various assessments of the earthquake's characteristics had to be gathered. This was performed successfully with the systems that were available. At the same time, the earthquake caused damage to most of the critical infrastructure in the area, including the power system, communications system, electrical system, transportation system, and entire residential communities. It was important to be able to sense and assess these critical infrastructures, but this proved problematic with the tools available at the time. Another problem was locating and tracking victims of the earthquake. Similarly, keeping track of deployed responders was a problem.

Communication and Coordination

Immediately after the earthquake, many injuries occurred that required immediate assistance. Coordination was required to deploy medical responders in the most logical manner and to also administer care, once at the scene, in an organized and coordinated way. In order to make responder efforts most efficient, agency commanders would need to communicate to them such information as their dispatch orders, victim locations and status, hospital status, and road network conditions. Finally, there was an immediate need during the emergency phase for victims to communicate their needs with response agencies. All of these emergency functions proved problematic during the Northridge emergency phase.

Transportation Operations

Immediately after the earthquake, travel on the transportation network was difficult for both responders and civilians. Not only were they faced with traveling on a severely damaged transportation network, but they also had to do so with very limited real-time information about the status of the network. Particularly civilians would have no way to gather this information. Responders could hope that their agency command centers could provide them with some information over radio about the damage. However, even if some information was available, it would very likely not be of sufficient detail.

RELIEF PHASE

Sensing and Assessment

Relief activities such as shelter provision and setting up of transportation detours were necessary. Some tools were available to assist with tracking these activities, but they appear to have been quite limited. Similarly, tracking of relief resource flow to those that lost their homes and for other purposes was also necessary. Some technology tools were available, but they were, once again, quite limited by their capabilities and availability.

Communication and Coordination

During the relief phase, hundreds of different organizations became involved in the response efforts. Coordinating the activity of all of these to operate the most efficient and effective response was a challenge. Communication between agencies command centers was available during this phase, but communication with in-the-field personnel was still difficult.

Transportation Operations

Detours had to be established in the relief phase of the Northridge response. Managing these detours was important, but unfortunately, the available technology support capabilities were quite minimal at the time. Additionally, new transit services were provided during the relief phase. Lack of real-time traffic and transit information would continue to plague the efficiency of travel.

RECOVERY PHASE

Sensing and Assessment

During the recovery phase, critical infrastructure rebuilding took place. Tracking this activity was important for situational awareness of the recovery proceedings. Available tools worked reasonably well to track this progress.

Communication and Coordination

Communications between agencies to coordinate rebuilding of critical infrastructure was necessary. By the recovery phase, inter-agency communication was not a serious problem since standard means of communication such as phone communications were once again available.

Transportation Operations

Similarly to the relief phase transportation situation, detours and new transit services would continue to create a dynamic transportation environment for the Los Angeles area during the recovery phase. As reconstruction efforts were completed, traffic patterns would be able to return to normal operations and the need for transit services would subside. Nevertheless, the lack for real-time transportation information continued to hinder mobility during this phase.

2.3.2 "9/11" Case Analysis

In the morning of September 11, 2001, several terrorist attacks occurred on United States' soil. The infamous attacks involved successful attacks on New York City's World Trade Center (WTC) and the Pentagon in the Washington DC area as hijacked commercial jets were intentionally crashed into those buildings. The particularly devastating attack proved to be the one on the WTC. Both WTC towers were hit by different hijacked jets and shortly after the crashes occurred, both towers collapsed. Before the collapse, there were thousands of victims in the towers that needed to be rescued. Some of them were indeed rescued or able to evacuate the buildings themselves, but others did not make it out of the towers before the collapse. When the towers collapsed, in addition to causing a great number of civilian casualties, many responder casualties resulted as well.

Also, as a result of the attacks, aside from the WTC towers themselves, other critical infrastructure was adversely affected. For example, debilitating telecommunication failures ensued, important public administration headquarters were destroyed, and the transportation system was impaired for an extended period of time following the attacks. The damage to critical infrastructure created various problems for New York City in both the short and long term.

We next discuss more specifically the 9/11 disaster response, based on the framework presented in the beginning of this chapter.

2.3.2.1 Sensing and Assessment

EMERGENCY PHASE

2.3.2.1.1 Disaster sensing and assessment

FUNCTION BACKGROUND: This function involved assessment of the nature and status of the attacks on the WTC. An example of needed information included: who was flying the planes that crashed into the WTC and if there were other imminent threats. The reason this was important was because there was about a twenty minute time gap between the North tower crash and the South tower crash. During those twenty minutes, the Federal Aviation Administration (FAA) was aware of several planes that were in the air that had deviated from their planned route and were unresponsive to repeated attempts to communicate with them. (33) It is feasible that if the right information was pieced together during those twenty minutes, it could have been determined that the other WTC tower was at risk as well. If emergency responders at the WTC scene knew what the FAA knew, it is quite likely that they could have determined that they should immediately evacuate the South tower, instead of being somewhat indecisive.

TECHNOLOGY: No special technology was available for this function. Disaster assessment problems during the 9/11 attacks were mostly related to problems with communication and coordination between various agencies, both on the federal and local (New York City) level. More information about communication and coordination systems available will be provided in the section relevant to that subject.

2.3.2.1.2 Critical infrastructure sensing and assessment

FUNCTION BACKGROUND: This function involved sensing and assessment of critical infrastructure. Critical infrastructure for the 9/11 attacks included the energy system, information technology system (e.g. internet), telecommunications systems, transportation system, and key public administration facilities.

In the morning of September 11, New York City suffered debilitating communications systems failures. The US DOT (34) reported that 200,000 phone lines in Lower Manhattan were crippled and telephone and cellular service is overloaded when the Verizon hub at WTC damaged.

Additionally, structural damage occurred around the WTC complex. When the WTC towers collapsed, important facilities such as the Port Authority headquarters were destroyed in the collapse. Other important facilities were lost as well, since the WTC served as a "major inter-modal transportation hub for Lower Manhattan". (34) At the same time, damage was incurred to the subway stations that were below the WTC buildings.

Moreover, much of the transportation system was closed to the general public following the attacks. Although the closures resulted from decisions of authorities, it was important to keep a comprehensive record of the various parts of the transportation system.

TECHNOLOGY: Again, no special technology was available for this function. To gather information about the conditions at the WTC, New York Police Department (NYPD) helicopters were dispatched five minutes after the first tower (North tower) was hit. Fire

Department of New York (FDNY) boats on the Hudson River were also able to observe and report some status information such as the collapse of the South tower. These reports were apparently communicated via radio communications. (35)

To gather information about the transportation system, TRANSCOM was a key player. Its role will be discussed further in the transportation operations section.

2.3.2.1.3 Victim location / tracking

FUNCTION BACKGROUND: This function involved determining the locations and status of victims in the towers and the proximity. Hundreds of civilians were trapped on the floors above the zone of impact immediately after the attack on the North Tower. The same was true for the South tower, although it appears that there was no passable stairwell from above the impact zone in the South tower. Locating where these trapped civilians were was a challenge.

TECHNOLOGY: In order to locate victims, responders would have had to rely on information from 9-1-1 calls centers, which would be directly communicating with the victims. However, due to communications problems between the victims and 9-1-1 and then the problems with data sharing between 9-1-1 and the emergency response teams at the WTC, gathering victim location and status information appears to have been difficult. (35)

2.3.2.1.4 Responder / emergency response activity tracking

FUNCTION BACKGROUND: This function involved determining the locations of responders and their status and tracking their location and status throughout the emergency response process. It was not typically known how many officers were at the scene and where they were at a given time. (35)

TECHNOLOGY: Some efforts were made to keep track of responders. Responders had radios that would theoretically allow them report their location and status. However, this information would be reported only to their own agency. Additionally, radios experienced operational difficulties that prevented communication at times. Another tool that was used to attempt to track responders was FDNY's Field Communications van, or "Field Comm". Field

Comm attempted to track all units operating at the scene on a large magnetic board, but this did not work well. More details will be provided regarding this in the communication and coordination section. (35)

RELIEF PHASE

2.3.2.1.5 Relief activity tracking

FUNCTION BACKGROUND: This function involved tracking the relief activities of the various agencies involved in the relief effort. It is difficult to determine what exactly entailed the "relief" phase of 9/11. For our purposes, the only aspect that we would characterize as being in the relief phase was the temporary transportation situations in New York City following the 9/11 attacks.

TECHNOLOGY: No specific technology was available for this function. Some related technologies will be found in the transportation operations section.

2.3.2.1.6 Resource tracking

FUNCTION BACKGROUND: This function involved tracking of relief resources such as goods and supplies that were being distributed. This was not an issue for 9/11, since no victims were stranded without goods and supplies during the relief phase.

TECHNOLOGY: Not applicable.

RECOVERY PHASE

2.3.2.1.7 Recovery activity tracking

FUNCTION BACKGROUND: This function involved tracking the recovery activities of the various agencies involved in the recovery effort. Primary efforts included rebuilding around the WTC site. Rebuilding would include the above ground reconstruction (which is still ongoing as of June 2006), other rebuilding of infrastructure such as subway reconstruction and clean-up, and re-establishment of lost telecommunication and other utilities in the area.

Moreover, re-establishment of public administration centers such as the lost Port Authority headquarters is also part of the recovery process.

TECHNOLOGY: This function depends on communication and coordination between agencies responsible for recovery. Regular tools, such as phone, internet, and face-to-face meetings could be used to track recovery activities.

2.3.2.2 Communications and Coordination

EMERGENCY PHASE

2.3.2.2.1 Communication and coordination between response agencies for emergency operations

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies to implement the most effective emergency response possible. During the course of the events of 9/11, there was continuing confusion on the part of responders and effected civilians in regards to what exactly had occurred, what to expect, and what exactly was the state of events at the WTC. According to the 9/11 Commission report (35), there were several instances that indicated that key decision-makers did not know the basics facts of what had occurred in a timely manner.

For example, while the deputy fire chief director of the WTC's North Tower was immediately aware of the occurrence of a major incident after the attack on that tower, he was apparently unaware that a commercial jet had crashed into the North Tower even 10 minutes after this impact. (35)

As a result of general lack of awareness and difficulty in agreeing on and communicating an evacuation order for civilians and responders, various mixed messages regarding the evacuation of the towers resulted. In one case, it was noted by the 9/11 Commission (35), that some civilians who had actually descended the South Tower between the time when the North tower was hit and the South tower was hit were actually told that they can go back to their workspace. In addition, when civilians called 9-1-1 throughout the emergency, they were typically instructed to stay in place and either wait for further instructions or wait to be rescued. However, it appears that, in fact, while making such recommendation, 9-1-1 was not aware that an evacuation order was in place for the towers.

Transportation network related information also needed to be shared with relevant agencies so that their responders could try to make intelligent decisions about their travel.

TECHNOLOGY: One important communications element of the response community was FDNY's Field Comm. Field Comm was intended for two main functions:

- Relay information between the on-site overall command post and FDNY's dispatch
- Track all units operating at the scene on a large magnetic board

Field Comm experienced problems with its first intended function as it had communication difficulties in conveying news to chiefs at command posts. Field Comm also had difficulties with its second intended function since many responders simply did not report to Field Comm. Instead, they reported to other command posts. Field Comm attempted to listen to radio conversation, but the line to which they were listening was often so congested that conversations overlapped each other, making them indecipherable.

For transportation related inter-agency information sharing:

- NYC's 13 TMCs were linked via TRANSCOM's (see below) Interagency Remote Video Network (IRVN) and able to share data and video among each other. Hundreds of CCTV video links from around the New York metropolitan area were integrated.
- The TMCs served as important command centers for state DOT personnel, NYC DOT, NYPD, and NY State Police and sources of information dissemination via the ITS systems available. Information dissemination via these means proved valuable on September 11. (34)

TRANSCOM, or the Transportation Operations Coordinating Committee, is a coalition of transportation and public safety agencies in the New York metropolitan area whose purpose it is to coordinate regional transportation system management. During the 9/11 response, TRANSCOM first proved to be effective in communicating response decisions between its member agencies. Other agencies and organizations such as media outlets and private transportation firms and associations soon also realized that the information that

TRANSCOM was offering was important, so soon, TRANSCOM was communicating this information with over 400 organizations. (34)

Additionally, in order to communicate activity information to OEM and TRANSCOM, some transportation agencies such as NYC Transit and NJ Transit had "mobile" communications centers, which were essentially buses outfitted with satellite and computer technology that could relay information from the field to OEM and TRANSCOM. (34)

2.3.2.2.2 Communication and coordination between response agencies and emergency responders

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies and their emergency responders that were in the field. There was evidence that responders lacked situational awareness as a result of bad communications and coordination. For example:

- After the second plane hit the South Tower, FDNY chiefs met in order to discuss operations strategy. They agreed that communications capability with responders was a concern. This is a testament to the lack of communications during the response. (35)
- At 9:30 AM, the PAPD tried to regroup and create a makeshift response plan (which they didn't have sufficiently pre-planned for a disaster of this scale). Their planning was hampered, however, by the fact that they did not know how many officers were at the scene and where they were at the time due to lack of intra-agency communications capabilities. (35)
- At 9:37, a civilian on the 106th floor of the South Tower conveyed to 9-1-1 that a "91-something floor" was collapsing. This message was not relayed to the responders until 15 minutes later and in fact was not passed accurately. Overall, it appears that the potential for collapse was not well communicated among the response community. (35)

TECHNOLOGY: On September 11, Lower Manhattan suffered debilitating damage to its phone and cellular network. While first responders would use phone lines and cellular phones for communications if available, they also had their own communications systems, which were typically based on radio. As a result of the damaged phone lines and overload on the cellular communications network, immediate communications with field personnel via those means was difficult. Thus, they were faced with mostly relying on radio for communications. (34)

In general, two-way radios appeared to have been the most common way for communication with disaster response field staff. Those field staff without radios were generally out of touch. Additionally, technologies such as e-mail, Nextel phones with direct connect feature and blackberry phones (Personal Digital Assistants, or "PDAs", with cellular wireless email capability) were key for internal agency communication, but not universally available at the WTC site. (34)

For radio communication at the WTC scene, both interoperability and operability of radio communication proved troublesome. First of all, radio communications was for the most part not designed for inter-agency communication. In some cases, as was the case for Port Authority Police Department (PAPD), officers from around NYC lacked interoperable frequencies to communicate with each other, so even *intra*-agency communications was lacking. Moreover, as responders would experience, radio did not work during particular conditions. The first condition is when lots of transmissions are attempted at the same time. The other condition is when their use is attempted in high rises, such as the WTC towers. To illustrate a consequence of this, at 10:00 AM, for example, one minute after the collapse of the South Tower, several operations chiefs at WTC issued an evacuation order for responders. Many, however, did not receive order due to difficulties with radio communications in high rises as tall as WTC and an overload on radio bandwidth. In addition, we should mention that some responders did not react to the order immediately or apparently did not plan to do so at all. (35)

Finally, we mention again FDNY's Field Comm, which was involved with relaying information from the WTC to FDNY's dispatch center. It appears that this particular function was performed successfully. However, features intended for on-site coordination did not work well, as previously mentioned. (35)

2.3.2.2.3 Communication and coordination between emergency responders

FUNCTION BACKGROUND: This function involved communication and coordination between emergency responders, even if they were from different agencies. Assisting the victims at the WTC site and providing medical care required communication and coordination between responders.

Five minutes after the attack on the North Tower, the first arriving FDNY personnel encountered some badly burned civilians in the ground-level lobby. These people needed immediate treatment. At 9:35, the South Tower lobby was becoming overwhelmed with injured people who had descended the tower. Effective triaging of these civilians and timely provision of medical care for these people appeared to have been a challenge. (35)

While these victims were obvious to locate, there were also victims in need of assistance at various locations in the towers. Communicating these locations and victims' needs among the responders would have been important in order to direct assistance activity where it was needed most.

TECHNOLOGY: Again, in general, two-way radios appeared to have been the most common way for communication with disaster response field staff. Radios, though, as we mentioned, experienced various kinds of inter-operational and operational difficulties. Technologies such as Nextel phones with direct connect feature and blackberry phones were key for internal agency communication but not available to all responders. (34)

2.3.2.2.4 Communication and coordination between victims/general public and response agencies

FUNCTION BACKGROUND: This function involved communication and coordination between victims/general public and response agencies. The communication was necessary for response agencies to locate the victims / members of the general public that needed assistance and so that victims could get critical information about the disaster.

Survivors in the towers lacked situational awareness. First of all, there was confusion about whether to evacuate, how to best do that, and what the status of the towers was. In search of information and help, survivors in the building attempted to contact 9-1-1, but 9-1-1, as a result of problems with communication with other agencies, did not have adequate information to provide the survivors. (35)

Information about transportation options and evacuation modes available also needed to be available to the public. Various special services were available such as additional bus and ferry services, but evacuees needed information about these services. Many New Yorkers took hours longer than usual to get home on September 11, 2001. Some commutes could have been shortened with better information. (34)

TECHNOLOGY: Standard and cellular communications difficulties made communication between victims / general public and response agencies very challenging. It appears that some calls went through from victims in the towers to 9-1-1, although 9-1-1 was not very helpful with providing useful information to those victims. Additionally, no special technology was present to assist Manhattan evacuees with decision making regarding their transportation options.

RELIEF PHASE

2.3.2.2.5 Communication and coordination between response agencies to coordinate relief

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies to implement the most effective relief effort possible. Relief activities that were the primary focus for our analysis were related to transportation network relief efforts.

TECHNOLOGY: During this phase, normal communication means such as telephone and cellular phones could be used. Additionally, organizations such as TRANSCOM were instrumental in sharing information about the transportation network.

2.3.2.2.6 Communication and coordination between response agencies and responders during relief

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies and their responders that were in the field. Primarily, once again, the responders would include those that were involved in transportation related relief efforts.

TECHNOLOGY: Again, by this time, telephone networks resumed operation. Additionally, radio could be used.

RECOVERY PHASE

2.3.2.2.7 Communication and coordination between all relevant agencies to coordinate recovery

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies to implement the most effective recovery effort possible. The main focus of recovery for our analysis was for the rebuilding activity around the WTC, including clean up of debris and restoration of critical infrastructure in the area, such as the power, communication, and transportation systems.

TECHNOLOGY: As during the "relief" phase, normal communication means such as telephone and cellular phones could be used during the recovery phase to share information between agencies.

2.3.2.3 Transportation Operations

EMERGENCY PHASE

2.3.2.3.1 Mobility/evacuation of victims/general public

FUNCTION BACKGROUND: This function involved providing maximum mobility and evacuation efficiency to the general public in evacuating Lower Manhattan and staying mobile, when necessary, during the emergency phase of 9/11.

One result of the attacks related to mobility in Manhattan was that there was a mass evacuation of civilians from lower Manhattan. At about 11 AM on September 11, Mayor Giuliani issued a statement to the public to clear out all areas south of Canal Street. Tens of thousands abandoned their cars and transit in order to walk across bridges out of Manhattan. Many were reported to have evacuated by water ferry as well. Outside of Manhattan, long traffic jams were experienced as police began to shut down traffic links. Overall, the evacuation of Lower Manhattan was described by US DOT as happening "almost as if it were rehearsed." Still, as we mentioned, many commuters took hours longer than usual to get back home on September 11. At the WTC site itself, "control problems" were experienced as a result of "the intersection of hundreds of people arriving and thousands fleeing." (34)

Another consequence of the attacks was that there was a widespread shutdown of transportation facilities in and around the city, as well as on a nationwide scale. Initially, the following key closures occurred:

- Port Authority for New York and New Jersey (PANYNJ) closed all their bridges and tunnels eastbound.
- FAA ordered all NYC closed.
- FAA halted all US flights.
- NYC suspended all transit service.
- New Jersey Transit stopped rail service into Manhattan's Penn Station.
- Port Authority Trans-Hudson (PATH) operations were suspended.
- Amtrak canceled nationwide operations.

- Greyhound cancelled Northeastern US operations.
- NYC Police order highways to shut down.
- Water port shut down by Port Authority. (34)

The transportation closures in New York City would obviously affect the public's mobility. Most importantly, it was important for the public to be aware of these transportation conditions, so that they could make the most informed travel decisions.

TECHNOLOGY: HAR and VMS were used on highways inbound to New York to alert travelers to avoid New York. VMS were also used in the city to communicate major infrastructure closures such as the closing of George Washington Bridge. Other major transportation links such as the Holland and Lincoln tunnels were not equipped with VMS and thus travelers did not get this type of information at those locations.

TRANSCOM was instrumental in sharing transportation related information between hundreds of relevant agencies. In fact, NYC's 13 TMCs are linked via TRANSCOM's IRVN and are able to share data and video among each other. Hundreds of CCTV video links from around the New York metropolitan area were integrated and used following 9/11.The TMCs served as important command centers for state DOT personnel, NYC DOT, NYPD, and NY State Police and sources of information dissemination via the ITS systems available. Information dissemination via these means proved valuable on September 11.

In order to disseminate transportation related information to the public, the internet played a large role. Website such as www.metrocommute.com, which provides traffic information and CCTV images from IRVN-accessible cameras, were utilized by travelers. NYC Transit also used its website to communicate with its patrons. Radio, TV, and newspapers provided information to the public as well. (34)

2.3.2.3.2 Mobility of emergency responders

FUNCTION BACKGROUND: This function involved providing maximum mobility to emergency responders. Mobility included transport of responders to the WTC and from the WTC to area hospitals to transport the injured.

While much of the road network was shut down for general public access, it was in fact closed so that responders had a clear path to get to and from the WTC. Responder mobility did not appear to be problem for the 9/11 response. However, clearing some streets would have taken time, so information regarding traffic backup would have been important for the responders to have.

TECHNOLOGY: In order to receive any necessary travel related information, responders had to rely on their radios and cellular phones (when signal was available) to contact their agency dispatcher for traffic information. The information was, of course, not guaranteed to be known by their dispatcher.

RELIEF PHASE

2.3.2.3.3 Support of temporary transportation movements

This function involved the support of temporary transportation movement patterns while the recovery phase was still being awaited.

After the initial closures of much of the transportation systems in New York, within several days after September 11, much of the transportation network was open again for operation. The main exception was Lower Manhattan, which would remain closed to civilian vehicles for about a month. Also, in the afternoon of September 11, partial NYC transit service resumed operation. However, service near the WTC would be disrupted for an extensive period of time. In addition, on September 27, 2001, NYC began a morning hours ban on Single-Occupancy Vehicles (SOVs) entering Manhattan.

As a result of the longer term service disruptions, commuting patterns changed in New York City following the 9/11 attacks. For the first 13 days after the attack, Manhattan workers worked from home if they could. However, on Monday, September 24, commuters were expected to fully return to work in Manhattan. They were encouraged by the New York City Department of Transportation (NYCDOT) to use mass transit such as ferries and subway as well as bikes.

Travel behavior did indeed change as NJ Transit reported November 4, 2001 that they had seen a 44% increase in ridership since 9/11. Public and private ferry operators indicated on December 21, 2001 that their daily ridership figures jumped from 30,000 to 65,000 per day.

At the same time, there were other reasons for huge shifts in commuting patterns to Midtown. Companies were relocating offices from Lower Manhattan to other locations as they attempted to resume normal company operations.

Mobility problems also effected delivery distribution and trucking in the New York City area. For example, initially, two days of bridge, tunnel, and road blockages into Manhattan lead to widespread disruption of commercial deliveries, including FedEx and USPS.

In the longer-term, mobility problems continued as the city stayed on alert and commuter experience altered traffic patterns. For example, US DOT requested that "shippers and transporters of hazardous materials to consider altering routes to avoid populated areas whenever possible." However, in order to be able to do so, trucking firms would need to have a good method of navigating these alternate routes. (34)

TECHNOLOGY: As transportation facilities closed, opened, and made alterations to their usual operations, keeping track of all of these development would be difficult for commuters and shippers / suppliers. There were some developments that occurred shortly after 9/11 that seem to indicate the realization for that strong need for real-time information. Two important examples of new real-time travel information services that started were:

- On September 14, 2001, NY Taxi and Limousine Commission (TLC) established 24-hour hotline that addressed members' need for real-time information on transportation access information. This is one clear testament to the need for better route information during such situations for taxis.
- On September 30, 2001, General Motors' OnStar service adds real-time traffic reports in a dozen cities, including New York. This is another testament to the need for real-time transportation information during such situations.

Traffic sensors were used to measure traffic conditions. One important purpose of this was to decide when the SOV time restrictions in Manhattan would be set.

At the same time, many of the same technologies as were utilized during the emergency response phase for mobility of the general public were used here again. This included VMS, HAR, websites for information dissemination, CCTV stream sharing, radio, and TV. Newspapers were also used to disseminate travel information. Moreover, the Port Authority set up a 24-hour customer service / information phone line that handled a tremendous amount of calls. (34)

RECOVERY PHASE

2.3.2.3.4 Support of new (or original) transportation movements

FUNCTION BACKGROUND: This function involved the support of original transportation movement patterns, as they once again became available. As the transportation system, particularly in Lower Manhattan, was returned to normal, original transportation movement patterns could resume. Primary, this meant the re-establishment of the WTC area subway stations with their original functionality and resuming of normal traffic flow in Lower Manhattan with the end of the SOV ban.

TECHNOLOGY: The technologies available to support transportation operations for this phase would be the same as the technologies that was available during the relief phase.

2.3.2.4 "9/11" Case Summary

EMERGENCY PHASE

Sensing and Assessment

Immediately after the attacks on the WTC (particularly on the North tower), there was a need to assess what exactly had occurred and the details of the events. Critical infrastructures, including the power grid, telecommunications, transit, and the towers themselves, were adversely affected during the emergency phase. Additionally, there were trapped victims in the towers that needed assistance. Tracking the locations and status of these victims was important for the response efforts. Responders also needed to be tracked. However, tracking technologies were either not existent or did not work well for these purposes.

Communication and Coordination

There were substantial problems with situational awareness for all involved parties in the immediate aftermath of the 9/11 attacks. Some agencies lacked knowledge of what exactly had occurred at the WTC and all agencies lacked knowledge regarding the activities of other agencies. Agencies also had no sufficient means to communicate with their deployed responders. Responders, in turn, did not have situational information, either, and additionally were not able to communicate with responders from other agencies due to both operational and interoperability challenges. As a result, coordinating search and rescue and medical care proved difficult. The victims in the towers primarily interacted with 9-1-1 during their effort to get help. Due to telecommunications breakdowns, however, this communication was hindered. Even when assistance pleas were able to get through, however, 9-1-1 had difficulty communicating them accurately to deployed agencies and responders at the WTC.

Transportation Operations

Following the 9/11 attacks, much of the transportation network around New York City was closed for civilian use. Additionally, the general public was expected to evacuate Lower Manhattan. In order to make the commute back home, however, real-time information was needed. Some ITS tools were available to provide such information. However, they were quite minimal and not personalized. Road closures did not necessarily affect responders. In fact, the closures were often done in order to clear a path for responder vehicles. Thus, since general travel rules did not apply to them during the emergency phase, to get real-time travel information, responders had to rely on their radios to ask which roads they should use to get to the WTC site. Their agency dispatcher would, however, not necessarily have the information that they need, making their travel less efficient than it would be otherwise.

RELIEF PHASE

Sensing and Assessment

Tracking relief activities that, for our purposes, primarily included temporary transportation solutions was important. TRANSCOM, the central transportation agency in New York City, helped a great deal in gathering transportation related information.

Communication and Coordination

One again, the primary relief activity that we investigated was transportation relief. As mentioned, TRANSCOM was an important player in disseminating the necessary transportation network information to all necessary organizations.

Transportation Operations

By the time of the relief phase of the 9/11 response, much of the transportation infrastructure was reopened in New York. The main exception was Lower Manhattan, which would remain closed to civilian traffic for about a month. In the meantime, as companies temporarily moved business out of Lower Manhattan, traffic patterns shifted. Additionally, transit ridership increased substantially. During this particularly dynamic state of travel in New York City, it was clear that there was a demand for real-time travel information. Some technologies and services were available for this purpose. Many of these helped, but information was still often quite generic and not necessarily suited for personal needs.

RECOVERY PHASE

Sensing and Assessment

Recovery efforts that needed to be tracked primarily included rebuilding around the WTC site. Tracking this progress could be done via normal means of communication such phone, internet, and face-to-face meetings.

Communication and Coordination

To communicate recovery activities, standard means of communication just mentioned could be used.

Transportation Operations

During the recovery phase, as during the relief phase, the transportation system continued to be dynamic, although less and less so. Nevertheless, the need for real-time travel information would continue as the city awaited normal traffic flow to be allowed again in Lower Manhattan and the WTC area subway stations to be re-instated.

2.3.3 Katrina Case Analysis

In contrast to Northridge and 9/11, the Katrina disaster is a case where there was warning that a major disaster will likely strike the area that was affected. In the morning of August 29, 2005, a Category 4 hurricane with speeds of 145 m.p.h. made landfall on the United States Gulf Coast. The largest city to be effected was New Orleans. By the time landfall occurred, many of New Orleans' citizens had already evacuated, since stern warnings were given for several days prior to August 29 that this could be a particularly devastating hurricane. Nevertheless, when the hurricane made landfall, tens of thousands of civilians remained in the city. Massive search and rescue efforts were needed to assist many of the remaining civilians after the hurricane's landfall.

The situation became dire when the New Orleans levy system failed and began letting water into the city's low-lying areas. This failure caused 80% of New Orleans to be flooded. (37) Various other critical infrastructures were also damaged, including the telecommunications system, power system, as well as roads and bridges. Recovery from this disaster is still ongoing as the city continues to be rebuilt.

We next discuss more specifically the Katrina disaster response, based on the framework presented in the beginning of this chapter.

2.3.3.1 Sensing and Assessment

EMERGENCY PHASE

2.3.3.1.1 Disaster sensing and assessment

FUNCTION BACKGROUND: This function involved information gathering about the Katrina hurricane and prediction its path and characteristics by landfall.

TECHNOLOGY: Advanced systems exist today to predict with reasonable certainty a hurricane's path and characteristics. Such systems were successfully used in the case of Katrina, and allowed for the issuance of strong warnings regarding a hurricane of "unprecedented strength" in the days and hours before the hurricane's landfall.

2.3.3.1.2 Critical infrastructure sensing and assessment

FUNCTION BACKGROUND: This function involved sensing and assessment of critical infrastructure. For Katrina, in addition to the typically mentioned critical infrastructure, the New Orleans levy system was an additional infrastructure of interest.

The "disaster" for Hurricane Katrina appears to have had to do much more so with the resulting flooding than the hurricane itself. The massive flooding of New Orleans occurred because the levees, which keep the below sea-level city dry, were breached when Katrina made landfall. News of flooding came to authorities from various sources through phone calls. Detailed status of the levy system could not be immediately ascertained. By mid-day on August 29, the day the hurricane made landfall, authorities realized that there was widespread flooding in New Orleans, but concrete details were still lacking. It was only by the morning of August 30 when the U.S. Army Corp of Engineers (USACE) were able to survey New Orleans and visually inspect the extent of the flooding.

TECHNOLOGY: Manual inspection had to be used to assess the status of the levy system and status of the flooding in New Orleans. Additionally, authorities did receive some information about flooding through phone calls. (39)

2.3.3.1.3 Victim location / tracking

FUNCTION BACKGROUND: This function involved determining the locations of victims and their status and tracking their location and status throughout the treatment and assistance processes.

The hurricane left the citizens that remained in New Orleans in dire conditions. Some were injured, and others were distressed with a lack of food, water, or medical care. Many civilians were endangered by the storm as water level rose and conditions worsened. The storm also caused deaths in the flooded areas.

The evacuation and medical care for people with "special needs" was problematic in the New Orleans. By "special needs", we mean those individuals that are not normally hospitalized but would need more than just a general population shelter to survive a storm. For example, these are people who need dialysis or are diabetics, and thus need special medical attention and equipment. It appears that there was some attempt made to assist such individual prior to the hurricane's landfall. In this effort, the Superdome was designated as the shelter for some of the "special needs" individuals and some were brought there the day before the storm. Others, however, who did not get to a shelter or another facility with medical care before the storm would face particularly dire conditions after the flooding ensued. By that time, finding these people would be difficult since New Orleans does not keep a list of its "special needs" population with details about their residence locations.

Coast Guard used aircraft, various water vessels, and thousands of personnel to support search and rescues missions, damage assessment, and logistical support. Initially, Coast Guard helicopters were sent out in the flooded area without specific orders regarding particular survivors that needed to be rescued. There were so many civilians that needed help that the helicopters would randomly perform rescues. Rescued civilians were brought to higher ground, or if they needed medical treatment, they were brought to the New Orleans Airport. Coast Guard also used boats to perform rescues. However, once the rescues commenced mid-day on September 29 (the day Katrina hit), communication by radio became difficult because of the large volume of conversation that was occurring. Boats had some limited communications with each other but did not generally have communications with airborne units. Although the rescue efforts of the Coast Guard were immense, organization and coordination with other agencies was lacking. First of all, when survivors were brought to higher, dry ground, they were initially dropped off in random locations and their names and conditions were not recorded and communicated to other agencies. As a result, many of these civilians were left stranded without food, water, shelter, and medical attention. Tracking these civilians would have made for a more efficient rescue process. Eventually, central drop-off points were designated at places such as the Superdome and the Airport, which alleviated this important initial problem.

As for those patients that did require medical assistance who arrived at the airport via truck, bus, ambulance, or helicopter, one key problem was that medical responders did not have access to patients' medical records. Since the patients themselves may have not known their own medical history and needs very well, this proved to be a problem when proper care needed to be applied. In fact, this was not just a problem at only the airport. Other medical personnel involved anywhere in the response process faced a similar lack of information. Moreover, these patients could have also already developed a new medical history during just the post-landfall events, and this recent history would also have been helpful for medical personnel to know. (39)

TECHNOLOGY: No special technology was available to track victims.

2.3.3.1.4 Responder / emergency response activity tracking

FUNCTION BACKGROUND: This function involved determining the locations of responders and their status and tracking their location and status throughout the emergency response process. The responders' agencies' overall activity tracking could be associated with responder tracking.

Overall, neither the Department of Defense (DOD), which got involved in the response effort to this nationally declared emergency, or the responding civilian personnel had the coordination, communication, or the sensing on the available to quickly assess the damage and track the situation. (39)

TECHNOLOGY: No technology specific to this function was available. See communication and coordination section for more information about technology availability to track responders during the Katrina response.

RELIEF PHASE

2.3.3.1.5 Relief activity tracking

FUNCTION BACKGROUND: This function involved tracking the relief activities of the various agencies involved in the relief effort. Relief activity tracking included such activities as continued medical care, evacuation of remaining citizens from the city, and food and water shipping. Most of these activities were tracked by direct communications between relevant agencies.

TECHNOLOGY: Again, no technology specific to this function was available. See the communication and coordination section for some relevant technologies.

2.3.3.1.6 Resource tracking

FUNCTION BACKGROUND: This function involved tracking of relief resources such as goods and supplies that were being distributed.

FEMA's logistics and supply chain system appeared to have been very ineffective during the Katrina response. Problems included that "response and relief personnel had little visibility into available federal assets and resources. The process for requesting assistance could not support the volume of requests, and the technology supporting the process proved inadequate." (39)

The local and state governments that requested supplies such as food, water, and ice often only got a portion of what they requested from FEMA. This led to widespread shortfalls of supplies. Moreover, it appeared that FEMA did not even have a good tracking system of the available supplies and where they needed to go. As a result, the distribution process was ineffectual. (39)

TECHNOLOGY: The process for requesting supplies from FEMA was not well designed, and the additional lapses in communications that occurred after the storm hit made the entire supply request process particularly problematic. The system in Louisiana, for example, was designed to work as follows: during disasters, local governments are supposed to request supplies via a software called E-Team. This E-Team request goes to the state, which then assesses whether they have enough state-owned supplies available to fill the request or if a nearby local government has available supplies. If not, then the state next turns to nearby state governments to request assistance with the supplies. Finally, if supplies are not available via these means, then the state can make a request to FEMA.

If FEMA agrees to meet the request, then the request is entered into FEMA's own system called National Emergency Management Information System or NEMIS. NEMIS helps to track the progress and completion status of the request. Of note is that FEMA may decide to task the request to another government agency or a private contractor.

During Katrina, loss of communications and power resulted in widespread difficulties with using the E-Team system. Local governments relied on radio or other available communications means to make the request. Typically, perhaps due to the chaotic situation, the requests were not logged on the E-Team system. Instead, they were just transferred over to FEMA without the process of first checking in the state's own supplies and with other local and state governments first to check for availability. In turn, FEMA also began to fulfill supply requests without logging them into their system and instead began filling requests on an ad-hoc basis. Once this occurred, neither FEMA nor the state or local governments had an overall picture of supply availability and request status. The whole process became extremely disorganized.

On top of this chaotic situation, even if everything had worked properly and had been planned well, there were inherent technological drawbacks to the supply chain process. One important drawback was that NEMIS was not integrated with E-Team. As a result, even if a supply request was logged in E-Team, the status of this request would not be visible by NEMIS. The reverse would also be true as the E-Team software would not be able to access request status information logged on NEMIS. It also appears that although FEMA's IT systems contained information about the location and quantity of supplies but keeping track of the expect shipments and their arrival times was not possible. FEMA is currently making some efforts to accomplish better interoperability with IT systems from other agencies, and better shipments tracking by using global-positioning technology, for example. (39)

RECOVERY PHASE

2.3.3.1.7 Recovery activity tracking

FUNCTION BACKGROUND This function involved tracking the recovery activities of the various agencies involved in the recovery effort. In fact, this activity is still ongoing in the New Orleans area. The city has still not been (and may never be) re-established as it once was.

TECHNOLOGY: Various information sharing tools are used to track recovery activities of the Katrina response. However, at this point, tracking of activities is mostly related to administrative process rather than immediate knowledge of all ongoing activities.

2.3.3.2 Communications and Coordination

EMERGENCY PHASE

2.3.3.2.1 Communication and coordination between response agencies for emergency operations

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies to implement the most effective emergency response possible. Widespread deployment confusion and uncertainty about mission assignments was experienced. Coordinating all of the medical personnel, supplies, and equipment in such a disaster response was a complicated endeavor. This endeavor was hampered by a lack of planning and understanding of the response process and the role that different organizations would take on. However, it was also made more difficult by the fact that situational awareness and communication were lacking. Hundreds of e-mails sent by medical first responders during the Katrina response help attest the fact that there was widespread confusion and frustration about deployment orders. Cross-agency activity visibility was also extremely lacking. Overall, there was an absence of information regarding which responders and resources were already deployed and which were available. In the end, this lack of planning and technological support resulted in an ineffective response process where response personnel and resources were often lacking where they were needed, and were also sometimes over-abundant at certain locations and in certain processes.

As an example of the consequences of emergency response confusion, the Coast Guard's lack of coordination with other involved agencies was described earlier. The Coast Guard was, of course, not the only agency doing search and rescue operations. For example, the National Guard also was involved in such missions. However, due to the lack of planned coordination and lack of communications capability, their efforts were not expended in the most efficient manner.

Federal troops and National Guard under state command are typically tasked in a major disasters, such as Katrina, to assist in the disaster response process. However, the Katrina response lacked coordination between the Department of Homeland Security, responsible for FEMA and disaster response, and the Department of Defense, responsible for the military. Emails in the aftermath of the hurricane from DOD to FEMA indicate confusion about what constitutes a formal request for assistance. At the same time, emails from FEMA to DOD indicated confusion about the levees, shelter status, and DOD's search and rescue activities.

Various divisions of the DOD contributed by taking on the challenges of the Katrina response in the following ways:

- The Army National Guard performed search and rescue missions, evacuations, commodity distribution, military transportation, clearance of debris from roads and residences, and assistance to law enforcement.
- The Air National Guard brought evacuation, rescue, airlift capabilities, and emergency medical teams which treated more than 13,000 patients by September 19.
- The Louisiana National Guard did search and rescue missions after the flooding ensued using both boats and helicopters to rescue stranded people from roofs and other floodwater locations, conducted roving patrols, manned checkpoints, supported law enforcement operations, provided security and other support at the Superdome.

- In addition to assisting law enforcement in maintaining law and order and controlling crowds during the evacuation of the Superdome and performing search and rescue operations, DOD also eventually took over FEMA's supply chain distribution operations. They became in charge of "planning and execution for the procurement, transportation and distribution of ice, water, food, fuel and medical supplies in support of the Katrina disaster in Louisiana and Mississippi." (39)

DOD, although perhaps more unexpected given their larger array of technology and resources, lacked situational awareness during the initial stages of the disaster response just as many of the other responding agencies. Overall, neither the DOD nor the responding civilian personnel had the coordination, communication, or the sensing on the available to quickly assess the damage and track the situation.

Another example of communication and coordination problems in the emergency phase of the Katrina response was related to area hospitals. As a result of poor planning and a debilitating storm, many hospitals and their patients faced extremely difficult conditions. Hospitals in the area lacked sufficient guidance in regards to what should be done when a hurricane is approaching the area. As a result of the difficulty of evacuating a hospital, without strong guidance, hospitals tended to not evacuate their patients. However, after Hurricane Katrina passed, many hospitals were subject to flooding and power outage. Clearly, this situation put many patients who remained in these hospitals in very difficult conditions as medical equipment that requires electricity became inoperable. Search and rescue teams were dispatched to hospitals to help evacuate, but some of these teams were intercepted by other victims of the hurricane trapped on roofs and in other flooded areas.

For hospitals, as was the case for others attempting to communicate in the wake of the Katrina disaster, the radio communications network that they typically rely on to communicate with Emergency Medical Services (EMS) and the rest of the disaster response community did not work since phone lines were lost and their radio communications network was lost as well. Cellular phones and satellites worked sporadically. Generally, however, hospitals were left isolated and struggled to provide critical care to patients while they waited to be rescued. (39)

TECHNOLOGY: In situations where all communications were lacking, there were actually instances when commanders in Louisiana and Mississippi had to send "runners" to communicate information. Failed, destroyed, or incompatible communications were a huge problem in the Katrina disaster response. Failed or destroyed communications examples include the following facts and figures: about 3 million customer telephone lines were knocked down, thirty eight 9-1-1 call centers went down, there was extensive damage to the wireless cellular network grid, and most of the radio stations in the New Orleans area were knocked of the air. Overall, it is estimated that 20 million telephone calls were dropped on September 29 in the entire effected area.

Since police lost their standard radio communications, they came to rely on two-way radios instead. The internet was available in some situations, such as for Mayor Nagin's headquarters. Satellite phones were also useful means of communications when cloud cover did not prevent their use.

In anticipation of communications problems, FEMA actually had command unit vans called Mobile Emergency Response Support (MERS) which they can deploy at any location to support communications and situational awareness for FEMA. However, these vans were not pre-positioned in the New Orleans area and by the time the storm hit and flooded the area, it became more difficult to deploy one of these units.

The National Communications System (NCS) is the primary government agency to support the communications function of the National Response Plan (NRP). NCS used Shared Resources High Frequency Radio Program (SHARES) and Amateur Radio Emergency Services (ARES) to provide a messaging system using volunteer operators. This system was used to assist in tracking first responders, coordinate communications between FEMA's Emergency Operations Center (EOC) along the Gulf Coast, relayed medical and welfare information between volunteer agencies, and also provided other important communications capabilities.

NCS also dispatched satellite communications vans to key locations at New Orleans City Hall, Louisiana State Police in Baton Rouge, and New Orleans Airport. They also deployed AT&T and MCI cellular communications vans to the state EOCs in Louisiana and Mississippi. Overall, NCS appeared to have been an essential facilitator of critical communication. Nevertheless, major gaps still exist in gathering and disseminating information during a disaster such as Katrina.

We know that the Hospital Emergency Area Radio (HEAR) was present with the objective of helping hospitals communicate with EMS. However, the system encountered problems, and hospitals were left isolated without communications. (39)

2.3.3.2.2 Communication and coordination between response agencies and emergency responders

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies and their emergency responders that were in the field. Since much of the infrastructure in New Orleans was destroyed as a result of the storm, the "agencies" in this case really would often be field commanders who are representing the agency. As a result, communication and coordination is closely related, in this case, to the communication and coordination between emergency responders. Thus, related function background information will be further explored in the function that deals with that type of communication and coordination.

TECHNOLOGY: Responders suffered from a lack of communications capability as cell phones and landlines were not working, blackberries were either unavailable or their service was spotty, and satellite phones were also not possessed by everyone and had service problems as well. Radios, when they worked, typically did not provide interoperability for responders from different organizations. As a result, responders could not communicate needs of victims and situational awareness could not be gained by the community as a whole.

Radio communications for the New Orleans fire and police departments had to use backup generators immediately after the hurricane hit but even these were quickly lost when the generators were rendered inoperable by the ensuing floods. Louisiana State Police also suffered widespread damage to their radio communications system.

Satellite phones proved once again to be quite effective tools of communications for those personnel that had them. Ideally, they can provide communication service virtually anywhere on earth, since they rely on satellite communications instead of land-based cellular towers, as do standard mobile phones. However, satellite service is expensive to maintain for many agencies and thus satellite phones were first of all not that common. Second, satellite phones actually do not work when the weather conditions are cloudy or when they are inside a building. Particularly the cloudiness in the post-landfall days of Katrina thus limited the effectiveness of satellite phones in many cases.

The NCS proved to be an effective relief of communications capabilities for the Katrina first responders. During the disaster, as with many disasters, both land and wireless phone lines that were not downed became congested. NCS' Government Emergency Telecommunications Service (GETS) provides emergency responders a priority usage of the lines and thus increases their call completion rate. The wireless counterpart to GETS is called the Wireless Priority Service (WPS), and this performs an analogous function, except for wireless phones by giving them priority treatment. During Katrina, 4,000 WPS enabled phones were distributed. Additionally, the NCS distributed satellite phones to first responders. (39)

2.3.3.2.3 Communication and coordination between emergency responders

FUNCTION BACKGROUND: This function involved communication and coordination between emergency responders, even if they are from different agencies. This would involve coordination of medical care to all victims of the storm.

Coast Guard used aircraft, various water vessels, and thousands of personnel to support search and rescues missions, damage assessment, and logistical support. Initially, Coast Guard helicopters were sent out in the flooded area without specific orders regarding particular survivors that needed to be rescued. There were so many civilians that needed help that the helicopters would randomly perform rescues. Rescued civilians were brought to higher ground, or if they needed medical treatment, they were brought to the New Orleans Airport. Coast Guard also used boats to perform rescues. However, once the rescues commenced mid-day on September 29 (the day Katrina made landfall), communication by radio became difficult because of the large volume of conversation that was occurring. Boats had some limited communications with each other but did not generally have communications with airborne units. Additionally, as was mentioned earlier, lack of coordination with other agencies led to stranded victims.

The Superdome was originally planned to shelter and have enough personnel and supplies to care for 1,000 individuals. These individuals would be "special needs" people. Instead, before the Superdome was finally evacuated days after the storm hit, there were 23,000 people at the location. Understandably, conditions at shelter such as this as well as other shelters in the city such as the Convention Center quickly became difficult, particularly after the roof of the stadium began to leak. Particularly, continuing to care for the "special needs" population there became more difficult. Another point of evacuee congregation that developed later in the response stage was the New Orleans International Airport. Medical patients that were being evacuated out of the city were brought there to be triaged and for the most ill individuals to then be airlifted out of the city. Medical care was also provided at the airport. Overall, 25,000 evacuees were processed during the evacuation of New Orleans. About 21,000 of them did not require medical attention and simply needed a temporary shelter and an eventual flight out of the city to designated shelters in other states. However, the number of individuals at the airport overwhelmed the resources available. There proved to be too little water, food, and sanitation at the airport to support such a large group. Thus, this too turned into a "dehumanizing environment". (39)

TECHNOLOGY: The situation was similar as for the other related communication and coordination functions during the emergency phase. Failed, destroyed, or incompatible communications were a huge problem for responder-to-responder communication and coordination.

2.3.3.2.4 Communication and coordination between victims/general public and response agencies

FUNCTION BACKGROUND: This function involved communication and coordination between victims/general public and response agencies. The communication was necessary for response agencies to locate the victims / general public that need assistance and so that victims could get critical information about the disaster. This was a serious problem during the emergency response phase when the search and rescue missions were ongoing. Also, this was a problem when victims were dropped off at random dry land locations around the New Orleans area without a way to communicate with response agencies.

TECHNOLOGY: Although some civilians may have had cell phones, the cell networks were not operational in the emergency phase of the Katrina response. Even if they were able to make calls, 9-1-1 centers were generally not operational.

RELIEF PHASE

2.3.3.2.5 Communication and coordination between response agencies to coordinate relief

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies to implement the most effective relief effort possible.

Information sharing was a challenge for responders. Particularly, this was found to be so for the military. First, they struggled to track the status of in-transit forces and the activities of already deployed forces. They also struggled to keep track of what non-military response activities were also. As an example, questions in a September 4 email from DOD included:

- "How many Meals Ready to Eat (MREs) have been made available by the DOD?
- What is the number of hospital beds on USN ships?
- What is the status of aerial surveillance capability?
- What is the status of the New Orleans Police Department (NOPD)?
- How linked up is the Guard with the NOPD?" (39)

In general, they needed to know what activities were ongoing, who was doing it, and what was the progress. Efforts were made to share information via the methods possible but overall, it is clear that communication and coordination was lacking for the military response. Agencies other than DOD agencies also experienced situational awareness problems. (39)

TECHNOLOGY: Technologies to communication and coordinate between agencies during the relief phase were lacking. Communications were still heavily impaired during the relief phase, as they had been during the emergency phase. Some relief communications were provided by FEMA and the NCS, as described earlier, but overall, it was clear that there were still serious problems. (39)

2.3.3.2.6 Communication and coordination between response agencies and responders during relief

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies and their responders that were in the field. Once again, this communication would be needed between field commanders (who were representing their agency) and responders. At the same time, during the relief phase, various agencies would also need to communicate from their command centers with their deployed responders to gather status information and provide orders and information back to the field.

TECHNOLOGY: As in the emergency response phase for communication and coordination between agencies and responders, similar technology capabilities was still significantly lacking for this function during the relief phase.

RECOVERY PHASE

2.3.3.2.7 Communication and coordination between all relevant agencies to coordinate recovery

FUNCTION BACKGROUND: This function involved communication and coordination between response agencies to implement the most efficient recovery effort possible. Recovery efforts in New Orleans are still ongoing.

TECHNOLOGY: Standard (non-emergency) means of communication and coordination can be used for this function. These means include internet, phone, and face-to-face meetings.

2.3.3.3 Transportation Operations

EMERGENCY PHASE

2.3.3.3.1 Mobility/evacuation of victims/general public

FUNCTION BACKGROUND: This function involved providing maximum mobility and evacuation efficiency during the emergency phase. Most of the public was able to evacuate before the landfall of Katrina. After the hurricane made landfall, 80% of New Orleans became flooded and other damage to the road and bridge network was incurred. (37)

TECHNOLOGY: Overall, it does not seem that technology played a large role in assisting with the pre-landfall evacuation. After the landfall of the hurricane, emergency mobility by personal means for the remaining population was not a major issue since most of the remaining population either didn't have cars or was in the flooded zone anyway, if they did.

2.3.3.3.2 Mobility of emergency responders

This function involved providing maximum mobility to emergency responders. Mobility includes transport of responders to scenes where their assistance is needed. Responders would have to have appropriate means (e.g. boats) to traverse flooded areas and would also need information about passable parts of the road and bridge network.

TECHNOLOGY: No special technology was used here. Responders would have to rely on their radios to try to get information about the state of the road network in New Orleans.

RELIEF PHASE

2.3.3.3.3 Support of temporary transportation movements

This function involved the support of temporary transportation movement patterns while the recovery phase is still being awaited. Since most of New Orleans' citizens had evacuated during the emergency phase and most of the road network was either flooded or damaged, there was not too much of a need for mobility, in the normal sense of the word, for the remaining citizens. The main issue for "temporary" mobility was simply to evacuate the remaining citizens from New Orleans.

At the time when the mandatory evacuation was finally issued, 70,000 people remained in city. The rest of the population had already evacuated by that time in a fairly successful procedure that involved clever traffic management such as counterflow capabilities on the highways. As for the 70,000 that were left, many were left because they chose not to evacuate and take a risk on the storm, but many also did not leave because they lacked their own means of transportation. The city of New Orleans had planned on using hundreds of city school buses to evacuate such citizens. However, due to the extensive flooding that occurred in New Orleans, with about 80% of the city under water, the location where these buses were parked also flooded, rendering them useless. Nevertheless, the city needed a way to assist those that were left in the city after the storm.

The plan was to use hundreds of DOT-chartered buses and Louisiana school buses from other parts of the state to evacuate these citizens. However, first an access route of the buses had to be determined, since much of city's roads were, of course, flooded. Eventually, about 1,100 buses were sent to New Orleans. Despite the resources and apparent availability of an access route, there were still difficulties in coordinate the pickup and transfer of the citizens, largely due to situational awareness problems such as no location and status visibility on the deployed buses by the DOT or officials in New Orleans. The buses proved to be not enough to evacuate all of the citizens. An airlift operation out of New Orleans International Airport was then implemented to fly 13,000 evacuees using 129 airplanes volunteered by various airlines such as Delta, JetBlue, and Spirit. (39)

TECHNOLOGY: No special technology was available to coordinate and expedite the evacuation of the stranded citizens.

RECOVERY PHASE

2.3.3.3.4 Support of new (or original) transportation movements

FUNCTION BACKGROUND: This function involved the support of new transportation movement patterns, if they result from the recovery/rebuilding process. As the flood waters were pushed back and damage to roads and bridges were repaired, transportation related information needed to flow to the citizens of New Orleans as they moved back into the area, whenever possible. Still, much of the city's housing remains destroyed, so transportation management is much less of an issue than simpler quality of life challenges.

TECHNOLOGY: No special ITS technology was available to aid mobility during the recovery phase of the Katrina response.

2.3.3.4 Katrina Case Summary

EMERGENCY PHASE

Sensing and Assessment

The first sensing and assessment objective was to gather information about the approaching hurricane Katrina and assess its path and characteristics. This function was performed flawlessly during the Katrina response. However, sensing and assessment of critical infrastructure, victims, and responders was in fact very problematic. First, to gather status information about the critical infrastructure such as levies and the transportation system, manual inspections generally had to be used. Victim location was problematic since all telecommunications that would be available to victims were destroyed. During the rescue process, which often involved handling of victims by multiple agencies, many victims were lost or temporarily forgotten as a result of the lack of tracking. Additionally, almost no tracking of responders was possible as a result of the telecommunication failures.

Communication and Coordination

The coordination of the emergency response to Katrina was problematic as a result of the lack of situational awareness and lack of communication capabilities. Agencies were unaware of the activities of other agencies. As the situation became more complicated with the involvement of Department of Defense personnel, coordination grew even more difficult. Agencies were also not able to communicate well with their responders to gather their status information and provide them information and orders. Responders were not able to communicate with other responders as a result of operational and interoperability problems, hindering search and rescue efforts. Finally, victims and the general public were not able to communicate with agencies to ask for help as a result of the telecommunications breakdown.

Transportation Operations

Prior to Katrina's landfall, most of New Orleans' population evacuated. Although we do not have evidence that technology was an important facilitator of the evacuation, it appears that the evacuation was a relative success for those that attempted it. For those citizens that were stranded in New Orleans after the landfall of Katrina there, mobility was not a primary issue. Even for those remaining citizens that did have personal vehicles, travel in New Orleans would have been quite difficult since about 80% of the city was flooded. As a result, we did not consider mobility of the general public during the emergency phase of the Katrina response a key issue. Responders, on the other hand, were very much in need of mobility during the emergency phase. To achieve this, they needed information about road and bridge damage as well as flooding information. Receiving this information in real-time, however, would typically be impossible as a result of the telecommunications breakdowns.

RELIEF PHASE

Sensing and Assessment

Relief activities such as continued medical care, evacuation progress of remaining citizens, and food and water distribution had to be tracked so as to provide situational awareness to the response community. However, doing so was quite difficult even during the relief phase since communication was generally unavailable even during this phase. Additionally, resource ordering and tracking systems experienced operational problems that further worsened the situation.

Communication and Coordination

During the relief phase of the Katrina response, problems of coordination between agencies continued as telecommunication problems lingered. Some communication capabilities were established, but they appeared to have improved the situation only slightly. Thus, situational awareness problems continued, and communication with deployed responders continued to be a problem.

Transportation Operations

During the relief phase, the primary transportation related events had to do with the evacuation of the remaining population of New Orleans. Coordination of this evacuation via bus or air routes was involved. Bus tracking proved to be a problem during this process.

RECOVERY PHASE

Sensing and Assessment

Recovery activities are still ongoing in New Orleans as the city gets rebuilt. At this point, information sharing is not typically time sensitive, and additionally, telecommunications is now reinstated, allowing for ample information gathering.

Communication and Coordination

Coordination of recovery efforts is still ongoing in New Orleans. However, now, with the telecommunication system in tact and the timeliness of information sharing less important, sufficient tools such as internet, phone, and face-to-face meeting can be used to communication and coordinate these activities.

Transportation Operations

As New Orleans gets rebuilt and repopulated, transportation related information needs to flow to the citizens. Information should include road and bridge repair and flooding related information. We are not aware of any technologies that are available to provide this type of information to the returning citizens.

2.4 Chapter Summary and Conclusions

The goal of this chapter was to analyze three prominent disaster case studies with the intention of assessing the response performance for various disaster response functions, and also, assessing the details of the IT/ITS systems and technologies that were available to support the disaster response operations. Before performing the analysis, a framework was set up which broke disaster response operations up on several different dimensions. First of all, we divided response operations on the basis of time into three phases: *emergency, relief,* and *recovery*. Additionally, on the basis of operational categories, we divided response operations into three primary categories of disaster response functions: *sensing and assessment, communication and coordination,* and *transportation operations.* Each of these categories was then comprised of multiple functions, each of which were also in one of the three phases.

2.4.1 Overall Summary and Conclusions

Using this framework for analysis, the three disaster cases, Northridge, "9/11", and Katrina, were investigated. The cross-cutting findings regarding the disaster response performance for these cases follow.

Emergency Phase

Sensing and Assessment

For all three disaster cases, similar emergency sensing and assessment needs were encountered. First, sensing and assessment of critical infrastructure had to primarily be done via manual efforts. Additionally, locating and tracking victims was a major issue for all three disasters. The same was true for responders, since no good system of tracking responder locations and status was available in any of the disaster cases.

Communication and Coordination

In all three cases, immediate telecommunications breakdowns resulted in enormous communication and coordination difficulties. Phone communications were generally not available in any of the cases. Radios were used by responders, when possible, but these suffered from operational problems and inherent interoperability constraints. As a result of these difficulties, agencies, responders, and victims were all generally disconnected and disorganized in the aftermath of the disasters.

Transportation Operations

Immediately after the disaster occurrence in each of our cases, transportation conditions were severely hampered. In the case of Northridge and Katrina, widespread damage to the transportation network made much of it unusable. In the case of 9/11, much of the transportation network was closed by authorities after the attacks for security purposes. To travel on the hindered transportation network, responders and victims would have benefited by receiving real-time status information. Although some status information was available in the case of 9/11 (both road-side and via internet and media), transportation status information would have been impossible to receive in the cases of Northridge and Katrina during the emergency phase. In all three cases, responders could additionally radio their agency for information regarding travel, but the information would not be guaranteed or easily conveyed to them. Finally, Katrina and 9/11 response involved evacuations procedures. Katrina's pre-landfall evacuation appears to have been fairly successful (for those that were willing and able to leave). The 9/11 evacuation from Lower Manhattan also was fairly successful, even though it took evacuees several hours longer than usual to get back home on the day of the attacks. It is likely that better evacuation monitoring and management tools could have benefits and streamlined these processes.

Relief Phase

Sensing and Assessment

Tracking efforts of relief activities and resources experienced varying degrees of difficulty for each of the three cases. For 9/11, relief activities were generally not extremely critical. Primarily, for our purposes, they dealt with temporary transportation solutions. Tracking such activities was not a problem. For Northridge, the relief phase was more active as temporary shelter and quality of life provisions were sought for the portion of the population that lost their homes as a result the earthquake. Tracking relief activities and supply shipments would thus have been a bigger challenge. Katrina's relief phase was the most involved as medical care of remaining citizens in New Orleans, food and water distribution, and the prolonged evacuation process continued. At the same time, keeping track of these activities was most challenging for this disaster as well, since communications infrastructure was still largely unavailable during the relief phase.

Communication and Coordination

As was the case with sensing and assessment, varying degrees of communication and coordination challenges were felt during the three cases. For 9/11, the relief phase did not involve many activities and communications was freely available. Thus, tracking these few activities was not a problem. For Northridge, there were more activities to track and telecommunications problems still lingered, making tracking efforts a bigger challenge in this case. Katrina was once again the worst since the relief effort was very involved but communications were still largely unavailable.

Transportation Operations

The transportation situation was quite different in the Katrina case from the cases of Northridge and 9/11. By the relief phase in the case of Katrina, most of New Orleans population had evacuated and thus there was no general need for mobility in the city. The main transportation related effort was to evacuate the remaining population out of the city. However, for Northridge and 9/11, the populace had remained in Los Angeles and New York, respectively. The populace continued to have everyday mobility needs but the transportation system continued to be hampered. Detours and new transit services were set up. However, keeping the public informed about these changes was clearly a challenge, particularly when real-time information was necessary. As a result of lack of travel related information during this time, mobility of the general public suffered.

Recovery Phase

Sensing and Assessment

Tracking recovery activities was not judged to be a problem for any of the disaster cases that were investigated. First, such tracking is typically not as time-sensitive as tracking of activities during the emergency and relief phases. Additionally, by the recovery phase, communication means were reestablished and tracking such activity becomes manageable.

Communication and Coordination

Related to keeping track of recovery activities, communication and coordination during the recovery phase was similarly apparently not a problem for any of the investigated cases. Standard means of communication were used by this time to coordinate.

Transportation Operations

In all three disaster cases, the transportation system continued to dynamically change during the recovery phases. Rebuilding and reopening news of transportation infrastructure would need to be conveyed to the traveling public so that they can make optimal travel decisions. Although general (not real-time) information could be procured in all three cases via standard means, the continued lack of real-time travel information still left the general public with sub-optimal tools to traverse the dynamic transportation network.

2.4.2 Technology Summary

For Northridge, the normal communications network became backlogged as the phone system became overloaded. Other devices such as pagers, fax machines, and electronic data sharing were used as means of communications, but were largely subject to power outages.

The media played a big role in information dissemination, but television was not available either while power was out during the emergency phase. Radio communications appears to have been used somewhat successfully by response agencies such as the fire department but signal strength problems were encountered. Additionally, as with the other disaster cases, radios were not designed to be interoperable between agencies, which was a problem since many different agencies were responding to the earthquake and needed to cooperate.

Other technology available for the Northridge disaster response team included the CUBE/REDI system, which helped them to characterize the earthquake's location, magnitude, and other details. Specialized satellite communications were also available to disseminate vital information to the disaster response agencies and the media. GIS tools were available during the recovery phase for tracking flow of resources and assistance activity.

Some ITS facilities were present, including a centralized TMC to coordinate transportation information gathering and dissemination. While it provided some capabilities, the TMC proved to be insufficient to act as the central transportation management hub during the disaster. More capability and capacity was needed. TMC's ITS capabilities included some VMS for dynamic messaging to drivers and CCTV and loop detectors for traffic monitoring. Some on-ramp metering was available to control traffic. The TMC was also able to use radios (when signal was adequate) and some mobile traffic data terminals to communicate with responders. Finally, the Fire Department had a CAD system, which they were able to make use of after regaining power about 6 hours after the storm. Los Angeles' famous ATSAC traffic management system also helped to manage traffic in certain parts of the metropolitan area.

For 9/11, we must note that the event occurred 7.5 years after the Northridge event, so the use of cell phones and other technology became much more prevalent by this time. For the event, we saw a similar breakdown in phone communications, however, as we did for Northridge, since the cell network became congested with calls. Thus, for communications, responders used two-way radios, e-mail, Nextel phones with direct connect features, and blackberries. All of these technologies had limitation, however, varying from lack of availability to operational issues. Also, mobile communications vans were used by FDNY as well as NYC Transit and New Jersey Transit to facilitate communications.

Standard ITS systems were fairly prevalent in NYC in 2001 when this disaster occurred. In order to collect traffic data, hundreds of CCTV cameras were used all over the metropolitan area. This visual information stream was provided to necessary responding agencies, but could also be viewed by civilians along with other information on the www.metrocommute.com website. Another tool used for traffic condition measurement was traffic sensors, which helped to make important decisions such as the SOV ban during morning rush hour in Manhattan. Radio, internet, TV, newspapers, and 24-hour customer phones lines (for both civilians and taxi drivers) were also used to disseminate travel information. On the road, HAR, VMS, and OnStar (for those that had it) were available. Additionally, as was the case for the Northridge response, the New York TMCs served as important command centers for city and state transportation and public safety personnel.

For Katrina, we know that standard means of communications were once again disrupted as cell and standard phones lines were largely unavailable. Police lost standard radio communications and relied on two-way radios instead, which had limited range and capability. The internet was available in some instances. Satellite phones also seemed fairly popular, although there were not enough of them, their service was also prone to disruptions, and since there was no power for some time in New Orleans, once their batteries were used up, they could not be used. The NCS was instrumental in getting thousands of WPS phones to first responders as well as satellite phones. Cellular communications vans were also used to facilitate communications. Finally, volunteer radio networks were used to disseminate information.

ITS usage during Katrina is currently mostly unclear to us. More research needs to be done to learn more in this regard. This is something that was not done as part of this research.

More specifically in regards to the technologies, Tables 2.2, 2.3, and 2.4 below outline the findings regarding the values of IT/ITS technologies that were available for each case study. In the leftmost part of the tables, there are tabs that indicate phase: "E" denotes Emergency Phase, "R1" denotes Relief Phase, and "R2" denotes Recovery Phase. The first column in the tables, named "Function", is the function name. The second column, "IT/ITS available", lists IT/ITS technologies that played a role in the disaster response. The third column, "Status during disaster", provides information regarding the operational status of the technologies.

Finally, the last column, “Value of IT/ITS”, rates the technologies’ value on a 0-3 scale, with the following meanings:

- “0” means no value
- “1” means little value
- “2” means significant value
- “3” means exceptional value

Table 2.2 Northridge: Available IT/ITS Values Summary

	[illegible]			
	Sensing and Assessment			
E	Disaster sensing and assessment	CUBE/REDI	Operational	2
	Critical Infrastructure sensing and assessment	None.		
	Victim location / tracking	None.		
	Responder / emergency response activity tracking	None.		
R1	Relief activity tracking	GIS (Sparsely available)	Operational	1
	Resource tracking	GIS (Sparsely available)	Operational	1
R2	Recovery activity tracking	GIS	Operational	2

	Communications and Coordination			
E	Communication and coordination between response agencies for emergency operations	OASIS/EDIS	Operational	2
		Fax machines	Operational	2
		Electronic Data Interchange (EDI)	Operational	2
		Internet (Sparsely available)	Used, when possible	0
	Communication and coordination between response agencies and emergency responders	Radio	Poor signal	1
		Standard phones	Overloaded	0
		Cell phones	Sparsely available	1
		Pagers	Operational	2
		LAFD CAD system	Not fully functional because of power failure	1
	Communication and coordination between emergency responders	Radio	Poor signal and no interoperability	1
		Cell phones (Sparsely available)	Poor signal	1
	Communication and coordination between victims / general public and response agencies	Standard phones	Overloaded	0
		Cell phones (Sparsely available)	Poor signal	1
R1	Communication and coordination between response agencies to coordinate relief	OASIS/EDIS	Operational	2
		Standard phones	Operational	2
		Fax	Operational	2
		EDI	Operational	2
	Communication and coordination between response agencies and responders during relief	Radio	Poor signal and no interoperability	1
		Cell phones (Sparsely available)	Poor signal	1
R2	Communication and coordination between response agencies to coordinate recovery	OASIS/EDIS	Operational	2
		Standard phones	Operational	2

	Transportation Operations			
E	Movement / evacuation of victims / general public	Media	Television not available when power out	1
		VMS (Sparsely available)	Susceptible to power outages	1
		HAR	Susceptible to power outages	1
	Mobility of responders	Media	Television not available when power out	1
		VMS (Sparsely available)	Susceptible to power outages	1
		HAR	Susceptible to power outages	1
		Radio	Signal problems and difficulty in transmitting useful information	1
R1	Support of temporary transportation movements	Media	Operational	2
		VMS (Sparsely available)	Susceptible to power outages	1
		CCTV (Sparsely available)	Susceptible to power outages	1
		On-ramp metering (Sparsely available)	Susceptible to power outages	1
		Loop detectors (Sparsely available)	Susceptible to power outages	1
		1-800-COMMUTE	Operational	2
		ATSAC (Only available in limited area)	Susceptible to power outages	1
R2	Support of new (or original) transportation movements	Media	Operational	2
		VMS (Sparsely available)	Operational	1
		CCTV (Sparsely available)	Operational	1
		On-ramp metering (Sparsely available)	Operational	1
		Loop detectors (Sparsely available)	Operational	1
		1-800-COMMUTE	Operational	2
		ATSAC (Only available in limited area)	Operational	1

Table 2.3 9/11: Available IT/ITS Values Summary

	[illegible]	[illegible]	[illegible]	[illegible]
	Sensing and Assessment			
E	Disaster sensing and assessment	None.		
	Critical Infrastructure sensing and assessment	None.		
	Victim location / tracking	Standard phones	Overloaded	1
		Cell phones	Overloaded	1
		911	Lack of interoperability with other response agencies	1
	Responder / emergency response activity tracking	Radio	No interoperability, lack of operability	1
		Field Comm	Lack of operability	1
R1	Relief activity tracking	None.		
	Resource tracking	None.		
R2	Recovery activity tracking	Standard phones	Operational	2
		Internet	Operational	2

	Communications and Coordination			
E	Communication and coordination between response agencies for emergency operations	Standard phones	System crippled and overloaded	1
		Cell phones	System crippled and overloaded	1
		Field Comm	Lack of operability	1
		IRVN	Operational	2
		"Mobile" centers	Operational	2
	Communication and coordination between response agencies and emergency responders	Standard phones	System crippled and overloaded	1
		Cell phones	System crippled and overloaded	1
		Radio	Operational problems	1
		E-mail (Sparsely available in the field)	Operational problems	1
		Nextel phones (Sparsely available)	Operational	1
		Blackberries (Sparsely available)	Lack of interoperability	1
	Communication and coordination between emergency responders	Radio	Operational problems	1
		Nextel phones (Sparsely available)	Operational	1
		Blackberries (Sparsely available)	Lack of interoperability	1
	Communication and coordination between victims / general public and response agencies	Standard phones	Overloaded	1
		Cell phones	Overloaded	1
		911	Lack of interoperability with other response agencies	1
R1	Communication and coordination between response agencies to coordinate relief	Standard phones	Operational	2
		Cell phones	Operational	2
		TRANSCOM	Operational	2
	Communication and coordination between response agencies and responders during relief	Standard phones	Operational	2
		Cell phones	Operational	2
		Radio	Operational	2
R2	Communication and coordination between response agencies to coordinate recovery	Standard phones	Operational	2
		Cell phones	Operational	2
		TRANSCOM	Operational	2

	Transportation Operations			
E	Movement / evacuation of victims / general public	Media	Operational	2
		VMS (Sparsely available)	Operational	1
		HAR	Operational	1
		IRVN	Operational	2
		Internet	Operational	2
	Mobility of responders	IRVN	Operational	1
		Radio	Difficulty in transmitting useful information	1
		Cell phones	Difficulty in transmitting useful information	1
R1	Support of temporary transportation movements	Media	Operational	2
		VMS (Sparsely available)	Operational	1
		HAR	Operational	1
		IRVN	Operational	2
		Internet	Operational	2
		Traffic information hotlines	Operational	2
		New real-time services such as GM's OnStar (Sparsely available)	Operational	1
R2	Support of new (or original) transportation movements	Media	Operational	2
		VMS (Sparsely available)	Operational	1
		HAR	Operational	1
		IRVN	Operational	2
		Internet	Operational	2
		Traffic information hotlines	Operational	2
		New real-time services such as GM's OnStar (Sparsely available)	Operational	1

Table 2.4 Katrina: Available IT/ITS Values Summary

	Sensing and Assessment			
E	Disaster sensing and assessment	Hurricane sensing systems	Operational	3
	Critical Infrastructure sensing and assessment	Standard phones	Prone to failure and difficulty in gathering comprehensive information	1
	Victim location / tracking	None.		
	Responder / emergency response activity tracking	None.		
R1	Relief activity tracking	None.		
	Resource tracking	E-TEAM	Lacked interoperability and proper use	1
		NEMIS	Lacked interoperability and proper use	1
R2	Recovery activity tracking	None.		

	Communication and Coordination			
E	Communication and coordination between response agencies for emergency operations	Standard phones	Destroyed by storm	0
		Cellular network	Destroyed by storm	0
		911 centers	Destroyed by storm	0
		Radio stations	Destroyed by storm	0
		Radios	Had limited range and no cross-agency interoperability	1
		Internet	Lacked operability	1
		Satellite phones (Sparsely available)	Problems with signal strength	1
		Satellite communications vans	Operational	2
		HEAR	Destroyed by storm	0
	Communication and coordination between response agencies and emergency responders	Standard phones	Destroyed by storm	0
		Cellular network	Destroyed by storm	0
		Radios	Had limited range and no cross-agency interoperability	1
		Satellite phones (Sparsely available)	Problems with signal strength	1
		Blackberries (Sparsely available)	Problems with signal strength	1
	Communication and coordination between emergency responders	Standard phones	Destroyed by storm	0
		Cellular network	Destroyed by storm	0
		Radios	Had limited range and no cross-agency interoperability	1
		Satellite phones (Sparsely available)	Problems with signal strength	1
		Blackberries (Sparsely available)	Problems with signal strength	1
	Communication and coordination between victims / general public and response agencies	Cellular network	Destroyed by storm	0

R1	Communication and coordination between response agencies to coordinate relief	Standard phones	Destroyed by storm	0
		Cellular network	Destroyed by storm	0
		911 centers	Destroyed by storm	0
		Radio stations	Destroyed by storm	0
		Radios	Had limited range and no cross-agency interoperability	1
		Internet	Lacked operability	1
		Satellite phones (Sparsely available)	Problems with signal strength	1
		Satellite communications vans	Operational	2
		HEAR	Destroyed by storm	0
	Communication and coordination between response agencies and responders during relief	Standard phones	Destroyed by storm	0
		Cellular network	Destroyed by storm	0
		Radios	Had limited range and no cross-agency interoperability	1
		Satellite phones (Sparsely available)	Problems with signal strength	1
		Blackberries (Sparsely available)	Problems with signal strength	1
R2	Communication and coordination between response agencies to coordinate recovery	None.		

	Transportation Operations			
E	Movement / evacuation of victims / general public	None.		
	Mobility of responders	None.		
R1	Support of temporary transportation movements	None.		
R2	Support of new (or original) transportation movements	None.		

2.4.3 Final Chapter Conclusions

Overall, although there were some differences in the technologies and systems that were present for the three disaster cases, it is apparent that none of disaster response cases that we investigated had sufficient disaster response support systems. By sufficient, we mean that the technologies available were either not inherently capable and/or abundant enough. Even if intended capabilities would have been enough, technologies were generally not resilient enough to remain operational during disaster situations. Additionally, although the details of the problems and challenges of performing basic disaster response functions differed, we argue that the core of the problems due to the lack of better IT/ITS support systems experienced for the three disasters that we studies are very much the same. All of them experienced sensing and assessment problems, communication and coordination problems, and transportation operation problems. Based on all of this evidence, we conclude that there is a clear need for better disaster response support technologies and systems.

The following chapter, Chapter 3, introduces and discusses many such technologies and systems, which could have been helpful with all three of the disaster responses that we studied.

Chapter 3. Emerging IT and ITS Technology Review for Disaster Response Operations

The purpose of this chapter is to provide the results of an Information Technology (IT) and Intelligent Transportation Systems (ITS) technology review. In the review, emerging technologies were sought which have the potential to support Sensing and Assessment, Communication and Coordination, and Transportation Operations functions of a disaster response, the same three categories that were introduced in the beginning of Chapter 2 as part of the analysis framework. In this chapter, reviewed technologies will be presented under each of these three categories. First, however, we briefly introduce IT and ITS and explain why they are relevant to disaster response operations.

3.1 What is Information Technology (IT) and why does it apply to disaster response?

According to one source's definition, Information Technology refers to the "the entire array of mechanical and electronic devices which aid in the storage, retrieval, communication, and management of information." (81) IT technologies will be central to the technology review in this chapter since they have a wide variety of applications for disaster response operations. Examples of IT technologies that are applicable to disaster response are infrastructure sensor networks, 9-1-1 systems, responder field communication systems, and wireless communication technologies.

3.2 What are Intelligent Transportation Systems (ITS) and how do they apply to disaster response?

Intelligent Transportation Systems are in fact a subset of Information Technology. ITS involves using information technology and computing to support better management of the transportation system. According to Joseph Sussman (43), ITS build on four main functions: sensing, communications, processing, and utilization of data. More specifically, these functions are presented as defined by Sussman below.

- Sensing: “The ability to sense the presence and identity of vehicles or shipments in real-time on the infrastructure through roadside devices or global positioning systems.”
- Communications: “The ability to communicate (i.e., transmit) large amounts of information more cheaply and reliably.”
- Processing: “The ability to process large amounts of information through advance information technology.”
- Utilization of Data: “The ability to use this information properly and in real-time in order to achieve better transportation network operations. We use algorithms and mathematical methods to develop strategies for network control and optimization.”

ITS technologies have broad-ranging applications to support transportation-related disaster response functions. Examples of ITS technologies relevant to disaster response are evacuation support software, traveler information technologies, vehicle-infrastructure integration systems, and responder mobility enhancement technologies.

3.3 Emerging IT and ITS Technologies for Disaster Response

The purpose of this section is to present emerging IT and ITS technologies that have the potential to be useful technological support tools for disaster response operations. The technologies are presented under the categories of disaster response functions that were defined in Chapter 2, which were Sensing and Assessment, Communication and Coordination, and Transportation Operations. As mentioned at the very beginning of this chapter, technologies were sought that could assist with these categories. In particular, reviewed technologies were those which could provide better disaster response support than typical, currently available technologies. “Better” support entails both more sophistication and more resilience to disaster disruptions.

3.3.1 Sensing and Assessment Technologies

The technologies and systems that are applicable for sensing and assessment are described in this sub-section. General categories include:

1) Infrastructure and Environmental Sensing Systems
2) Vehicle Tracking Technologies

3) Incident Tracking Technologies

3.3.1.1 Infrastructure and Environmental Sensing Systems

Infrastructure sensor networks can be used to detect failed bridges, building, water lines, or power grids. Portions of such a sensor network already exist in some locations, and as infrastructure sensors become more and more prominent in our society, detecting locations and impacts of certain disasters can become virtually instantaneous. For example, for monitoring the transportation infrastructure, Closed-Circuit Television (CCTV) cameras and loop detectors are already quite common. Along similar lines as the infrastructure sensor networks, environmental sensing systems can provide detection and characterization capabilities for a variety of disasters ranging from natural disasters to biological attacks. (69)

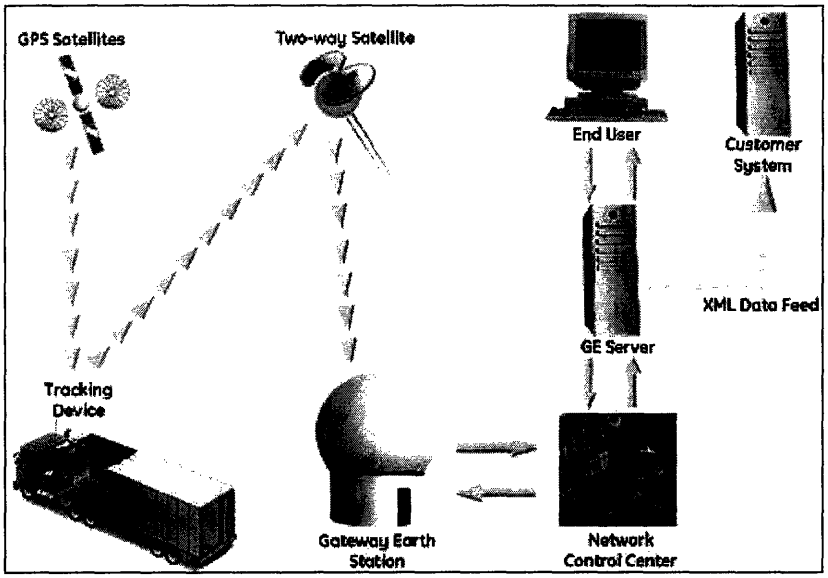
3.3.1.2 Vehicle Tracking Technologies

Vehicle tracking can be used to track response vehicles and supply shipments. Automated Vehicle Location (AVL) technologies are now rampant, with many different choices of technologies and software available to track vehicles. These AVL technologies could be used to track response and supply vehicles. Supply tracking technology, in particular, is becoming commonplace in the private transportation sector. Two examples, one from General Electric and the other from the U.S. Military, are described below.

General Electric (GE) VeriWise system

General Electric's VeriWise system can track the location and status of supply trailers and then provide the information to system managers. The basic set up of the system is shown in the figure below. A GPS tracking device is used for the location of the trailers. Wal-Mart has recently decided to outfit its fleet of 46,000 over-the-road trailers with the VeriWise technology. In addition to the basic tracking technology, Wal-Mart is also getting an interior-mounted cargo sensors as part of their package that provide information regarding the interior conditions and the status of the contents in within the trailers. (77, 78)

Figure 3.1 GE's VeriWise System.

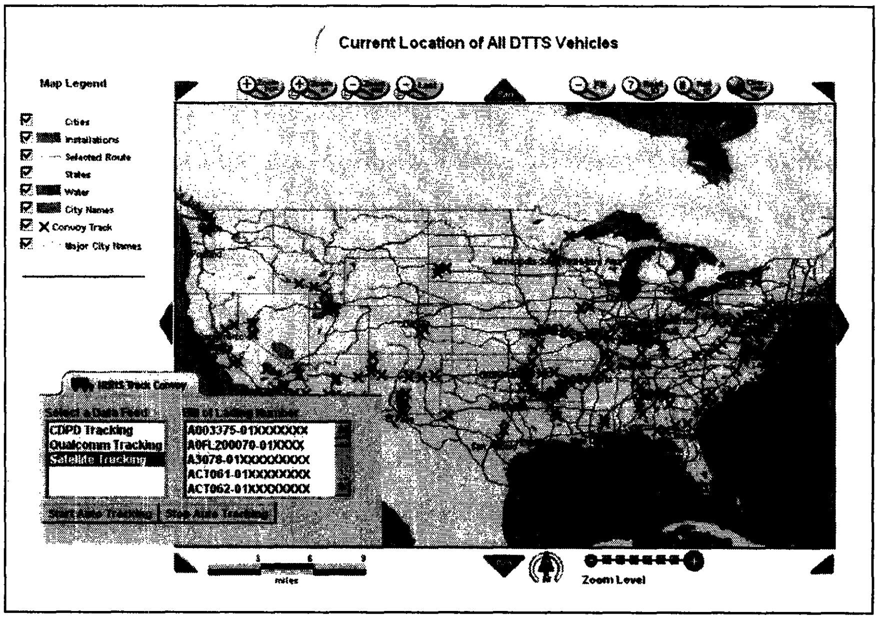


Source: 78

U.S. Military Intelligent Road & Rail Information Server (IRRIS)

Also in the realm of asset tracking, the U.S. Military has a system called the Intelligent Road & Rail Information Server (IRRIS). IRRIS provides transportation logistics capabilities and real-time asset tracking information. Global Positioning System (GPS) devices are first used to track vehicles. Location information is displayed on a Geographic Information System (GIS) interface, where more than 140 different layers of information are also available including locations of hospitals, roads, bridges, railroads, waterways, and traffic and weather conditions. Although most of the data layers provides static information, layers that provide traffic and weather reports are dynamic. IRRIS is currently being expanded to also provide real-time route guidance capabilities that incorporate dynamic information and also information about the capabilities and limitations of the transport vehicle. (79)

Figure 3.2 IRRIS cargo tracking on GIS.



Source: 79

3.3.1.3 Incident Tracking Technologies

Technologies are also available to automatically gather incident information. The technologies in this section are all related to the 9-1-1 system. The 9-1-1 system is the most prevalent and well-known incident reporting system that is available to civilians. The basic 9-1-1 system connects a civilian caller with a Public Safety Access Point (PSAP), allowing emergency personnel at the PSAP to gather incident information from the caller and dispatch response personnel, when necessary. Traditional 9-1-1 systems also have a capability to recognize the caller's precise location by accessing a database that relates phone numbers to addresses.

The basic 9-1-1 functionality is being built upon with new features. There are various enhancements that are now becoming available for the 9-1-1 system that improve its capabilities for incident tracking. Some enhanced systems are described in this section, including capabilities to determine the geographic coordinates of 9-1-1 callers from cellular phones, pass multi-media information between the caller and the PSAP, integrate 9-1-1 with automated collision notification (ACN) systems, and analyze aggregate 9-1-1 caller data to look for patterns of interest.

Wireless Enhanced 9-1-1

Wireless Enhanced 9-1-1 is a system by which the precise location of a wireless telephone can be determined when an emergency 9-1-1 call is placed from that device. The U.S. has about 7,000 PSAPs, which receive all 9-1-1 calls. For 9-1-1 calls made from landline phones, the PSAPs already have the capability to locate the source of the call. However, this capability is still being developed for wireless phones. The Federal Government previously instituted a requirement that wireless telecommunication service providers must allow for the location positioning capability for 9-1-1 purposes. According the ITS Public Safety Program website, this initiative was supposed to be implemented by 2005. (57) The website does not indicate how far along the implementation has progressed. In addition to the Wireless Enhanced 9-1-1 system, there is also the concept of the Next Generation 9-1-1 system that will allow PSAPs to gather information from an incident scene beyond just voice accounts. Other data gathered could include telematics or visual data.

Telematics / 9-1-1 Integration

Telematics can be described as "the integration of wireless communications, vehicle monitoring systems and location devices." (67) An important component of telematics are Automatic Crash Notification (ACN) systems. ACN systems automatically signal to an emergency call center that an accident has occurred and can stream data and voice transmissions from the accident scene to the center. The ACN is activated either when the vehicle occupant presses a designated button or can be triggered by such an event as a deployed airbag. An example of such a system that has ACN capabilities is General Motor's OnStar feature. (66)

There are new systems now being tested in Minnesota and Texas, which attempt to integrate this ACN feature with the already existing 9-1-1 feature. The idea for this to stream the information gathered from the ACN system to the 9-1-1 personnel in order to facilitate a quick and efficient response. Such data as "crash severity is determined by sensors that measure deceleration and direction of g-force changes in the vehicle, information regarding air bag deployment, occupancy of each of the vehicle's seats, and use of seat belts by each occupant" (66) can be gathered by the ACN. The integrated system would make this data automatically accessible electronically to 9-1-1 personnel or otherwise easily communicated to them. The information can also be shared with medical personnel in nearby hospitals. (66)

Calit2's[1] Spatio-Temporal Analysis of 9-1-1 Call Stream Data

Recognition of a disaster can occur based on spatio-temporal analysis of otherwise normal events. Just as a major traffic accident could be recognized by traffic managers if a sudden slowdown in roadway speeds was sensed, looking for particular patterns of other types of events can help disaster responders and managers to quickly recognize a potential disaster. Additionally, such a system could be used through the emergency response process to track 9-1-1 incident locations. One example of such a capability is Calit2's Spatio-Temporal Analysis of 9-1-1 Call Stream Data.

Calit2's research suggests that 9-1-1 call patterns appear to be rather predictable. According to this research, we can fairly readily predict how many calls to predict in a particular urban setting on an hourly, daily, and weekly basis and the spatial density that we can expect from different geographical sections. This prediction is made based on historical data and statistical analysis. Call patterns can be analyzed for any irregularities in these established patterns and these irregularities can be investigated when deemed necessary. The idea behind this analysis is to try to establish faster recognition of the occurrence of certain disasters such as chemical or biological attacks. The people calling 9-1-1 may not even realize what is causing them illness but by analyzing the 9-1-1 call patterns, this type of system can quickly help to realize that, for example, an unusually high volume of calls is originating from a certain location. (71)

Additionally, this system can be paired with Wireless Enhanced and Next Generation 9-1-1 system capabilities, described later in this chapter, which would provide location, text, image, and video information from mobile callers, allowing for more specified analysis.

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[1] Calit2, or the California Institute of Telecommunications and Information Technology, is the sponsor of the author's Research Assistant position at MIT.

3.3.2 Communication and Coordination Technologies

Critical to the success of an emergency response is communication and coordination. The technologies and systems that are applicable for this support are described in this sub-section. General categories include:

1) CAD-ITS Integrated Systems
2) Central Technology Hub Systems
3) Disaster Response Field Communication Systems
4) Wireless Networking Technologies
5) Portable, Wireless Technologies

3.3.2.1 CAD-ITS Integrated Systems

Coordination between public safety operations and transportation operations is a key to the success of creating efficient response systems. A specific type of related coordination effort is the Computer-Aided Dispatching (CAD) and ITS integration. "CAD systems, used by law enforcement and other emergency response agencies, provide dispatchers and response units with real-time incident information. CAD systems typically track data on response unit assignments, incident address locations, equipment location and status, utility locations, and special hazards data." (68) At the same time, ITS systems can of course provide real-time traffic and road condition information. The pairing of CAD with ITS seems natural since it would be ideal if response units took the fastest and safest route to an accident scene, about which both they and their central command are well-informed before arriving on the scene.

CAD-ITS integrated systems are being tested in Utah and Washington states. Each system has its own unique features. Utah's system wants to integrate an AVL and GIS functionality that allows for easy real-time tracking of response vehicles. In Washington, the transportation community (state, local, and regional agencies) already uses a system called Condition Acquisition and Reporting System (CARS) to collect and share real-time information pertinent to the transportation network including road incidents, weather conditions, traffic delays, and so forth. The system was developed by Castle Rock Consultants and is used as a basis for 5-1-1 travel information content in several states. (5-1-1 is intended to be a standard, national number that can be used to receive real-time traffic information.) The CAD-ITS integrated system will allow a particular incident's information, entered by a safety patrol officer into the CAD system, to be automatically sent to the CARS systems and is displayed on-screen at the Washington DOT office. Once in the CARS system, this information can be integrated with other CARS information, including traffic, construction, or weather conditions. This information can then be provided back to Washington Safety Patrol's (WSP) CAD system to assist them if they need to dispatch more vehicles. At the same time, the integrated data can be shared with towing and recovery personnel as well as EMS. (68)

Integrated Incident Management System (IIMS)

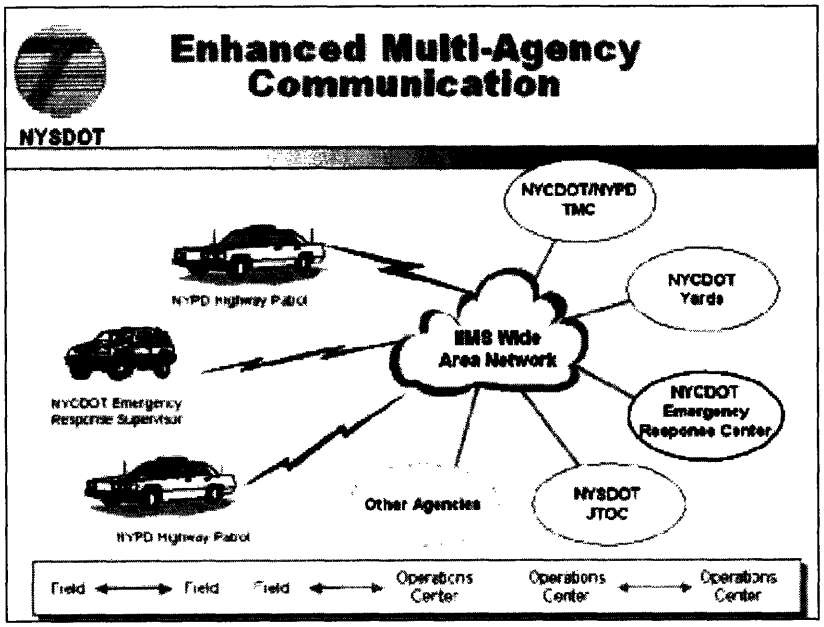
One manifestation of an ITS-CAD integration is the Integrated Incident Management System (IIMS). The system has been developed for the New York City metropolitan area. Although the IIMS focuses specifically on traffic incident response management, it is a good example of a management system that could be extended for other types of incidents as well.

A need for an IIMS type of system, we reiterate, stems from the current lack of efficiency in responding to traffic-related incidents throughout the country. The inefficiency occurs because of the difficulty of disseminating pertinent incident information to the various agencies that would potentially respond to the incident. As it typically occurs now, the first first responder that arrives at the scene has to provide the incident information via voice communications (e.g. radio) to his home base, where the information can then be spread to other agencies. However, the process of passing on data by voice accounts is slow and can often lack detail and accuracy, critical when time is of the essence.

In New York City, the disaster response community have decided to develop an IIMS prototype system in order to better streamline their incident response system. Currently, a police responder is typically the first to arrive at a traffic incident scene. He then has the job of communicating with other first responders to acquire their assistance. One of the key responders is the NYC Department of Transportation (NYCDOT). Their response protocol has historically been to first send out a representative to further investigate the scene and determine the response needed to properly clear the scene and re-establish traffic flow. After they do that, they then call for a second round of responders from their agency to perform whatever actions are needed to clear the incident. Predictably, such a response process is slow and inefficient. The average travel time for the NYCDOT representative to travel to a traffic incident is 30 minutes. Then, once the first round responder calls for the second round of responders, it will take another 30 minutes, on average, for them to arrive at the scene.

IIMS offers a more efficient alternative to this response system. IIMS establishes a communications network between the main agencies that are responsible for incident response and also with particular New York Police Department (NYPD) and NYCDOT Emergency Response Supervisor vehicles, as can be seen in Figure 3.3 provided below. This network allows for much more efficient incident data dissemination and data sharing. With IIMS, an equipped NYPD highway that would be first to arrive at a traffic incident scene would be tracked by GPS and would have image gathering and data entry capabilities. The images and data that are gathered would then be shared via the IIMS Wide Area Network with the pertinent response agencies. This system would allow an agency like NYCDOT to dramatically streamline their incident response process. Now, the hope is that they would no longer need to send a representative to investigate the scene before determining their specific response strategy. Instead, they could receive all the information that the need via IIMS and immediately deploy what was previously the second round of first responders. (65)

Figure 3.3 The IIMS Wide Area Network for NYC.



Source: 65

3.3.2.2 Central Technology Hub Systems

A central technology hub is important to integrate various technological systems that would be used for a disaster response. Additionally, such a center would allow for face-to-face responder communication, which has a special value that cannot usually be replaced by information technology's communications capabilities. A central location is going to be important to make inter-agency decisions during the disaster response. Austin's CTECC is one good example of a central technology hub. Another larger, more well-known example of such a hub is the TranStar center in Houston.

Austin's Combined Transportation, Emergency & Communications Center (CTECC)

Austin's CTECC center is an important example of physically bringing together representatives from the transportation, emergency, and communications community and integrating their technological capabilities in one location. This best practice can serve as an example for other urban regions seeking better coordination for disaster response.

Although other centers around the country and the world have been established to co-locate transportation and public safety personnel, CTECC claims to have "a unique level of participation by different agencies." (62) CTECC has participation from local police, EMS personnel, fire departments, emergency managers, the state department of transportation, and the city transportation authority. According to their website (62), the center hosts the following transportation and public safety systems:

- Intelligent Transportation System
- CAD (Computer Aided Dispatch)
- 9-1-1
- Fire Records Management System
- Police Records Management System
- Regional Radio System

Houston's TranStar Center

Houston's TranStar consortium is another prominent example of integrating transportation, emergency, and communications elements into one organization and center. TranStar itself is composed of four government agencies that include those responsible for both transportation and emergency management. The four agencies, listed below, each have a presence at TranStar's Greater Houston Transportation and Emergency Management Center. The details of their role at this center are described alongside with the listing below. (82)

- Texas Department of Transportation (TxDOT) is the main Texas state transportation agency. At the TranStar Center, they operate their freeway management systems.
- Harris County covers about 1,800 square miles and contains within it the city of Houston. At the TranStar Center, Harris County representatives operate traffic signalization, Sheriff's Motorist Assistance Program (MAP), and the Office of Emergency Management.
- Metropolitan Transit Authority of Harris County (METRO) is responsible for mass transit operations in the Houston region. At the center, METRO performs its High-Occupancy Vehicle (HOV) Operations, Police Dispatch, state-of-the-art Bus Operations, and Rail Operations.
- The City of Houston is Houston's main city government organization. At the center, the City of Houston runs surface street signalization and operates part of its police command. (82)

3.3.2.3 Disaster Response Field Communication Systems

Once in-the-field, different responders from various organizations need to be able to communicate and share data with each other in real-time. Different known types of systems have been or are being developed to suit this purpose, including CapWIN in Washington DC, MIVIS in Boston, and WIISARD in San Diego. CapWIN and MIVIS are intended primarily for public safety responders while WIISARD is intended for medical care responders. The systems that are described here are the three most prominent and sophisticated field communication systems that were found in our technology review.

The Capital Wireless Integrated Network (CapWIN)

"CapWIN is a unique and challenging program which has created the first multi-state and multi-discipline interoperable public safety and transportation wireless data system in the United States." (54) Project partners of the Capital Wireless Integrated Network (CapWIN) have currently developed a prototype system for the Washington DC area. According the CapWIN website, the current capabilities include the following:

- "Incident management & coordination across agencies, regions, and public safety and transportation disciplines
- Secure one-to-one & group public and private discussions
- A robust and searchable directory of individual first responders -- a '411 Directory' for public safety and transportation agencies
- Access to operational data/resources, including multiple state and federal law enforcement criminal databases"

The following page provides the CapWIN Connectivity Diagram in Figure 3.4. The diagram helps to visualize who is intended to be connected in the CapWIN system and by what means.

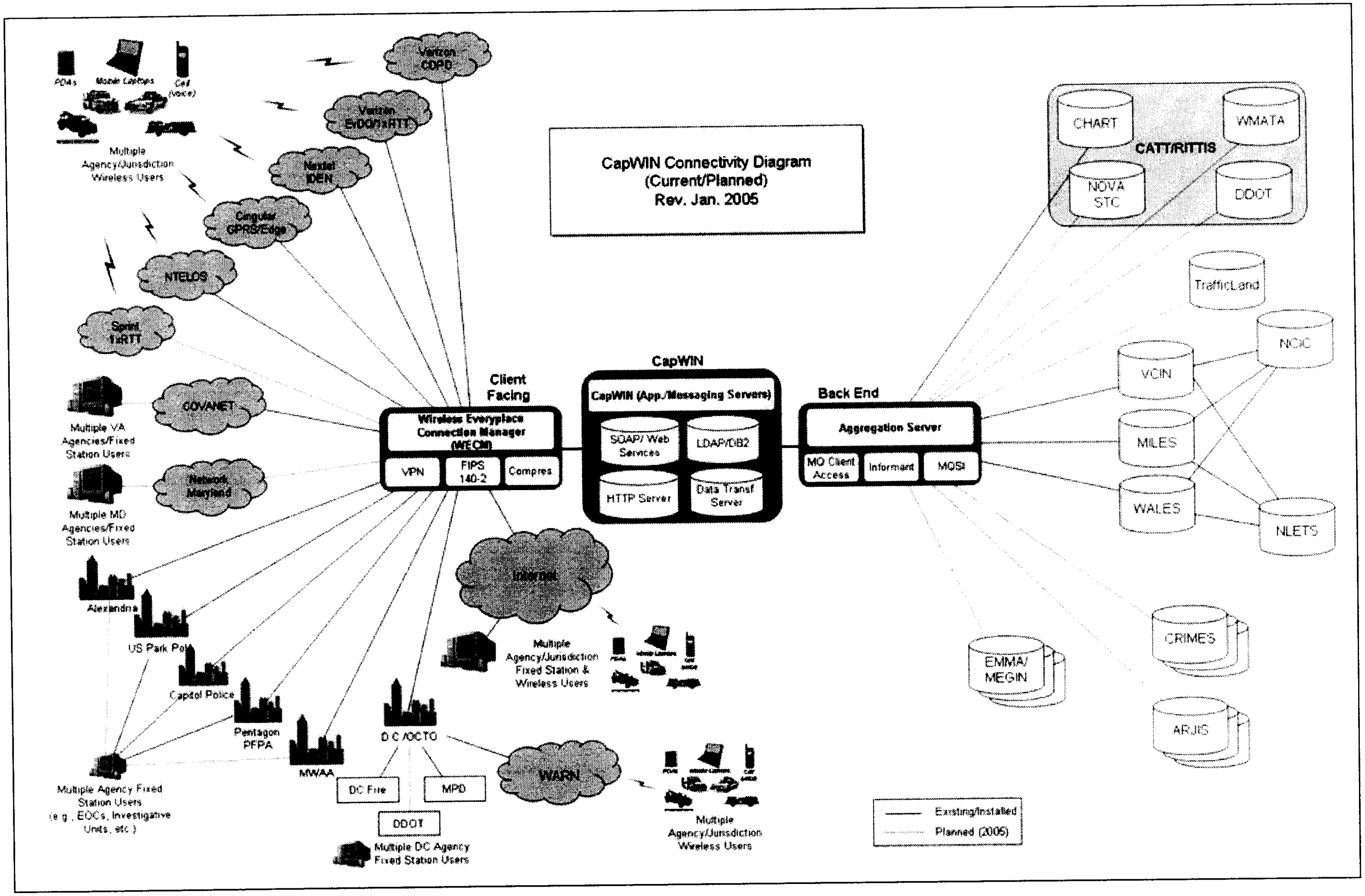


Figure 3.4 The CapWIN Connectivity Diagram. Source: <http://www.capwin.org/index.cfm?fuseaction=t2&ID=30>

CapWIN managers are continuing to develop the system capabilities. It is expected that future capabilities will include the following:

- "Multi-state sharing of local criminal data not available through the National Crime Information Center (NCIC)
- Transportation system integration, including remote video, incident logs, road sensors, etc.
- Computer Aided Dispatch (CAD) data exchange across jurisdictions and public safety disciplines
- Advanced GIS capabilities including incident/user GPS identification, aerial photo overlays, etc.
- Voice-over IP
- Secure email"

We should note here that these ambitions of future capabilities encompass a lot of the general ambition for the improvement of disaster response systems. It appears that CapWIN system can be looked at as the leader in enabling integrated responder communications systems.

As far as the progress that has been made, according the CapWIN website (54), as of March 7, 2006, 41 agencies and 980 total users from the Washington DC metropolitan area are participating in CapWIN. Users include police, transportation, and fire personnel from different jurisdictions. The wireless online information sharing platform that is currently offered by CapWIN is free, but it is planned that user fees will be instituted sometime around 2007-2008. (54)

CapWIN leases wireless connectivity through commercial or private wireless providers such as Verizon, Cingular, and Nextel to allow access for PDAs. Mobile Data Computers (MDCs), already deployed in some agencies, can also be outfitted to plug in to the CapWIN network. The system also allows for access directly via Local Area Network (LAN) or Wide Area Network (WAN) from desktop computers. (54)

CapWIN has been used to support recent major events in the DC region and outside of it. For example, fire, police, and transportation officials used CapWIN to coordinate and communicate regarding incidents during the 2005 Presidential Inaugural ceremony. CapWIN was also deployed for the Texas State Guard (TXSG) to support hurricane relief efforts in

October 2005. CapWIN allowed TXSG personnel "to communicate directly with multiple field units across a wide regional area." (54) It has also been used to support operations for events in the DC area such as September 11 memorial activities. (54)

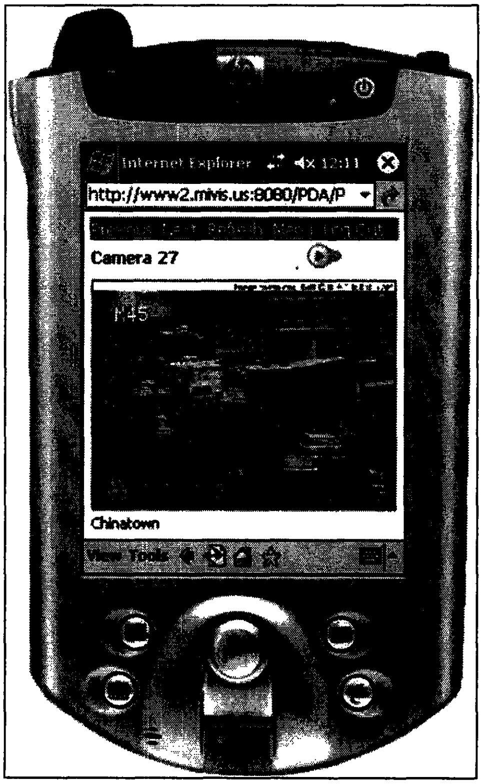
IBI Group's Massachusetts Interagency Video Information System (MIVIS)

IBI Group was hired prior to the 2004 Democratic National Convention to build the system, to be called MIVIS, in order to integrate and distribute video streams from cameras owned by different transportation and public safety agencies in the Boston metropolitan area. The system would be used for security and surveillance, as well as inter-agency coordination. There were about 100 cameras in the Boston area that provided coverage for critical areas. Communication between the various agency operations centers was established via the Interagency Communications Network (ICN). Then, the Video Distribution System (VDS) was used to provide video signal access over the internet. To access the video signals, according to a presentation by IBI Group (63), three methods were available:

- "Direct network connections (wireless) to agency operations centers
- On desktop computers through a web-based application on the Internet
- Through web-enabled PDAs (distributed to specific officials) via GPRS wireless Internet connections"

An example of a MIVIS user interface is presented in Figure 3.5 below.

Figure 3.5 MIVIS interface on a PDA.



Source: 63

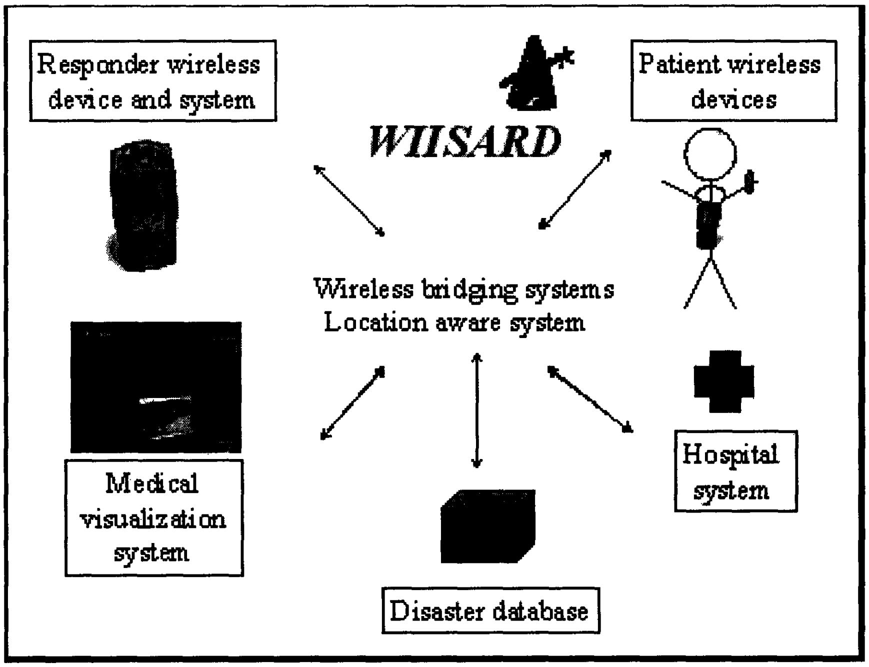
Calit2's Wireless Internet Information System for Medical Response in Disasters (WIISARD)

Once on a scene that requires immediate medical attention for a large group of people, a system such as the Wireless Internet Information System for Medical Response in Disasters (WIISARD) can be used to coordinate and manage care and transfer of patients to medical care facilities. Harvard University's CodeBlue project is another very similar system. (80)

WIISARD's goal is "to coordinate and enhance care of mass casualties in a terrorist attack or natural disaster." (70) In the event of a disaster, the first responders would be dispatched to the scene and the premises of the site would be immediately outfitted with mobile transponders to collect data and transmit information to the command center, which would also be set up directly at the scene. The responders would each have a RF tag and PDA that allows for location tracking of the responders and provides them with a communications means. Medical personnel would evaluate victims and place RF tags with triage information.

The sickest patients would also have a pulse oximeter placed on the fingertip to measure blood oxygen saturation and pulse rates. That information would then be sent to the responders' PDAs and the command center. (70)

Figure 3.6 The WIISARD network.



Source: 70

The command center will have a Medical Visualization System (MVS) that allows it to track, in the case of a chemical attach for example, "hot", "warm", and "cold" danger zones, track locations and conditions of tagged victims, track responders at the scene, gather information about transportation resources, send messages to responders, and view outside hospital data. With this information, the command center can direct responders at the scene to the victims most in need, assign transport vehicles and hospital vacancies for victims, and generally manage the medical care at the disaster scene. (70)

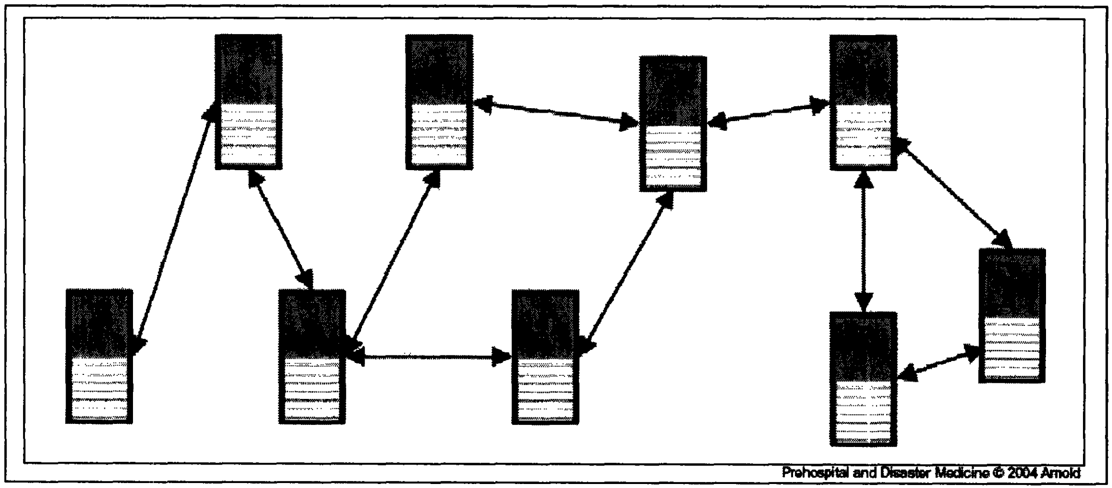
3.3.2.4 Wireless Networking Technologies

New wireless technologies are becoming available that may be resilient to breakdowns during disaster situations. One example is Wireless Peer Networking, described below.

Wireless Peer Networking for Disaster Response Information Sharing

Wireless technology will need to have a major role in information sharing during a disaster response. Recent and continued improvements in wireless technology have created a real potential for new applications such as disaster response information sharing. A problem with the standard, current wireless networks is that they rely on a centralized architecture and that their use during a disaster response assumes that power and wireless infrastructure will remain operational after such an event. A potential solution to this dependence on a centralized wireless network is a wireless peer network. In such a wireless Peer-to-Peer (P2P) network, each "peer" can produce, receive, and transmit information. The result is that there is no dependence on a centralized communications system that may become inoperational during a disaster, as each device can have its own power and computer processing capability. Moreover, as more "peer" device join the network, more paths for transmitting information are created, strengthening the network. (73)

Figure 3.7 Wireless Peer-to-Peer (P2P) Network Communications.



Prehospital and Disaster Medicine © 2004 Arnold

Source: 73

Various applications of the wireless peer network are suggested by Arnold et al (73). These networks could be used in order to automatically update situational awareness databases that keep track of such things as key disaster and response related events, scene assessment reports, and victim assessment reports. Victim and resource tracking can also be implemented using Radio Frequency Identification (RFID) tags that are able to communicate as "peer" devices. All tracked elements can then be mapped using GIS. "Peer" devices can additionally be used to retrieve information such as field medical manuals, World Health Organization

(WHO) Disaster Medicine Library, and immunization algorithms. Such information may need to be housed locally for reliable, fast access, however. "Peer" devices can also be utilized for reliable audio communications. (73)

3.3.2.5 Portable, Wireless Devices

Recently, there has also been rapid technological development in the realm of portable, wireless devices. Among other types of relevant technologies, smart phones and new Personal Digital Assistants (PDAs) are gaining new features both for their interface and networking capabilities that could prove useful in constructing a successful disaster response support system. Some details about emerging functionalities of smart phones and PDAs follow.

Smart Phones / Personal Digital Assistants (PDAs)

Wireless technology devices such as smart phones and PDAs are becoming more and more sophisticated. These devices have the potential to work as "peer" devices that were just described. A current, popular smart phone is Research-in-Motion's Blackberry. The blackberry offers advanced services such as mobile access to email, wireless internet, organizer feature, online data access, as well as text and instant messaging. Although some of these features are also currently available on many regular cell phones, Blackberries' "qwerty" keyboard, relatively large screen, and diverse features make it an ideal example of today's smart phone. The device also offers automatic synchronization with computers. Moreover, some Blackberries are now capable of operating on a wireless local area network (WLAN) in addition to the usual cellular wireless network over which it typically operates. (74)

Figure 3.8 A Blackberry Smartphone.

Source: 74

The potential utility of blackberries for public safety purposes has already been recognized by some prominent agencies. In 2003, the Fire Department of New York (FDNY) began using blackberries to allow FDNY staff to have mobile email access. In 2004, the Los Angeles Police Foundation was provided 200 Blackberries for use by LAPD lead officers. The primary benefit was again cited to be the enablement of mobile email access. (75)

Smart phones appear to have tremendous promise in the near future. Research-in-Motion is certainly not the only company that is developing smart phones. For example, in 2006, Microsoft and Qualcomm have detailed a pact to accelerate the development of smart phones. Microsoft has developed a Windows Mobile operating system that facilitates PC-like feature integration in cellular devices. According to analysts at the Stamford, Connecticut based company, Gartner, "sales of smart phones running on Windows Mobile should reach 64.5 millions by 2009." (76) These new capabilities will create further opportunities for use of smart phones-type devices for disaster response purposes.

3.3.3 Transportation Operation Technologies

A key challenge during a disaster response is mobility of the affected public and responders. Systems and technologies that can assist with such processes are divided into the following categories:

1) Evacuation Management and Modeling Systems

2) Traveler Information Technologies
3) Vehicle-Infrastructure Integration Technologies
4) EMS/Responder Mobility Enhancement Technologies

3.3.3.1 Evacuation Management and Modeling Systems

Monitoring of evacuation proceedings via various technologies as well as software that can be used to forecast traffic patterns during such events are important elements of achieving mobility goals during a disaster. During emergency evacuations, the state of the transportation network will be especially dynamic. Managers of the network must be able to respond to the real-time changes by re-routing traffic as incidents progress or new emergency-related events occur. US DOT is seeking technology that is particularly aimed to assist Transportation Management Centers (TMCs) to have a support system capable of evacuation re-routing in real-time. (47) Traveler information technologies (described in the next section) can be used to provide generic or personalized evacuation guidance to evacuees.

Traffic Estimation and Prediction System (TrEPS) Software

The US DOT project will build on software whose development has already begun, called Traffic Estimation and Prediction System (TrEPS). A system such as TrEPS is needed, because ITS systems need not only real-time traffic information but also need a prediction of the developing traffic patterns in order to support the best decision making during evacuations. This software is built to provide such prescriptive support. (49)

3.3.3.2 Traveler Information Technologies

If available during a disaster, an area Advanced Traveler Information System (ATIS) system can be used in order to disseminate transportation system related information to the public. Such systems as Variable Message Signs (VMS), Highway Advisory Radio (HAR), websites, and 5-1-1 all are common parts of an ATIS system. This information can be integrated with other information technologies to be provided via other mediums such as portable navigation devices, for example. Recently, NAVTEQ and CBS radio have implemented just this with their new feature of broadcasting real-time traffic data that can be interpreted by a portable, wireless device.

VMS, HAR, Websites, and 5-1-1

ATIS systems such as VMS, HAR, websites, and 5-1-1 systems exist and are used during disasters, if still available, to disseminate information the public. However, anecdotal experience has shown that the information that is provided to the public with these systems is too general and does not adequately meet the needs of the public since it is not route-specific and not detailed enough. US DOT is currently interested in further researching the challenges of ATIS information dissemination during disasters and the strategies and technological tools that can help to remedy the problems. (51) One possible solution is personalized delivery of real-time traffic information, such as could be accomplished by the NAVTEQ/CBS project, discussed below.

Real-time broadcasting of traffic information over the Radio Data System (RDS)

In 2006, NAVTEQ and CBS Radio teamed up to provide real-time traffic information to mobile, wireless devices, including Portable Navigation Devices (PNDs) and PDAs. The information will be streamed via the Radio Data System (RDS) protocol. The RDS traffic information will be understood by the mobile devices and appropriately displayed for the user. Information such as planned incidents (e.g. construction), unplanned incidents (e.g. accidents), and traffic flow conditions (e.g. congestion) will be gathered for processing and distribution from Westwood One's Metro/Shadow, departments of transportations, police and emergency services, road sensors, cameras, and airborne reports. (72)

3.3.3.3 Vehicle-Infrastructure Integration (VII) Technologies

A major government initiative commonly referred to as Vehicle-Infrastructure Integration, or "VII", refers to the development of advanced vehicle-to-vehicle and vehicle-to-infrastructure communications systems that are decentralized in nature. This means that communications will occur on an opportunistic (or proximity) basis. Although current applications tend to focus on collision safety systems, in fact, different stakeholders in VII appear to see broader applications. A system such as this can also be used for more general communication needs from infrastructure to vehicles and through to other vehicles.

In terms of disaster response, “drivers’ responses to emergencies such as incidents and evacuations are typically based largely upon their own knowledge of the environment and their perceptions of the emergency condition and alternatives available to them.” (53) To provide all necessary types of information to the public in a specific enough and useful form, the currently available ITS technologies may not be enough. For example, VMS signs for information dissemination are limited since they have to display the same message to everyone on the road and can not necessarily be seen by everyone on the road at any given period of time. (53)

Instead, US DOT hopes to use vehicle-infrastructure and vehicle-to-vehicle communication systems to establish direct links for each vehicle on the transportation network to both other vehicles and to a central IT infrastructure. The benefits of using VII for emergency transportation operations could include the following, according to US DOT:

- “Traffic volumes and flows on evacuation routes and routes surrounding the incident scene can be monitored by combining and analyzing anonymous data signals sent from individual vehicles.
- Automated in-vehicle systems can recognize incidents (for example, air bag deployment in a collision), or record event data (such as unusual deceleration rates, and more routine kinematical or operational data) that can be monitored remotely (and anonymously) to identify an event outside of the vehicle.
- Warnings can be sent to drivers of vehicles directly affected by, and endangered by an event.
- Route and path information can be communicated to drivers during an evacuation emergency, where messages are tailored to the location of individual vehicles.
- Messages can be sent to individual vehicles to encourage them to make way for emergency responders by vacating a travel lane, by moving to one side, or just to make them aware of the need to stay out of the way.” (47)

3.3.3.4 EMS/Responder Mobility Enhancement Technologies

During disasters, Emergency Medical Services (EMS) vehicles and other responder vehicles need to be able to traverse the transportation network (which is likely to be impaired) as quickly as possible in responding to incidents. Technology capabilities such as signal priority and real-time route guidance can be extremely useful in assisting EMS in arriving at incident scenes as quickly as possible. Together, these systems can be a supplement to other ITS systems, such as lane and ramp control systems, to provide better mobility for responders.

3.4 Chapter Summary

In this chapter, we provided the results of an IT and ITS technology review for disaster response operations. Both IT and ITS technologies are emerging that have the potential to allow for a better disaster response technology support system. The technologies that were discussed in this chapter are summarized below.

Sensing and Assessment Technologies included:

1) Infrastructure and Environmental Sensing Systems
2) Vehicle Tracking Technologies
3) Incident Tracking Technologies

Communication and Coordination Technologies included:

1) CAD-ITS Integrated Systems
2) Central Technology Hub Systems
3) Disaster Response Field Communication Systems
4) Wireless Networking Technologies
5) Portable, Wireless Devices

Transportation Operation Technologies included:

1) Evacuation Management and Modeling Systems
2) Traveler Information Technologies
3) Vehicle-Infrastructure Integration Technologies
4) EMS/Responder Mobility Enhancement Technologies

In the next chapter, Chapter 4, we will use the information from Chapter 2's three disaster cases and the information from the technology review in this chapter to propose specific applications of emerging IT/ITS technologies to improve the disaster responses of the three case studies.

Chapter 4. A Disaster Response Support System and Its Application to the Disaster Cases

The purpose of this chapter is to propose a Disaster Response Support System (DRSS) that could be used to provide better technological support for the disasters such as those that we investigated in Chapter 2. Based on that chapter's findings, we concluded that all three of our disaster cases actually experienced many rather similar response problems due to the lack of sufficient IT/ITS systems. As a result, we hypothesize that using the emerging technologies that were subsequently presented in Chapter 3, a generic technology support system can be conceived that could be applied to all of the cases. This is what we intend to do in this chapter. First, the "backbone" of the intended system will be presented. This will set up the basic structure of the DRSS. Following this, specific descriptions of how such a system could have been used to improve the disaster response of each of our three disaster cases will be provided.

4.1 The Disaster Response Support System (DRSS): Its Benefits and Proposed "Backbone"

Compared to the current disaster response support systems, the DRSS would provide much more advanced capability, interoperability, and robustness. The improved capability will stem from the advanced technologies and systems that are going to be integrated into the DRSS. The interoperability will result from the DRSS' ability to provide a communication and coordination link among the entire disaster response community, including engaged responders and effected civilians. Finally, DRSS will be significantly more robust than current systems since will not rely on centralized, physical communications infrastructure (e.g. cellular network). Instead, the Peer-to-Peer (P2P) wireless network will allow DRSS components to interact without relying on such vulnerable systems.

The proposed DRSS backbone is comprised of four main components:

1. "Peer" Personal Digital Assistants (PDAs)

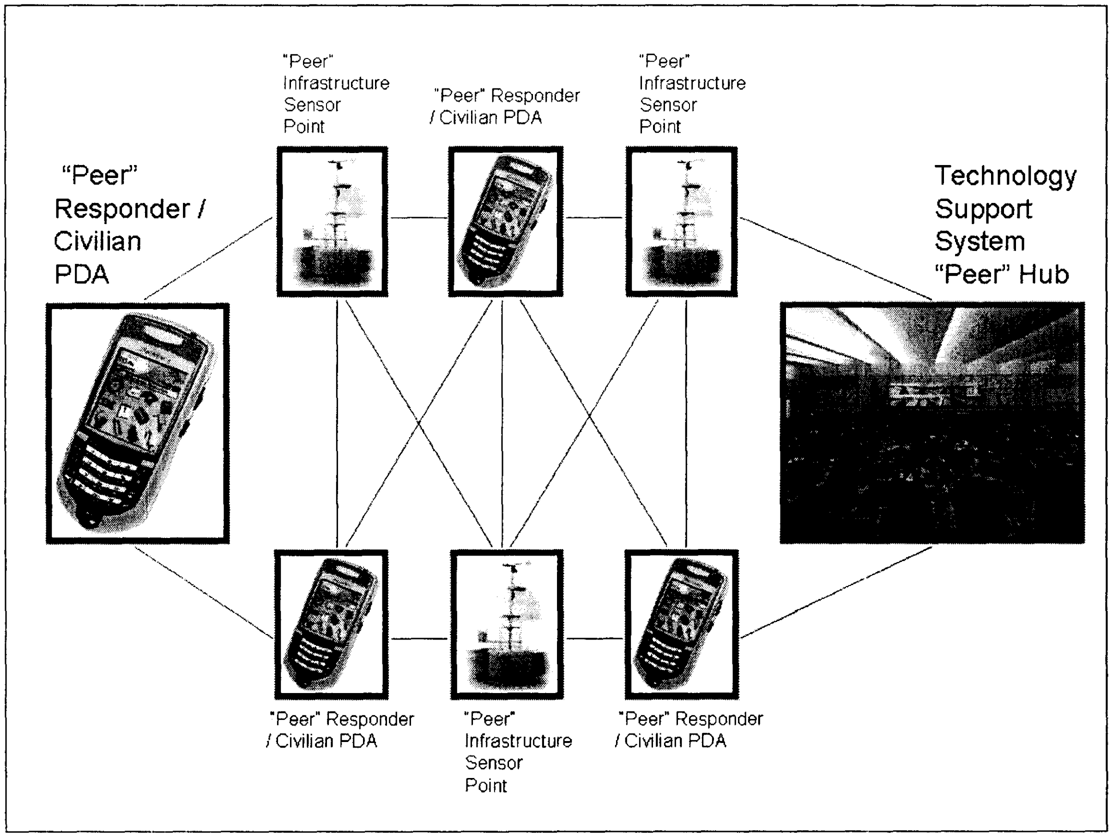
2. “Peer” Infrastructure Sensor Points
3. P2P Wireless Network
4. Technology Support System “Peer” Hub

Figure 4.1 shows the basic backbone structure of the DRSS and the text that follows explains the four basic components.

First, the backbone will require that responders and civilians have (some form of) a PDA device. Even the basic PDA will be equipped with several key capabilities, including P2P wireless networking capabilities, data storage and processing software, and the ability to be docked with a vehicle’s computer systems. PDAs will allow for the capability for direct communications with other PDAs via voice, data, and visual mediums. Additionally, other PDA capabilities will include, for example, location reporting and route-guidance systems.

Second, “peer” infrastructure sensor points, with information technology capabilities, will also be an integral part of the backbone. These points will primarily serve as sensing information gathering points. For example, these could be sites of hardware installments such as CCTV cameras, air sensors, or structural integrity sensors. “Peer” infrastructure points will, in addition to hardware, have software that controls the gathering of pertinent information. Additionally, there will be a capability for automatic uploading of gathering sensed information. Communication will be enabled via the P2P network.

Figure 4.1 Disaster Response Support System Backbone Architecture.



Third, the P2P network itself is a key to the backbone of the proposed system. The decentralized communications network will create a communications backbone that will be resilient to typical disaster communications disruptions such as infrastructure damage and power outages. The P2P network will pass information between all of the "peer" entities in the support system, including PDAs, infrastructure points, and the hub. The P2P network has to be capable of passing information rapidly in certain situations, since the proposed system will allow information sharing from vehicle-to-vehicle (while stationary or moving) when the PDAs are docked with a vehicle's computer system.

Finally, at least one central hub will be used to store and process disaster response-related information. The hub will integrate many of the key technologies and systems that were discussed in Chapter 3. First, all infrastructure and environmental sensing, vehicle tracking, and incident tracking related information will be uploaded to the hub for storage and processing. Computer-Aided Dispatching (CAD) and ITS technologies will also be operated in an integrated manner from the hub. CAD system will work together with incident tracking systems to make incident response more efficient. ITS technologies to be integrated with the hub and the CAD systems will include traveler information, Vehicle-Infrastructure Integration (VII), and EMS/responder mobility enhancement technologies. Additionally, evacuation management software will be housed at the hub. Lastly, security of the Disaster Response Support System will also be administered from the hub. Security will entail, for example, restricting unnecessary information access to civilians that only belong on responder PDAs. All communication with PDAs and infrastructure sensor points will be accomplished via the P2P network. We note that although a hub adds much capability to the DRSS, in the event that no hub is available, the rest of the system can still operate and sustain a substantial portion of the intended DRSS functionality.

4.2 Disaster Response Support System Application to the Northridge Disaster Response

In this section, we present our vision for how the Disaster Response Support System could have been used to improve the disaster response function operations for the Northridge earthquake. The same framework as was set up in the introduction to Chapter 2 was used in this analysis, with the standard set of functions serving as the basis.

4.2.1 Northridge -- Sensing and Assessment

EMERGENCY PHASE

Disaster sensing and assessment

This function was performed rather successfully during the Northridge response. The CUBE/REDI system, discussed in Chapter 2, successfully gathered earthquake characteristic information.

Critical infrastructure sensing and assessment

The Northridge response team had to generally rely on manual inspection of critical infrastructure, such as the transportation network. To gather information quicker and in a manner that is comprehensive and easy to re-transmit, an infrastructure sensor network would be needed to monitor all of the various critical infrastructures.

Victim location / tracking

A spatio-temporal analysis of 9-1-1 calls could have a role in assessing where assistance is most needed. Of course, after the Northridge earthquake hit, phone communications were not available. However, if civilians are equipped with "peer" PDAs capable of communications on a metropolitan area scale, then calling in for assistance to a 9-1-1 command center would no longer be a problem. Moreover, a system that is an extension of the new 9-1-1 systems that allows for automatic location of a call as well as the exchange of multiple forms of media could additionally allow for more comprehensive analysis of emergency assistance needs. The spatio-temporal analysis of all of the calls can be used in order to map on a GIS interface the locations of the calls, as well as particular needs and urgencies of particular situations.

Responder / emergency response activity tracking

The primary technologies that we propose to be used for responder / emergency response activity tracking were actually ones that were originally intended for use for communication and coordination. Essentially, we propose that responders also have "peer" PDAs. These devices, communicating over the P2P wireless network, could be used to automatically track the location of responders. Additionally, responders could use the devices to report on their status.

RELIEF PHASE

Relief activity tracking

Similarly to the previous function, once the relief phase begins, responders can continue using their "peer" PDAs to report information about shipments of food, provision of shelter, or other relief updates. Their location could again be tracked via their "peer" devices.

Resource tracking

Real-time location tracking of supplies is very important for a disaster such as Northridge. Many citizens were displaced into shelters, for example, and so food and water would need to be delivered for them. Also, the visibility of the location of these supplies to a wide variety of managers and responders would be important for situational awareness. A tracking system such as GE's VeriWise or the U.S. Military's IRRIS system would be great starts to establishing such a system.

RECOVERY PHASE

Recovery activity tracking

This function was performed successfully during the Northridge response using available IT/ITS tools.

4.2.2 Northridge -- Communications and Coordination

EMERGENCY PHASE

Communication and coordination between response agencies for emergency operations

Using the proposed wireless "peer" network, there would no longer be a need to rely primarily on slow satellite communications for inter-agency communications. Command center personnel could also be equipped with "peer" PDAs that could allow for communications with personnel from other agency command centers. Additionally, some automated systems could help coordination of the response. For example, the CAD-ITS integrated system that would be housed at the "peer" hub would automatically generate incident information and routing information to provide for responders.

Communication and coordination between response agencies and emergency responders

"Peer" PDAs could provide a means for agencies to issue information and orders to their responders via various mediums: voice, graphics, or data. In turn, responders could also pass information back to their agency via similar means.

Communication and coordination between emergency responders

Responders could additionally use the "peer" PDAs to communicate with other responders in the field. The interface on their PDAs to accomplish this could be modeled on the emerging CapWIN system. Additionally, for medical care coordination, a system such as WIISARD could be used to coordinate and manage care and transfer of patients to medical care facilities or shelters. WIISARD, in particular, is designed to be used for one medical emergency scene. However, in the Northridge emergency response, there would be many, decentralized emergency situations requiring immediate attention. Thus, the functionality of this system needs to be expanded to be able to coordinate care and transfer of patients for an entire affected region.

Communication and coordination between victims/general public and response agencies
Civilian "peer" PDAs could be used by civilians to make requests for help and by response agencies (e.g. 9-1-1) to provide civilians with whatever standard information they typically provide to victims of an earthquake such as Northridge. Additionally, civilians could use the PDAs to receive general disaster information as well as transportation related information.

RELIEF PHASE

Communication and coordination between response agencies to coordinate relief
During the relief phase, many standard means of communications were still being repaired after the devastation of the Northridge earthquake. Using the proposed system, command center personnel could continue using their "peer" PDAs to communicate with other command centers during the relief phase.

Communication and coordination between response agencies and responders during relief
Similar communication problems between agencies and responders continued during the transition from the emergency to relief phase. With the proposed system, responders could continue using their "peer" PDAs to maintain communications with command centers.

RECOVERY PHASE

Communication and coordination between all relevant agencies to coordinate recovery
Once standard means of communications were beginning to be re-established during the recovery phase, there would not be as much of a need for disaster response-enabling communications. The available means during this phase were sufficient for the Northridge response.

4.2.3 Northridge -- Transportation Operations

EMERGENCY PHASE

Mobility/evacuation of victims/general public
No evacuation was necessary after the Northridge earthquake. However, victims and the general public had to maintain mobility during the emergency phase. To enable them to

maximize their mobility, the best method would have been to provide them with travel information. Thus, traveler information technologies would have been useful here. This information could have been received via “peer” PDAs, which could process the information to provide route-guidance.

Mobility of emergency responders

Traveler information technologies could also have been used by responders to receive real-time travel information on their “peer” PDAs, which could also provide them route-guidance. Vehicle-Infrastructure Integration (VII) could be used to enable communication from responders’ docked PDAs with the signalization system to provide them signal priority.

RELIEF PHASE

Support of temporary transportation movements

During the relief phase, civilians could use their “peer” PDAs to receive traffic (e.g. detour) and transit (e.g. new services) updates and real-time information. Additionally, transportation managers at the “peer” hub could use the civilians’ “peer” PDAs to track activity on the transportation network to make informed management decisions.

RECOVERY PHASE

Support of new (or original) transportation movements

As during the relief phase, civilian “peer” PDAs could continue to be a useful monitoring and information dissemination tools that could allow for the most effective use of a transportation system that continues to undergo repair.

4.3 Disaster Response Support System Application to the 9/11 Disaster Response

In this section, we present our vision for how the Disaster Response Support System could have been used to improve the disaster response function operations for the 9/11 terrorist attacks on New York. Again, the same framework as was set up in the introduction to Chapter 2 was used in this analysis, with the standard set of functions serving as the basis.

4.3.1 September 11 -- Sensing and Assessment

EMERGENCY PHASE

Disaster sensing and assessment

The fact that 9/11 was a terrorist attack in which commercial jets were crashed into the World Trade Center (WTC) was very quickly recognized by the response community. Thus, the basic characteristics gathering was not a problem for the disaster response.

Critical infrastructure sensing and assessment

Sensing and assessment of the critical infrastructure would best be accomplished in the 9/11 scenario with better communication capabilities. Again, as with the Northridge earthquake, the applicable emerging technology for this function was originally intended for communication and coordination purposes, but it also appears to be the best fit for this function. We propose that responders and civilians reporting information about various critical infrastructure to a "peer" hub would be the most efficient way to gather reliable information in the case of 9/11. For example, to assess the conditions in the various floors of the towers, gathered facts from 9-1-1 callers and responders about their surrounding conditions could be aggregated at the "peer" hub to create a reasonable picture of the overall conditions inside. Another example would be for subway operators to report on their surrounding conditions (which they actually did). Integrating all of this gathered information in one location would result in a comprehensive view of the status of critical infrastructure.

Victim location / tracking

Incident tracking technologies could be used to maintain a real-time map of the incidents within the towers. Using the new 9-1-1 systems, information could be streamed between victims and the "peer" hub via multiple media. "Peer" PDAs would provide the communications capability to allow for a resilient tracking method that would work even when a disaster such as 9/11 damaged the standard communications network.

Responder / emergency response activity tracking

Responder "peer" PDAs could be monitored to track the location of responders. Additionally, responders could use the PDAs to report their status information.

RELIEF PHASE

Relief activity tracking

As we defined it, the relief phase of 9/11 mostly dealt with transportation relief. The systems that were available to share relief activity information were sufficient for this purpose since it just involved updates from various transportation agencies regarding the status of their facilities. Thus, emerging technology applications were not sought.

Resource tracking

Again, resource tracking was not judged to be a significant problem for the 9/11 response. Thus, emerging technologies were again not sought to support this function.

RECOVERY PHASE

Recovery activity tracking

Recovery activity tracking was also not judged to be a significant problem. Thus, the tracking tools available during the 9/11 response appear to have been sufficient.

4.3.2 September 11 -- Communications and Coordination

EMERGENCY PHASE

Communication and coordination between response agencies for emergency operations

The P2P wireless network can be used to connect agency command centers with each other. Agency commanders that were in the field would be equipped with "peer" PDAs that would allow them to communicate and share information with other agency commanders.

Communication and coordination between response agencies and emergency responders

Emergency responders could use their "peer" PDAs to maintain contact with their agency command. Conversely, agency command could also issue orders and pass information to responders' "peer" PDAs.

Communication and coordination between emergency responders

Responders can use their "peer" PDAs to communicate with each other over the P2P network. The interface can be modeled after that of CapWIN for general information sharing. For medical care coordination, WIISARD would be very appropriate for the 9/11 emergency response.

Communication and coordination between victims/general public and response agencies

The victims inside the towers could use their "peer" PDAs to communicate with 9-1-1 to ask for help, transmit data to 9-1-1 systems, and receive instructions from 9-1-1 regarding their best course of action. The general public outside of the towers could use their "peer" PDAs to receive instructions for how to best evacuate Lower Manhattan and what the overall status of New York City transportation network is.

RELIEF PHASE

Communication and coordination between response agencies to coordinate relief

The tools available for communication and coordination during the relief phase of the 9/11 disaster response were sufficient for the intended purposes.

Communication and coordination between response agencies and responders during relief

Again, the tools available for communication and coordination during the relief phase of the 9/11 disaster response were sufficient for the intended purposes.

RECOVERY PHASE

Communication and coordination between all relevant agencies to coordinate recovery

The communication and coordination during the recovery phase was sufficient as well. Thus, no emerging IT/ITS are needed to improve response.

4.3.3 September 11 -- Transportation Operations

EMERGENCY PHASE

Mobility/evacuation of victims/general public

The general public that was evacuating Lower Manhattan needed information regarding how to best do that. Evacuation management software could have been used to monitor evacuation activity via civilian "peer" PDAs. Then, traveler information technologies could stream evacuation related information directly to these "peer" PDAs. The PDA can then provide route-guidance or transit-related instructions to the traveler. Similar services could have been provided for those not necessarily evacuating Lower Manhattan but still traveling within the New York metropolitan area during the emergency phase of the 9/11 response.

Mobility of emergency responders

Responders could, as the general public, also receive traveler information on their "peer" PDAs. However, since some of the roads were closed explicitly to allow responder vehicles to pass, they would need specialized treatment regarding data sharing and processing. Additionally, when in their vehicle, docked "peer" PDAs could communicate via a VII-type of platform with the signalization system to provide signal priority for responders.

RELIEF PHASE

Support of temporary transportation movements

During the relief phase of the 9/11 response, New York's transportation network was disrupted in multiple ways. Still, some commuters and other travelers continued to use the network. Using the proposed system and providing these users with traveler information on the "peer" PDAs would make their travel more efficient in the degraded circumstances.

RECOVERY PHASE

Support of new (or original) transportation movements

As during the relief phase, New York's transportation network continued to be impaired by detours and travel restrictions in Lower Manhattan. Traveler information on "peer" PDAs would continue to be a useful travel support tool for commuters and travelers in the area.

4.4 Disaster Response Support System Application to the Katrina Disaster Response

In this section, we present our vision for how the Disaster Response Support System could have been used to improve the disaster response function operations for Hurricane Katrina. Once again, the same framework as was set up in the introduction to Chapter 2 was used in this analysis, with the standard set of functions serving as the basis.

4.4.1 Katrina -- Sensing and Assessment

EMERGENCY PHASE

Disaster sensing and assessment

Characteristics of Hurricane Katrina were successfully gathered in advance of the hurricane's landfall. The currently available technology tools for a disaster such as Katrina were sufficient, and thus, no emerging technologies were sought.

Critical infrastructure sensing and assessment

In order to gather critical infrastructure status information, for the most part, the best way would have been to aggregate information reported via responder and civilian "peer" PDAs. Information regarding flooding, for example, would probably best be gathered via this method. Various bits of information could create flood maps while satellite and aerial imagery could not yet be obtained. At the same time, infrastructure sensing systems could also have been used to automatically gather information. One application would be to implement automatic sensing of the levy system. To download data from such a sensing system, the P2P network could have been used, although a system which would work even when the levies became flooded would be needed.

Victim location / tracking

Emerging 9-1-1 tools could be used to map out assistance requests from victims of the storm. To make the requests in the first place, civilian "peer" PDAs could be used. Additionally, in the Katrina scenario, if the "peer" hub were located in the city of New Orleans, it is possible that the center would be flooded. Thus, the "peer" hub ideally needs to be located so that it is resilient to this type of disaster.

Responder / emergency response activity tracking

Responder "peer" PDAs could be used to track real-time locations of responders. Responders could also use their "peer" PDAs to report their status information.

RELIEF PHASE

Relief activity tracking

Responder "peer" PDAs could be used to enable communications with responders to gather information regarding relief activities. As during the emergency phase, "peer" PDA locations could be tracked.

Resource tracking

Real-time location tracking of resources such as food, water, and medical supplies could have provided information to relief managers regarding the status of these shipments, assisting them in making more informative decisions. Systems such GE's VeriWise or U.S. Military's IRRIS system could be used as the basis for accomplishing this.

RECOVERY PHASE

Recovery activity tracking

By the time the recovery phase had begun for the Katrina response, enough communications had been brought in to sufficiently track recovery activities. Thus, an emerging technology was not sought to improve this function.

4.4.2 Katrina -- Communications and Coordination

EMERGENCY PHASE

Communication and coordination between response agencies for emergency operations

Agency commanders could stay connected via their "peer" PDAs to coordinate agency activities. "Peer" hubs could also be connected to the rest of the response community via the same P2P network.

Communication and coordination between response agencies and emergency responders

The P2P network could also be used to maintain communications between responders and agency commanders as well as "peer" hubs.

Communication and coordination between emergency responders

The P2P network could also be used to establish a robust communications network between the various emergency responders. A CapWIN-type of platform could be used for general information sharing, and a WIISARD-type of platform could be used for medical care coordination.

Communication and coordination between victims/general public and response agencies

The P2P network could be used to provide a communication means between civilians and response agencies.

RELIEF PHASE

Communication and coordination between response agencies to coordinate relief

During the Katrina response, communication and coordination problems continued during the relief phase. The P2P network could have served as a useful tool to connect agency commanders.

Communication and coordination between response agencies and responders during relief

Again, as during the emergency phase, the P2P network could continue to be used to connect agencies with responders.

RECOVERY PHASE

Communication and coordination between all relevant agencies to coordinate recovery
By the recovery phase of the Katrina response, available communication and coordination tools were sufficient for the intended purposes.

4.4.3 Katrina -- Transportation Operations

EMERGENCY PHASE

Mobility/evacuation of victims/general public
Prior to Katrina's landfall, most of New Orleans' population evacuated the area. Although those that wanted to and could leave were generally able to get out of the city successfully, emerging evacuation management technologies could have helped to streamline the evacuation operation. In order to monitor evacuation activity and provide information to the evacuees, civilian "peer" PDAs could once again be used.

Mobility of emergency responders
After the storm made landfall and caused heavy damage, in order to most efficiently traverse the damaged and mostly flooded transportation network of New Orleans, emergency responders would have benefited from received real-time transportation network related updates on their "peer" PDAs. Additionally, for the many responders that would not necessarily be familiar with New Orleans, route-guidance (for both responder vehicle and for responder boats) would have been extremely useful.

RELIEF PHASE

Support of temporary transportation movements
During the relief phase of the Katrina response, all remaining New Orleans were in the process of being evacuated by responding authorities. There does not appear to have been substantial need for personal mobility for commuting to work or other "every day" type of activities since the city was being completely evacuated. Thus, we do not propose an application for an emerging technology.

RECOVERY PHASE

Support of new (or original) transportation movements
As civilians continue to return to the New Orleans area, there becomes more of a need to support transportation movements in the metropolitan area. Various reconstruction activities are going to continue to create a dynamically changing transportation network. Civilian "peer" PDAs could be used to provide civilians with personalized travel information and route-guidance.

4.5 Chapter Conclusion

In this chapter, we presented a vision of a Disaster Response Support System (DRSS) that could be used to improve current disaster response operations. The backbone of the DRSS consists of four main components: "peer" PDAs, "peer" infrastructure sensor points, the P2P wireless network, and at least one "peer" hub. Using this framework as a basis for the DRSS, specific applications of emerging IT and ITS technologies comprising the DRSS can be proposed for improving disaster response operations. The focus of application of the DRSS was for the three disaster cases that were discussed in Chapter 2. The results of the application analysis done in this chapter for the three cases are summarized below in Tables 4.1, 4.2, and 4.3. These tables are formatted in a similar style as the summary tables from Chapter 2 with tabs on the left-hand side where: "E" denotes Emergency Phase, "R1" denotes Relief Phase, and "R2" denotes Recovery Phase.

Table 4.1 DRSS Application to the Northridge Response

	[illegible]	[illegible]	[illegible]
	Sensing and Assessment		
E	Disaster sensing and assessment	None.	
	Critical infrastructure sensing and assessment	Infrastructure Sensing Systems	Use sensing for automated data gathering rather than manual data gathering
	Victim location / tracking	Incident Tracking Technologies, Wireless Networking, Portable Devices	Use emerging 9-1-1 technologies to keep better track of incidents, use P2P networking to ensure communications
	Responder / emergency response activity tracking	Wireless Networking, Portable Devices	Use P2P networking to track responder locations and provide them with robust communication means
R1	Relief activity tracking	Wireless Networking, Portable Devices	Use P2P networking to track responder locations and provide them with robust communication means
	Resource tracking	Vehicle Tracking Technologies	Use something like GE's VeriWise or U.S. Military's IRRIS to track resource shipments
R2	Recovery activity tracking	None.	
	Communication and Coordination		
E	Communication and coordination between response agencies for emergency operations	Wireless Networking, CAD-ITS Systems	Use P2P networking to link agency command centers, use automated coordination software such as CAD-ITS systems to pool together information

	Communication and coordination between response agencies and emergency responders	Wireless Networking, Portable Devices	Use P2P networking to facilitate multi-media information exchange between command centers and responders
	Communication and coordination between emergency responders	Wireless Networking, Portable Devices, Field Communications Systems	Use P2P networking to ensure communication, use platforms such as CapWIN and WIISARD to coordinate responder activity
	Communication and coordination between victims / general public and response agencies	Wireless Networking, Portable Devices	Civilian "peer" PDAs can be used by civilians to request assistance and to receive disaster related information
R1	Communication and coordination between response agencies to coordinate relief	Wireless Networking, Portable Devices	Use P2P networking to link agency command centers
	Communication and coordination between response agencies and responders during relief	Wireless Networking, Portable Devices	Use P2P networking to facilitate multi-media information exchange between command centers and responders
R2	Communication and coordination between response agencies to coordinate recovery	None.	
	Transportation Operations		
E	Movement / evacuation of victims / general public	Traveler Information Technologies	Provide civilians traveler information on their "peer" PDAs, which can provide route-guidance

	Mobility of responders	Traveler Information Technologies, VII, EMS/Responder Mobility Technologies	Provide responders traveler information on their "peer" PDAs, which can provide route-guidance; use VII and responder mobility enhancement technologies to provide signal priority
R1	Support of temporary transportation movements	Traveler Information Technologies	Civilians "peer" PDAs can be anonymously tracked to monitor transportation network, information can be provided to "peer" PDAs to facilitate mobility
R2	Support of new (or original) transportation movements	Traveler Information Technologies	Civilians "peer" PDAs can be anonymously tracked to monitor transportation network, information can be provided to "peer" PDAs to facilitate mobility

Table 4.2 DRSS Application to the 9/11 Response

	[illegible]	[illegible]	[illegible]
E	Disaster sensing and assessment	None.	
	Critical infrastructure sensing and assessment	Wireless Networking, Portable Devices	Use victim and responder "peer" PDAs to report on critical infrastructure status
	Victim location / tracking	Incident Tracking Technologies, Wireless Networking, Portable Devices	Use new 9-1-1 systems for advanced incident tracking, use victim "peer" PDAs to communicate with 9-1-1 operators
	Responder / emergency response activity tracking	Wireless Networking, Portable Devices	Use responder "peer" PDAs to track responder location and status

R1	Relief activity tracking	None.	
	Resource tracking	None.	
R2	Recovery activity tracking	None.	
	Communications and Coordination		
E	Communication and coordination between response agencies for emergency operations	Wireless Networking, Portable Devices	Use P2P networking to connect command centers, use "peer" PDAs to connect agency commanders
	Communication and coordination between response agencies and emergency responders	Wireless Networking, Portable Devices	Use responder "peer" PDAs to communicate with command centers
	Communication and coordination between emergency responders	Wireless Networking, Portable Devices, Field Communications Systems	Use "peer" PDAs to communicate with each other via CapWIN or WIISARD platforms
	Communication and coordination between victims / general public and response agencies	Wireless Networking, Portable Devices	Use civilian "peer" PDAs to facilitate communication between victims and 9-1-1 as well as the general public and transportation authorities
R1	Communication and coordination between response agencies to coordinate relief	None.	

	Communication and coordination between response agencies and responders during relief	None.	
R2	Communication and coordination between response agencies to coordinate recovery	None.	
	Transportation Operations		
E	Movement / evacuation of victims / general public	Evacuation Management Systems, Traveler Information Technologies	Use civilian "peer" PDAs to provide real-time travel information
	Mobility of responders	Traveler Information Technologies, VII, EMS/Responder Mobility Technologies	Use responder "peer" PDAs to provide real-time travel information as well as signal priority capabilities
R1	Support of temporary transportation movements	Traveler Information Technologies	Use civilian "peer" PDAs to provide real-time travel information
R2	Support of new (or original) transportation movements	Traveler Information Technologies	Use civilian "peer" PDAs to provide real-time travel information

Table 4.3 DRSS Application to the Katrina Response

	[illegible]	[illegible]	[illegible]
	Sensing and Assessment		
E	Disaster sensing and assessment	None.	
	Critical infrastructure sensing and assessment	Infrastructure Sensing Network, Wireless Networking, Portable Devices	Use responder and civilian "peer" PDAs to gather critical infrastructure information, use infrastructure sensing to assess levy system
	Victim location / tracking	Incident Tracking Technologies, Wireless Networking, Portable Devices	Use new 9-1-1 systems to better track incidents in real time, Use civilian "peer" PDAs to make assistance requests
	Responder / emergency response activity tracking	Wireless Networking, Portable Devices	Use responder "peer" PDAs to track responder location and receive status information from them
R1	Relief activity tracking	Wireless Networking, Portable Devices	Use responder "peer" PDAs to track responder location and receive status information from them
	Resource tracking	Vehicle Tracking Technologies	Use something like GE's VeriWise or U.S. Military's IRRIS to track resource shipments
R2	Recovery activity tracking	None.	
	Communications and Coordination		
E	Communication and coordination between response agencies for emergency operations	Wireless Networking, Portable Devices	Use P2P network to enable communications between agencies and between agency commanders in the field via their "peer" PDAs

	Communication and coordination between response agencies and emergency responders	Wireless Networking, Portable Devices	Use P2P network to connect agencies to responders
	Communication and coordination between emergency responders	Wireless Networking, Portable Devices, Field Communications Systems	Use responder "peer" PDAs to enable communication between responders, use CapWIN and WIISARD as platforms for coordination
	Communication and coordination between victims / general public and response agencies	Wireless Networking, Portable Devices	Use civilian "peer" PDAs to enable communication
R1	Communication and coordination between response agencies to coordinate relief	Wireless Networking, Portable Devices	Use P2P network to enable communications between agencies and between agency commanders in the field via their "peer" PDAs
	Communication and coordination between response agencies and responders during relief	Wireless Networking, Portable Devices	Use P2P network to connect agencies to responders
R2	Communication and coordination between response agencies to coordinate recovery	None.	

	Transportation Operations		
E	Movement / evacuation of victims / general public	Evacuation Management Systems	Use evacuation management tools to optimize pre-landfall evacuation, use civilian "peer" PDAs to track evacuation progress and disseminate information
	Mobility of responders	Traveler Information Technologies, EMS/Responder Mobility Technologies	Use responder "peer" PDAs to provide real-time transportation information, use route guidance on responder "peer" PDAs
R1	Support of temporary transportation movements	None.	
R2	Support of new (or original) transportation movements	Traveler Information Technologies	Use civilian "peer" PDAs to disseminate transportation information

An important observation that should be pointed out regarding the application discussed in this chapter is that many of the same technologies were suggested for the same functions of the three different disaster cases. As a result, as we had originally hypothesized, it appears that a generic DRSS does indeed have the potential to support disaster response operations of various disasters. This finding makes a DRSS such the one we suggest a practical and economical system to improve disaster response.

Although the creation of a DRSS has many advantages, there are certainly going to be barriers to implementing such a system. In the following chapter, Chapter 5, we discuss potential barriers, but also offer some strategies for overcoming them.

Chapter 5. Institutional and Technological Issues for Deploying the Disaster Response Support System (DRSS)

While there are apparent benefits to developing and deploying a system such as our proposed Disaster Response Support System (DRSS), there are also issues that will likely need to be overcome to achieve successful deployment. This chapter discusses issues that the author has anticipated will be barriers to deployment. While these are likely barriers, the author also believes that they can be overcome by various means. Ideas regarding how this might occur are also discussed.

5.1 Issues to Overcome

The issues presented are of two varieties: institutional and technological. Three institutional and two technological issues are proposed. They are as follows:

- Institutional Issue #1: Government responsibility for disaster response
- Institutional Issue #2: Upfront & maintenance costs
- Institutional Issue #3: Cultural change and training
- Technological Issue #1: "Peer" component compatibility
- Technological Issue #2: Security

We now discuss each of these issues more specifically.

5.1.1 Institutional Issue #1: Government responsibility for disaster response

First, there is a fundamental, innate characteristic of the United States' approach to disaster response that is in fact a barrier to implementing an integrated system such as our proposed DRSS. In the U.S., disaster response is currently the responsibility of local governments. (1) These governments often have very limited financial resources, and thus, it would most likely be very difficult for them to develop a system such as DRSS. Even if localities did successfully develop such a system, their system would still need to be able to interact with external systems. For example, in the case of Katrina, while some response personnel were local, external personnel such as personnel from the Department of Defense were also a substantive part of the response community there. The system needs to seamlessly integrate such external personnel into the DRSS.

While certain prominent federal government initiatives encourage development of IT/ITS for disaster response, the primary responsibility to act remains in the hands of the local governments. In the wake of, primarily, the growing terror threat to American soil, the U.S. government has made efforts to take on more of the responsibility of disaster response. The formation of the Department of Homeland Security, for example, reflects that. These types of steps that bring the issue of disaster management closer to the Federal Government appear to be the only way to develop systems that will protect the entire country, since only at this central level can comprehensive coordination occur and can sufficient funding be procured. Without this centralization, localities are likely to develop response support systems in an incompatible and insufficient way. Thus, strategies regarding perhaps placing more disaster response responsibility in the hands of the Federal Government should be considered.

5.1.2 Institutional Issue #2: Upfront & maintenance costs

Cost is clearly a huge inhibitor for any technological upgrade and it is no different for the situation of deploying a system such as the DRSS. There are two primary types of costs that will constrain deployment: upfront costs and maintenance costs. Upfront costs will include design of the DRSS, cost of purchasing hardware and software systems, and training of the response personnel. After the system is successfully deployed, it will need to be maintained via modifications to its design, purchasing of new and replacement hardware and software, and retraining of response personnel.

Although overall costs of the DRSS will be significant, deployment will be benefited by the fact that many of the components of this system will have day-to-day purposes that go beyond just their utility for supporting disaster response operations. For example, responder "peer" PDAs will be able to be used to assist response to everyday incidents that are encountered. Civilian "peer" PDAs can certainly be used for every day communication and information gathering purposes as well. Infrastructure sensors can be useful for monitoring and managing critical infrastructure. The "peer" hub will also be able to double as a center to manage every day incidents. Additionally, the Peer-to-Peer (P2P) wireless network will be available on a day-to-day basis to facilitate communications. As a result of these circumstances, the development of DRSS becomes much more feasible, since many of these components have multiple benefits.

5.1.3 Institutional Issue #3: Cultural change and training

It seems that it will also take some time for disaster response personnel and the general public to get used to using a system such as DRSS during crisis situations. Just as checking the internet for traffic information or using a route navigation system takes some time to get used to, so will other new IT/ITS systems. Moreover, this necessary cultural change will only be realistic if whatever the DRSS interface will be easy enough to adjust to. If there is too much difficulty in using the technology and it has too many complications and features, disaster responders and effected civilians will not use it, particularly since they know the hectic, emergency environments in which they will have to operate during a disaster response.

Even with the DRSS is designed in a sensible way, training will nevertheless be required, particularly for responders. This process will require time, effort, and financing, but will be made easier if the DRSS is designed in a way that maximizes its benefits while minimizing the effort of training and use. It is the belief of the author that since the intended interface devices for responders and civilians will be wireless PDAs, which already are commonly used for everyday purposes, the adjustment to use these devices' additional disaster response support features should be a natural extension.

5.1.4 Technological Issue #1: "Peer" component compatibility

Achieving compatibility between all of the intended components of the DRSS will be a challenge. "Peer" PDAs, for example, come in various forms, since multiple manufacturers produce them. Even if the disaster response community obtains one type of responder PDAs that are compatible with each other (which seems unlikely given today's decentralized approach to disaster response), the proposed design of the DRSS suggests that compatibility also needs to occur with civilian "peer" PDAs, "peer" infrastructure sensor points, as well as the "peer" hub. Civilians are sure to have devices that are designed by different manufacturers, since forcing them to carry a particular brand would be impossible (and certainly not being recommended by the author). Moreover, infrastructure sensor networks and "peer" hubs are also bound to have localized uniqueness.

Ensuring compatibility between these components of the DRSS will be a major technological challenge. It will be necessary to have a strong, centralized organization that can coordinate all necessary parties responsible for the various components of the DRSS. These parties will need to build into their technologies the capability of compatibility within the DRSS framework.

5.1.5 Technological Issue #2: Security

Security of the DRSS will be a key technological issue. Two primary vulnerabilities comprise the issue. First, there is the possibility that the DRSS P2P wireless network will get hacked. As with any computer network, the DRSS would be prone to such tampering. Standard security procedures should be followed to guard against such attacks.

Second, there is vulnerability that responder PDAs are taken and used by unauthorized people. Responder PDAs will need to be designed to have certain information sharing privileges. Additionally, senior ranking responders will likely need to have additional privileges (e.g. issuing orders) that regular responders will not have. It will be important that responder PDAs are used only by their owners, especially in the case of those responders that have additional privileges. Passwords and biometric checks can be used to secure these devices. Additionally, as was mentioned earlier, the "peer" hub will need to continually check and validate information that is being sharing on the DRSS network.

5.2 Chapter Conclusion

Although there are apparent benefits to deploying better IT/ITS systems for disaster response, such as our proposed DRSS, there are clearly going to be technological and institutional issues that will need to be overcome before deployment can successfully occur. At the same time, there is reason to believe that these issues can be overcome via various means.

On the institutional front, the fact that disaster response responsibility is decentralized into the localities presents a challenge to deploying a DRSS on a national scale. It appears that more responsibility and coordination will have to occur at the federal level to ensure an integrated system that can be used to protect the entire country. Additionally, upfront and maintenance costs of a DRSS may at first seem as if they are going to be insurmountable. However, since the proposed DRSS is comprised of components that are becoming commonplace for everyday use, adding disaster response support capabilities to these components and integrating them together becomes more feasible. Moreover, it is noted that a cultural change and training will be required during the deployment of the DRSS. To aid in this effort, it is hoped that since the primary interface device for responders and civilians will be PDAs, which are already commonly used, the adjustment to additionally use these devices during a disaster response situation will be less monumental.

On the technological front, the compatibility of "peer" components of the DRSS will be a barrier. Components will be produced by various manufacturers and local systems will have particular uniqueness. This technological issue is another reason why it will be important to have a strong, centralized organization coordinating the development and deployment of the DRSS, since this organization will be necessary to ensure compatibility on a national level. Finally, security of the DRSS as a whole and individual PDA "peer" devices is going to be a key technological issue. It will be critical to guard against hacking of the system and implement measures that ensure PDAs are being operated by their intended users.

This now completes the primary content chapters of this thesis, Chapters 2-5. The next chapter, Chapter 6, will conclude with the main findings of this report.

Chapter 6. Thesis Conclusions and Recommendations.

This final chapter first includes our summary of answers to the report's four main questions. These questions were defined in Chapter 1, the Introduction. Second, we provide general conclusions and recommendations. Finally, recommendations for future research are presented.

6.1 Summary of Answers to the Four Main Questions

In this report, we asked and answered four primary questions. Now, after presenting the detailed results, we summarize our answers to these four questions.

6.1.1 What are the problems and challenges facing typical disaster response processes in the United States? (Chapter 2)

The approach of answering this question was to analyze three prominent disaster case studies with the intention of assessing the response performance for various disaster response functions, and also, assessing the details of the IT/ITS systems and technologies that were available to support the disaster response operations. The three chosen case studies were:

- The 1994 Northridge, CA Earthquake
- The September 11, 2001 Terrorist Attacks on the World Trade Center
- The 2005 Landfall in New Orleans, LA of Hurricane Katrina

Before performing the analysis, a framework was set up which broke disaster response operations up on several different dimensions. First of all, we divided response operations on the basis of time into three phases: *emergency, relief,* and *recovery*. Additionally, on the basis of operational categories, we divided response operations into three primary categories of disaster response functions: *sensing and assessment, communication and coordination,* and *transportation operations*. Each of these categories was then divided into multiple functions, each of which were also in one of the three phases.

Using this framework for analysis, the three disaster cases, Northridge, "9/11", and Katrina, were investigated. Overall, it was found that although there were some differences in the technologies and systems that were present for the three disaster cases, along with some success stories for each of the cases, it is apparent that none of disaster response cases that we investigated had sufficient disaster response support systems. By sufficient, we mean that the technologies available were either not inherently capable and/or abundant enough. Even if abundance and capabilities would have been enough, technologies were generally not resilient enough to remain operational during disaster situations. Additionally, although the details of the problems and challenges of performing basic disaster response functions differed, we argue that the core of the problems due to the lack of better IT/ITS support systems present for the three disasters that we studied are very much the same. All of them experienced sensing and assessment problems, communication and coordination problems, and transportation operation problems. Based on this evidence, we conclude that there is a clear need for better disaster response support.

More specifically, broken down into our framework's phases and function category components, the following were the overarching findings for the three cases studies.

Emergency Phase

Sensing and Assessment

For all three disaster cases, similar emergency sensing and assessment needs were encountered. First, sensing and assessment of critical infrastructure had to primarily be done via manual efforts. Additionally, locating and tracking victims was a major issue for all three disasters. The same was true for responders, since no good system of tracking responder locations and status was available in any of the disaster cases.

Communication and Coordination

In all three cases, immediate telecommunications breakdowns resulted in enormous communication and coordination difficulties. Phone communications were generally not available in any of the cases. Radios were used by responders, when possible, but these suffered from operational problems and inherent interoperability constraints. As a result of these difficulties, agencies, responders, and victims were all generally disconnected and disorganized in the aftermath of the disasters.

Transportation Operations

Immediately after the disaster occurrence in each of our cases, transportation conditions were severely hampered. In the case of Northridge and Katrina, widespread damage to the transportation network made much of it unusable. In the case of 9/11, much of the transportation network was closed by authorities after the attacks for security purposes. To travel on the hindered transportation network, responders and victims would have benefited by receiving real-time status information. Although some status information was available in the case of 9/11 (both road-side and via internet and media), transportation status information would have been impossible to receive in the cases of Northridge and Katrina during the emergency phase. In all three cases, responders could additionally radio their agency for information regarding travel, but the information would not be guaranteed or easily conveyed to them. Finally, Katrina and 9/11 response involved evacuations procedures. Katrina's pre-landfall evacuation appears to have been fairly successful (for those that were willing and able to leave). The 9/11 evacuation from Lower Manhattan also was fairly successful, even though it took evacuees several hours longer than usual to get back home on the day of the attacks. It is likely that better evacuation monitoring and management tools could have benefits and streamlined these processes.

Relief Phase

Sensing and Assessment

Tracking efforts of relief activities and resources experienced varying degrees of difficulty for each of the three cases. For 9/11, relief activities were generally not extremely critical. Primarily, for our purposes, they dealt with temporary transportation solutions. Tracking such activities was not a problem. For Northridge, the relief phase was more active as temporary shelter and quality of life provisions were sought for the portion of the population that lost their homes as a result the earthquake. Tracking relief activities and supply shipments would thus have been a bigger challenge. Katrina's relief phase was the most involved as medical care of remaining citizens in New Orleans, food and water distribution, and the prolonged evacuation process continued. At the same time, keeping track of these activities was most challenging for this disaster as well, since communications infrastructure was still largely unavailable during the relief phase.

Communication and Coordination

As was the case with sensing and assessment, varying degrees of communication and coordination challenges were felt during the three cases. For 9/11, the relief phase did not involve many activities and communications was freely available. Thus, tracking these few activities was not a problem. For Northridge, there were more activities to track and telecommunications problems still lingered, making tracking efforts a bigger challenge in this case. Katrina was once again the worst since the relief effort was very involved but communications were still largely unavailable.

Transportation Operations

The transportation situation was quite different in the Katrina case from the cases of Northridge and 9/11. By the relief phase in the case of Katrina, most of New Orleans population had evacuated and thus there was no general need for mobility in the city. The main transportation related effort was to evacuate the remaining population out of the city. However, for Northridge and 9/11, the populace had remained in Los Angeles and New York, respectively. The populace continued to have everyday mobility needs but the transportation system continued to be hampered. Detours and new transit services were set up. However, keeping the public informed about these changes was clearly a challenge, particularly when real-time information was necessary. As a result of lack of travel related information during this time, mobility of the general public suffered.

Recovery Phase

Sensing and Assessment

Tracking recovery activities was not judged to be a problem for any of the disaster cases that were investigated. First, such tracking is typically not as time-sensitive as tracking of activities during the emergency and relief phases. Additionally, by the recovery phase, communication means were reestablished and tracking such activity becomes manageable.

Communication and Coordination

Related to keeping track of recovery activities, communication and coordination during the recovery phase was similarly apparently not a problem for any of the investigated cases. Standard means of communication were used by this time to coordinate.

Transportation Operations

In all three disaster cases, the transportation system continued to dynamically change during the recovery phases. Rebuilding and reopening news of transportation infrastructure would need to be conveyed to the traveling public so that they can make optimal travel decisions. Although general (not real-time) information could be procured in all three cases via standard means, the continued lack of real-time travel information still left the general public with sub-optimal tools to traverse the dynamic transportation network.

6.1.2 What currently available and developing IT and ITS technologies and systems have the potential to ameliorate disaster response problems and challenges? (Chapter 3)

Based on the types of disaster response problems and challenges that were observed from the case analyses in Chapter 2, a technology review was performed to seek technologies that could provide better technological support for disaster response operations. Technologies were sought in our standard disaster response categories: *sensing and assessment*, *communication and coordination*, and *transportation operations*. More specifically, the technologies that were considered were the following:

<u>Sensing and Assessment Technologies included:</u>

1) Infrastructure and Environmental Sensing Systems
2) Vehicle Tracking Technologies
3) Incident Tracking Technologies

Communication and Coordination Technologies included:

1) CAD-ITS Integrated Systems
2) Central Technology Hub Systems
3) Disaster Response Field Communication Systems
4) Wireless Networking Technologies
5) Portable, Wireless Devices

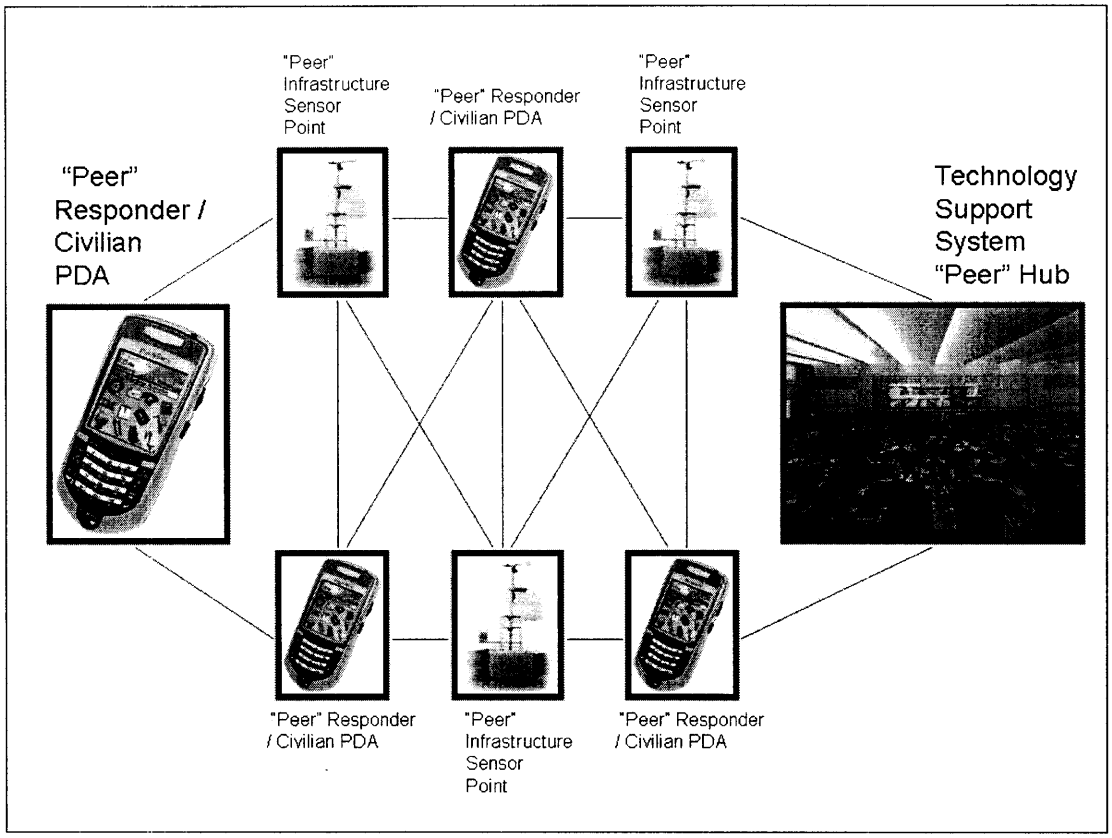
Transportation Operation Technologies included:

1) Evacuation Management and Modeling Systems
2) Traveler Information Technologies
3) Vehicle-Infrastructure Integration Technologies
4) EMS/Responder Mobility Enhancement Technologies

6.1.3 More specifically, how could these IT and ITS technologies be applied to resolve the challenges and problems of the three disaster cases that we studied? (Chapter 4)

To answer this question, we proposed a vision of a Disaster Response Support System (DRSS) that could be used to support disaster response operations. The backbone of the DRSS consists of four main components: “peer” PDAs, “peer” infrastructure sensor points, the Peer-to-Peer (P2P) wireless network, and at least one “peer” hub. Figure 6.1 shows this DRSS backbone architecture. Using the framework as a basis for the DRSS, specific applications of emerging IT and ITS technologies (from Chapter 3) comprising the DRSS were proposed for improving disaster response operations.

Figure 6.1 Disaster Response Support System Backbone Architecture.



Compared to the current disaster response support systems, the DRSS would provide much more advanced capability, interoperability, and robustness. The improved capability will stem from the advanced technologies and systems that are going to be integrated into the DRSS. The interoperability will result from the DRSS' ability to provide a communication and coordination link among the entire disaster response community, including engaged responders and effected civilians. Finally, DRSS will be significantly more robust than current systems since will not rely on centralized, physical communications infrastructure (e.g. cellular network). Instead, the P2P wireless network will allow DRSS components to interact without relying on such vulnerable systems.

In considering the technologies that have the potential to provide better support for disaster response, it was found that many of the same technologies could be suggested for the same functions of the three different disaster cases. As a result, as we had originally hypothesized, it appears that a generic DRSS does indeed have the potential to support disaster response operations of various disasters. This finding makes a DRSS such the one we suggest a more practical and economical system to improve disaster response.

6.1.4 What issues will we be faced with in attempting to implement these IT and ITS technologies to support disaster response operations and what might be some ways of overcoming them? (Chapter 5)

Although there are apparent benefits to deploying better IT/ITS systems for disaster response, such as our proposed DRSS, there are clearly going to be institutional and technological issues that will need to be overcome before deployment can successfully occur. At the same time, there is reason to believe that these issues can be overcome.

On the institutional front, the fact that disaster response responsibility is decentralized into the localities presents a challenge to deploying a DRSS on a national scale. It appears that more responsibility and coordination will have to occur at the federal level to ensure an integrated system that can be used to protect the entire country. Additionally, upfront and maintenance costs of a DRSS may at first seem as if they are going to be insurmountable. However, since the proposed DRSS is comprised of components that are becoming commonplace for everyday use, adding disaster response support capabilities to these components and integrating them together becomes more feasible. Moreover, it is noted that a cultural change and training will be required during the deployment of the DRSS. To the aid of this effort, it is hoped that since the primary interface device for responders and civilians will be PDAs, which are already commonly used, the adjustment to additionally use these devices during a disaster response situation will be less monumental.

On the technological front, the compatibility of "peer" components of the DRSS will be a barrier. Components will be produced by various manufacturers with differing features and local systems will have particular uniqueness. This technological issue is another reason why it will be important to have a strong, centralized organization coordinating the development and deployment of the DRSS, since this organization will be necessary to ensure compatibility on a national level. Finally, security of the DRSS as a whole and individual "peer" PDAs is going to be a key technological issue. It will be critical to guard against hacking of the system and implement measures that ensure PDAs are being operated by their intended users.

6.2 Final Thesis Conclusions

We believe that the development of better disaster response technological support systems in the United States is necessary. It is clear from studying three major disaster cases that there are many serious operations problems that currently plague disaster response processes due to the lack of sufficient IT and ITS support systems. However, the fortunate coincidence is that as the continuing and perhaps more serious threat of disasters in the U.S. is be looming, we are simultaneously experiencing a technological revolution that may allow us to make disaster response support systems more sophisticated and resilient. For disaster situations, our proposed DRSS is a support system that has the potential to provide much more advanced capability, interoperability, and robustness than the currently available systems. Moreover, based on consideration of the application the DRSS, we believe that a system such as this can be utilized in response to many different types of disasters, which makes its implementation even more desirable. There will certainly be barriers to successful deployment of a DRSS, but it is believed that these can be overcome via various means. If we want to maximize our protection against the threat of disasters to which we are currently vulnerable, it is vitally important to take advantage of our opportunity to make use of emerging technologies and systems to better optimize our disaster response systems.

6.3 Recommendations for Future Research

In this research area, much remains to be studied and improved. In this section, we describe several such possibilities.

6.3.1 Study other disasters and interview involved responders first hand

While we attempted to pick three disaster cases of various varieties and ones that occurred in different geographic locations of the U.S., this thesis is still based on only three disaster cases. In order to confirm our tentative conclusion that disaster response support systems can be developed to be used for many different types of disasters, all types of disaster scenarios have to be reviewed. There may be types of disasters for which a system such as the DRSS would not work well. Additionally, to gather the most accurate and comprehensive data, we recommend, in addition to reviewing literature, actually interviewing involved responders first hand, which is something that was not done for the disaster case analyses in Chapter 2.

6.3.2 Consider more emerging systems and technologies

While we included many different types of systems and technologies that could form a system such as DRSS, there are likely other systems and technologies that also could be integrated into this system. Further consideration of this matter could help to build on our vision of the DRSS.

6.3.3 Create a detailed design of the DRSS

Discussing potential technology applications and requirements of a system (disaster response system, in our case) is an important first step of innovative development, and we have initiated this discussion in this thesis with the DRSS proposal. However, the next step is to actually design the details of how a system such as DRSS would work. Thus, a possible research area is to create a detailed design that builds on our ideas for the DRSS.

6.3.4 Conduct a holistic study of the different stages of disaster management – planning, prevention, and response

In this report, we focused on disaster response. However, disaster management is more broad that just disaster response. Successful management of disasters needs to start with planning regarding how to build overall resilience to the threat of disasters, after which these plans need to actually be implemented. Additionally, even disaster related operations are not limited to just the response, since preceding that, prevention measures and activities also must be part of the disaster management effort. Studying disaster management overall or planning or prevention individually could constitute a good complement to our research.

6.3.5 Perform a cost-benefit analysis of developing IT/ITS for disaster response

Cost-Benefit analysis is a common process that can be used to try to show the worthiness of investment in particular technologies and systems. For example, research on the costs and benefits for ITS is ongoing. Such analysis with a particular focus on IT/ITS for disaster response applications could be another excellent extension of our work.

Appendix A. The Chronology of Events for Northridge

According to a US DOT report (12), the following was the chronology of the main events after the Northridge Earthquake:

Day 1 - Monday, January 17, 1994

4:30 AM	An earthquake of a magnitude of 6.8 occurs in the Los Angeles area, centered in Northridge. Damage spread over 2100 square miles and through three different counties.
4:31 AM	5.9 aftershock
4:35 AM	Emergency Operations Center is activated
4:45 AM	FEMA Response begins
5:35 AM	Region IX Regional Operations Center is activated
5:45 AM	Los Angeles Mayor Riordan declares a state of emergency
6:00 AM	FEMA Headquarters Emergency Support Team is activated
6:45 AM	As many as fifty structure fires have been reported, in addition to numerous ruptures in water and natural gas mains. Power outages reported citywide.
9:05 AM	California Governor Pete Wilson Declares a State of Emergency
9:45 AM	All active fires were under control
2:08 PM	President Clinton declares a national disaster for Los Angeles County
7:00 PM	Disaster Field Office is Opened
7:00 PM	First of several contracts was in place and crews had begun to work on debris clearance and highway demolition

According to the same report, other day 1 events included the following:

-March Air Force Base is designated as the Federal Mobilization Center
-U.S. Public Health Service deploys four Disaster Medical Assistance Teams to the disaster area
-FEMA deploys two urban search and Rescue teams
-American Red Cross sets up 26 shelters; Salvation Army sets up 5 shelters
-EPA responds to investigate a 200,000-gallon oil spill into the Santa Clarita River

-Many major freeways and roadways are partially or completely closed, diverting massive amounts of vehicles onto adjacent streets.

-Within hours of the earthquakes, existing Emergency Operations Centers set up initial detours for the damaged roadways.

-Caltrans Traffic Management Plan (TMP) is set in motion to organize detours, plan for transit adjustments, and deploy ITS technologies controlled by the Earthquake Planning and Implementation Center (EPI-center).

-Caltrans decides to take two arterials parallel to a damaged roadway, re-stripe them and operate them one-way only during peak periods, open truck bypass lanes to all traffic, and add an HOV lane in each direction.

Day 2 - Tuesday, January 18, 1994

-All I-5 lanes are closed except northbound I-5 to northbound SR-14 truck lanes.

-All SR-14 Lanes are closed. Local streets are used as detours.

-All I-10 lanes are closed between Centinela and Washington Blvd. Local streets were used as detours.

-All SR-118 lanes are closed between Tampa Ave and I-210. Local streets were used as detours.

-The Mobile Emergency Response System (MERS) arrives in southern California with 28 telecommunication specialists

-FEMA Special Facility Tele-registration Center is activated

Day 3 - Wednesday, January 19,1994

-Casualty Information Center reported 2,400 injuries treated and released at area hospitals, 526 hospitalized, and 40 deaths.

-President Clinton arrives in Los Angeles.

-Los Angeles Mayor Riordan declares a curfew.

-Caltrans and National Engineering Technology agree to design/build contract for new traffic operations technologies.

-Tele-registration lines are expanded from 57 to 336 lines

-Metrolink enhances services to handle immediate increase in ridership, including using buses and taxis as shuttles to Metrolink stations, adding three park-and-ride lots with 900 new spaces near a damaged interchange, enhancing routes and schedules for rail and bus service, allowing bicycles on Metrolink rail

-Metrolink adds parking spaces at Santa Clarita station and increases number of trains during peak rush hours

-A new station is opened in Northridge on the Metrolink Ventura rail line and 2 new stations are added to the end line

-Six LA county bus systems add new routes, modify existing routes, and extend schedules in areas affected by damaged roadways

Day 5 - Friday, January 21, 1994

-I-10 northbound and southbound connectors to I-405 were opened.

-Metrolink rail opens 2 (of 4) new stations (eventually with 7 new trains) extending the Santa Clarita line to service commuters in an area along one damaged freeway corridor

Day 9 - Tuesday, January 25, 1994

-Metrolink ridership hits 22,000 boardings per day, up from the normal average of 1,000 per day, along the new extension of the Santa Clarita rail line serving areas surrounding earthquake-damaged roads. (Ridership decreased steadily during road reconstruction, and leveled off at 4,500 upon completion of road repairs.)

Day 10 – Wednesday, January 26, 1994

-Demolition of the I-5 Gavin Canyon structures was complete

Day 12 - Friday, January 28, 1994

-The southbound SR-14 to southbound I-5 truck bypass opened one HOV and one mixed flow lane.

-I-5 detour route was opened using a reconstructed frontage road

Day 13 – Saturday, January 29, 1994

-The Old Road detour opened two lanes in each direction through Gavin Canyon

Day 15 – January 31,1994

-Sierra Highway was restriped for three southbound lanes and one northbound lane.
-San Fernando Road also began operating three southbound lanes and one northbound lane.
-Sepulveda Blvd operated as a one-way street between San Fernando and I-5

End of January

-Lane capacity in the damaged roadway corridors is restored to 70 percent of the pre-earthquake level
-Along one damaged freeway corridor, 4 new commuter rail stations have been opened, extending commuter rail service along the Santa Clarita line for 50 miles

January / February

-Commuter express bus services between Santa Clarita and downtown LA are rerouted to compliment Metrolink, but no additional services are provided

Early February

-Regular system of detours and emergency express bus service are in operation. A 5th new station is added on the Santa Clarita Metrolink line.

Day 20 - February 5, 1994

-Construction on I-10 Santa Monica Freeway begins
-Construction on Camarillo Metrolink begins

Day 23 - February 8, 1994

-Metrolink Princess Station Opens Day 28 – February 13, 1994
-For SR-118, all lanes remain closed from Roseda Blvd to I-405. Local streets were used as detours for this closed segment.

Day 29 - February 14, 1995

-Camarillo commuter rail station construction is complete

Day 34 – February 19, 1994

-SR-118 detour was opened

Day 36 – February 21, 1994

-Westbound SR-118 was reconstructed and restriped to provide three eastbound and three westbound lanes, replacing the detours on local streets.

Day 46 - March 3, 1994

-MTA is asked to submit strategies for further traffic reduction

Day 60 – March 17, 1994

-Demolition of the I-5 / SR-14 interchange is complete

Day 63 – March 20, 1994

-A 5.3 aftershock causes new damage
-Commuter bus service is expanded; 3 new express routes are added

Day 85 - April 11, 1994

-I-10 Santa Monica Freeway Opens 74 days ahead of schedule

Day 121 – May 17, 1994

-I-5 Golden State Freeway at Gavin Canyon opens

Mid May

-Major portions of the most heavily damaged freeways reopen to traffic

Day 173 – July 8, 1994
-The I-5 / SR-14 freeway interchange re-opens three weeks ahead of schedule

July

-Some mainline freeway connectors reopen

Day 230 - September 3, 1994

-SR-118 Simi Valley Freeway opens more than two weeks ahead of schedule

November

-Last connector ramps reopen.

Appendix B. The Chronology of Events for 9/11

The first part of the provided chronology was compiled by the author based primarily on two comprehensive studies of the events of 9/11. The first document is the 9/11 Commission Report (35). The second is a US DOT report that focuses on transportation system management and operations for New York City as a result of the 9/11 attacks (34). The first document is more focused on general information about the events and challenges with rescues from the towers and communication and coordination. The US DOT document, while it also covers general information about the disaster, understandably focuses more on transportation related consequences.

The majority of the initial chronology was developed based on the 9/11 Commission Report, so the details are by default based on information from this report unless otherwise indicated.

Initial 9/11 Chronology

8:46 AM A hijacked American Airlines commercial jet was crashed into the North Tower of the World Trade Center as part of a terrorist attack on the U.S. that day. The plane crashed into the 93rd to 99th floors of the 110-story tower. Some NYPD officers see the plane strike and immediately communicate the news to NYPD dispatchers. Hundreds of civilians in the building were killed immediately. On the floors above the point of impact, hundreds more were trapped without a way to descend the building. FDNY initiates response. North Tower security personnel are aware of a major incident but do not necessarily know exactly what happened.

8:47 New York City 9-1-1 system flooded with calls. Per standard protocol, 9-1-1 generally advised victims to remain in place and await further instructions.

8:47 "An MTA subway operator alerts MTA Subway Control Center of an explosion in the WTC and begins emergency procedures." (34)

8:48 Officials in OEM headquarters at 7 WTC request that their on-site EOC be activated and that representatives from FDNY, NYPD, Department of Health, and the Greater Hospital

Association be sent to 7 WTC. The Office of Emergency Management (OEM) also requests 5 Urban Search and Rescue Teams to be sent from FEMA.

8:49 The deputy fire chief director of the South Tower tells his counterpart in the North Tower that he will wait for direction from the Fire Department before proceeding.

8:50 Two NYPD helicopters are dispatched to WTC to report on conditions. They eventually rule out rooftop rescues due to heavy flames and smoke conditions. However, 9-1-1 operators did not know of this situation and many operators encouraged or at least did not discourage civilians in attempting to get to the roof. PAPD officers begin responding from all over the city to the WTC site, but they lacked interoperable radio frequencies to communicate with each other. OEM field responder arrives at lobby of North Tower.

8:52 One FDNY battalion chief, two ladders, and two engine companies arrive at North Tower and encounter badly burned civilians in the ground-level lobby.

8:52 "PATH trains begin emergency procedures and proceed to evacuate WTC station and express Manhattan trains to New Jersey." (34)

8:56 The deputy fire chief director of the North Tower was aware of the occurrence of a major incident but was still unaware that a commercial jet had crashed into the North Tower. He supposedly orders an evacuation of the North Tower. Some civilians trapped above the impact zone, facing unbearable smoke and heat, start to jump or fall from the building.

8:57 FDNY advises PAPD and building personnel to evacuate the South Tower as well. Some fire fighters begin climbing stairwell C of the North Tower.

8:58 NYPD Chief of Department sends 22 lieutenants, 100 sergeants, and 800 police officers from all over the city to the WTC.

9:00 7 of the 11 highest ranked chiefs of FDNY are at the scene. 235 firefighters are deployed at the WTC. NYPD Emergency Service Unit (ESU) enters North Tower lobby and plans to set up triage center in upper floors of the tower. PAPD commanding officer of the WTC orders an evacuation of all civilians in the towers. South Tower deputy fire safety director does not get the message because of radio incompatibility. PAPD Superintendent and Chief of Department both arrive at North Tower.

9:02 A message is given over the public-address system in the South Tower that evacuation can begin, if deemed necessary.

9:03 A second hijacked commercial jet is crashed into the 77th to 85th floors of the 110-story South Tower. Unlike the North Tower crash, this plane banked before impact. As a result, stairwell A remained passable for evacuation from the floors above the impact zone for some time, but this was not obvious to the survivors on those floors. Many survivors began attempting to evacuate the building. Some appeared to have been confused, however, by the tower's rather complicated stair systems and mixed messages regarding which stairwells were passable. Some civilians that were above the impacted floors hoped to get to the roof to be rescued there, but were prevented from getting to the roof by locked doors. NYPD calls more personnel to the scene, bringing the number of dispatched officers to about 2,000. Government buildings and other sensitive locations around the city were evacuated and secured. NYPD and PAPD personnel were responsible for civilian final evacuation to safety once they descended to the lobby floor.

9:04 FDNY Chiefs meet in North Tower lobby in order to discuss operations strategy. Particularly, they are worried about communications capability.

9:06 "John F. Kennedy International Airport closes for departures, Laguardia Airport closes for all arrivals and departures at 9:07 and Newark Airport closes at 9:09." (34)

9:07 Fire companies begin to ascend stairwell B of North Tower.

9:10 "Port Authority of NY and NJ closes all their bridges and tunnels eastbound." (34)

9:11 PAPD Superintendent and an inspector begin to climb the North Tower to assess damage. Also, the PAPD Chief and several PAPD officers began ascending the North Tower as well, with the hopes to reach the 106th floor and rescue at least 100 civilians who were reported to be trapped there.

9:12 "George Washington Bridge VMS signs flash 'Bridge Closed.'" (34)

9:15 FDNY responds with more personnel than commanding chiefs requested due to self-dispatching. NYPD ESU team arrives at North Tower lobby and prepares to begin climbing the tower. They attempt to coordinate with the FDNY chiefs at the scene but are rebuffed. Other ESU teams arrived shortly after and had varied success in actually coordinating with FDNY.

9:17 "FAA orders all NYC airports closed until further notice." (34)

9:18 Severe smoke conditions plague the floors in the 90s and 100s of the South Tower, creating difficult conditions for survivors trapped on those floors. The 911 system continued to be hampered by operators' lack of awareness of the zone of impact and rescue operations at the WTC scene. Similarly to the situation that was just faced in the North Tower, many 911 operators continued to recommend to callers that they should remain where they are. Other operators seemed to have broken protocols and suggested evacuation attempts or other things such as attempts to ascend to the roof.

9:30 A lock release order was issued for doors in the South Tower, but the command could not be executed due to damage to the software controlling system. FDNY was in need of additional companies in the South Tower, since fire fighters were already occupied at the North Tower and had to be reassigned to the South Tower. PAPD central police desk issued a command for all PAPD officers to meet on the ground near the WTC and await further instructions. They attempted to create a makeshift response plan, but were hampered by the fact that they did not know how many officers were at the scene and where they were at the time.

9:32 Senior FDNY chief radios all fire units in the North Tower to descend to the lobby. Theories as to why this order was given include a false reports of a 3rd hijacked plane or because of judgment that the building conditions were deteriorating too much.

9:35 Lobby level of the South Tower was becoming overwhelmed with injured people who had descended the tower.

9:37 A civilian on the 106th floor of the South Tower reported that a "90-something floor" below him was collapsing. The 911 operator conveyed a message based on this call 15 minutes later, but the message was in fact incorrect since it states that it was the 106th floor that was collapsing. Moreover, the message was only communicated via radio to a sub-set of deployed units and not on the City Wide channel 1.

9:40 "FAA halts all US flights." (34)

9:43 "Third plane crashes into the Pentagon." (34)

9:45 "The White House evacuates." (34)

9:50 An ascending fire fighter battalion reaches 78th floor of the South Tower and finds a group of civilians there trapped in an elevator.

9:51 NYPD helicopter personnel warn that large pieces of debris were hanging from the WTC.

9:54 An additional 20 FDNY engine and 6 ladder companies are sent to the WTC.

9:57 An EMS paramedic tells the FDNY Chief that he was advised by an engineer in front of 7 WTC that the twin towers were in imminent danger of collapse.

9:58 PAPD officers reach as high as the 44th floor in the North Tower.

9:59 South Tower collapses, killing all inside. All command posts in the North Tower lobby and other staging areas near the base of WTC cease operations as huge cloud of dust engulfs the area. A FDNY boat on the Hudson boat immediately reports the collapse, but actually, it appears that no one on the site received this information, since command posts were abandoned. An NYPD Aviation Unit also radioed in the news.

10:00 Several orders from operations chiefs at WTC go out for all responders to evacuate the North Tower. These orders were received by some responders and reiterated by various chiefs. However, others did not receive the order as a result of various reasons such as difficulties with radio communications in high rises and overload on radio bandwidth. By this time, fire fighters reached up to 54th floor of the North Tower. The reaction of those responders that did receive the order varied as some did indeed evacuate but others were slow to leave as they continued to assist or refused to do so at all. FDNY ESU units were also ordered out of the North Tower at this time, and the order was clearly heard by the ESU units within the tower.

10:04 NYPD Aviation Unit reports that top 15 stories of the North Tower "were glowing red" and might collapse.

10:20 "NYC Transit suspends all subway service." (34)

10:27 Some civilians in the North Tower's 79th and 92nd floors remain alive.

10:28 The North Tower collapses, killing all alive on upper floors and most that were below. The Port Authority headquarters are destroyed in the collapse.

10:29 Many chiefs only now start learning that the South Tower suffered a total collapse. (34)

10:30 "NJ Transit stops rail service into Manhattan's Penn Station." (34)

10:45 "PATH operations were suspended." (34)

10:53 "NY primary elections are postponed." (34)

11:02 As tens of thousands abandon cars and subway to stream across Manhattan bridges on foot, Mayor Giuliani urges, "Stay calm, stay at home… If you are south of Canal Street, get out. Walk slowly and carefully. If you can't figure what else to do, just walk north." (34)

Morning: "Amtrak suspends all nationwide train service; Greyhound cancels Northeast US operations." (34)

Morning: "NYC DOT reports that police ordered highways shut down." (34)

Morning: "NY state activates its Emergency Operations Center in Albany. Governor activates the National Guard." (34)

Post-initial 9/11 Chronology

The next part of the chronology is taken directly from the US DOT (34) report.

September 11, 2001

~ Noon: A NYC Transit employee stands in front of Grand Central Terminal with a megaphone to try to dispense advice to travelers.

12:48 PM: Partial NYC Transit subway service resumes, with many routes truncated or diverted to avoid Lower Manhattan.

1:15 PM: Long Island RR runs limited service eastbound only from Penn Station.

2:30 PM: Subway system begins to return to normal except for trains under Lower Manhattan.

3:50 PM: FEMA activates four urban search and rescue teams in New York.

4:12 PM: PATH service between Newark and Journal Square resumed.

4:40 PM: PATH uptown New York line to New Jersey resumes service.

Afternoon: By evening rush, several public and private water ferry companies are providing additional ferry service to New Jersey, Queens, and Brooklyn, evacuating about 160,000 people from Manhattan.

Afternoon: 200,000 phone lines in Lower Manhattan are crippled, telephone and cellular service is overloaded when Verizon central hub at WTC damaged.

5:20 PM: WTC Building 7, headquarters of NYC Office of Emergency Management (OEM), collapses.

6:00 PM: Amtrak resumes passenger rail service.

7:02 PM: Some NY bridges open to outbound traffic.

7:30 PM: Long Island Rail Road restores full schedule east and westbound.

Nightfall: 750 National Guard troops are in NYC to assist police.

End of day: 65% of subway service is back in operation. Throughout the day, MTA bus service continues running north of Lower Manhattan. AT&T reports that it has handled the largest one-day volume of calls in its history

September 12, 2001 (Day 2)

8:00 AM: As a result of President Bush's NYC disaster declaration, FEMA's 1-800 help line officially opens.
Day: 3,000 National Guard troops are deployed in or near NYC to patrol bridges, tunnels, train stations, and Ground Zero. Mission: protect transportation links.
Day: MTA Long Island RR and Metro-North RR resume normal weekday service.
Day: PATH ran free service between Newark and 33rd Street and between Hoboken and 33rd St.
Day: NJ Transit runs regular commuter rail service, but ridership is only 20% of normal as workers stay home from work.
Day: George Washington (upper level) and Queensboro bridges open to automobile traffic only.
4:40 PM: The FAA allows airports to reopen on a limited basis for diverted flights.
5:00 PM: Most bridges north of 14th St. reopen.

September 13, 2001 (Day 3)

3:00 AM: Port Authority reopens the Lincoln Tunnel and the George Washington, Bayonne, and Goethals Bridges and the Outerbridge Crossing
5:00 AM: Port Authority Bus Terminal reopens.
8:00 AM: Port Authority reopens water port to freight traffic.
Day: PATH began to run the 3 services it operates currently- Newark to 33rd St., Hoboken to 33rd St. and Hoboken to Journal Square. (service was no longer free as of this day)
Day: George Washington Bridge upper level opens. Staten Island bridges open.
Day: Greyhound announces it is fully operational at all 3,700 locations in the U.S. and Canada.
Day: Tunnel damage affecting the 1 and 9 subway lines found under the WTC (debris, flooding). Some station entrances on N and R lines are found to be damaged.

Day: NJ Transit resumes bus service to Port Authority Bus Terminal in Midtown Manhattan, except for two bus routes that serve Lower Manhattan.
Day: Amtrak increases capacity 30% to accommodate stranded airport passengers.
Day: Traffic downtown sparse; taxis outnumber cars.
6:00 PM: Working with NYC DOT and OEM, NYC Taxi & Limousine Commission arranges for TLC-licensed vehicles to give free rides to hospitals, blood banks, destinations in restricted areas.
Day: Two days of bridge, tunnel, and road blockages into Manhattan lead to widespread disruption of commercial deliveries, including FedEx and US Postal Service.

September 14, 2001 (Day 4)

6:00 AM: Manhattan and Williamsburg Bridges reopen.
11:25 AM: CNN reports all three NY area airports -- Kennedy, LaGuardia and Newark -- have reopened.
Day: NY Taxi and Limousine Commission (TLC) establishes 24-hour hotline to address the taxicab and for-hire vehicle (FHV) industries' need for real-time information on access limitations.

September 15, 2001 (Day 5)

Day: New York City Mayor's Office of Emergency Management moves to Pier 92

September 16, 2001 (Day 6)

Day: Amtrak and Greyhound report handling twice the normal number of riders systemwide since September 11. Rental cars also report a surge in business.

September 17, 2001 (Day 7)

6:00 AM: Staten Island Ferry service resumes. NYC DOT begins running free ferries: Brooklyn to Manhattan.

September 20, 2001 (Day 10)

Day: Two Manhattan-bound lanes of the Brooklyn Bridge reopen to private vehicles. Brooklyn-bound lanes remain closed.

September 22, 2001 (Day 12)

In anticipation of Monday September 24 as the worst day of traffic since 9/11 as commuters fully return to work, NYC DOT urges: use mass transit, “think bikes, think ferries, think subway.”

September 26, 2001 (Day 16)

USDOT requests shippers and transporters of hazardous materials to consider altering routes to avoid populated areas whenever practicable.

September 27, 2001 (Day 17)

6:00 AM: Ban on single-occupancy automobile vehicles (SOV) entering Manhattan weekdays between 6 AM and 11 AM south of 63rd Street on all East River bridges controlled by the City of New York goes into effect.

September 28, 2001 (Day 18)

3:00 PM: Holland Tunnel reopens to westbound auto and bus traffic. It remained restricted to emergency vehicles in the eastbound direction.
Day: SOV restriction introduced at the Lincoln Tunnel from 6:00 AM to noon weekdays.
Day: Mayor Giuliani says bridge/tunnel checkpoints set up by police and FBI will remain indefinitely.

September 30, 2001 (Day 20)

Day: OnStar communications adds real-time traffic reports in a dozen cities, including NYC.

October 4, 2001 (Day 24)

Day: Port Authority officials say they are hurrying to build a new ferry terminal near Battery Park to cut NJ commute time from 20 minutes to 10.

October 10, 2001 (Day 30)

8:00 PM: City reopens most streets south of Canal St. to regular traffic on weekdays from 8 PM to 5 AM and all day on weekends.

October 11, 2001 (Day 31)

Day: Port Authority reports that average one-way truck traffic over the George Washington Bridge and Lincoln Tunnel has increased by 1,700 per day.

October 15, 2001 (Day 35)

5:00 AM: Holland Tunnel reopened to revenue traffic eastbound, restricted to HOV+2 autos.

October 17, 2001 (Day 37)

Day: Ban on single-occupancy vehicles entering Manhattan is shortened by 1 hour, to end at 10 AM on weekdays instead of 11 AM

October 28, 2001 (Day 48)

5:00 AM: Service restored on the N and R subway lines, bypassing Cortlandt Station indefinitely.

November 4, 2001 (Day 55)

NJ Transit sees 44% increase in ridership in and out of Manhattan after September 11.

Dislocation and relocation of offices from Lower Manhattan and the loss of PATH is causing huge shift in commuting patterns to Midtown.

November 12, 2001 (Day 63)

9:17 AM: American Airlines Flight 587 explodes in mid-air, crashing in Queens after takeoff from Kennedy airport.
9:45 AM: Port Authority closes: all bridges and tunnels between Manhattan and NJ to private and commercial traffic, its bus terminal in Midtown Manhattan, and PATH rapid transit to NJ.
11:00 AM: Outbound traffic from Manhattan is allowed to resume.
12:10 PM: Most bridges and tunnels reopen.

December 21, 2001 (Day 102)

NYC DOT reports that public and private ferry ridership has more than doubled since the WTC attacks, from 30,000 to 65,000 daily. Almost a dozen new water ferry routes have been started, with more than 50 boats now in service. In just 6 weeks, Port Authority of NY and NJ has built a new Battery Park dock capable of holding 6 ferry boats.

Appendix C. The Chronology of Events for Katrina

The following chronology of events for Katrina was compiled by the Brookings Institute (37), based on various media sources and their timelines including New York Times, AP, CBC News, National Oceanic and Atmospheric Administration (NOAA), and Dkosopedia.

Wed 24-Aug

Tropical Depression 12 strengthens into Tropical Storm Katrina over the Central Bahamas.
Hurricane warning issued for the southeastern Florida coast

Thurs 25-Aug

Katrina strikes Florida as a Cat 1 hurricane with 80 mph winds. Nine people reportedly died.
Governor Jeb Bush declares State of Emergency in Florida

Fri 26-Aug

9:00 AM Windspeed: 75 mph. Expected to become Cat 2 soon.
White House declares impending disaster area. Orders FEMA and DHS to prepare. 10,000 National Guard troops dispatched along Gulf Coast (arrival time unclear).

5:00 PM Katrina moves out to Gulf of Mexico. Grows into Cat 2 storm with 100 mph winds. Veers northwest toward Louisiana and Mississippi. Expected to become Cat 3.

11:00 PM Center of landfall expected to be Gulfport and New Orleans.
Louisiana Governor Kathleen Blanco declares State of Emergency.

Sat 27-Aug

5:00 AM Katrina becomes Cat 3 storm with 115 mph winds. Hurricane warning issued for Louisiana's southeastern coast and for the northern Gulf Coast.

10:00 AM Expected Cat 4 storm.

Afternoon: National Hurricane center Director Max Mayfield calls New Orleans Mayor Nagin to advise for a mandatory evacuation.

5:00 PM Nagin declares State of Emergency. Voluntary evacuation order. Residents in low-lying areas encouraged to evacuate. Mississippi Gov. Haley Barbour declares a State of Emergency. A mandatory evacuation ordered for Hancock County.

6:00 PM Weather Service Prediction: 45% chance that a Cat 4 or 5 storm will hit New Orleans directly.

Sun 28-Aug

Early in the Day: DHS Secretary Chertoff and FEMA Director Brown given electronic briefings by Hurricane Center on possibility of levee break.

7:00 AM Katrina becomes Cat 5 storm with 160 mph winds.

8:00 AM Superdome opens. Allows people in.

9:30 AM Nagin announces that Regional Transit Authority (RTA) buses will pick up people in 12 locations throughout the city to take them to places of refuge, including the Superdome. The New Orleans Comprehensive Emergency Management Plan calls for buses to evacuate citizens out of the city (this component not in effect).

11:00 AM Nagin orders mandatory evacuation of New Orleans. Ten shelters set up for those unable to leave (Nagin referred to them as "refuges of last resort" rather than shelters). Evacuation orders posted all along coast. President Bush suggests mandatory evacuation after decision was already made but before it was reported to the public.

11:30 AM President Bush delivers statement vowing to help those affected.

Noon: Highways packed. City activates contraflow traffic system so some highways become one-way only. Gov. Blanco requests disaster relief funds (some evidence this request was on 8-27) Alabama Gov. Bob Riley declares a State of Emergency. FEMA sends water, food and supplies to Georgia and Texas in preparation. President Bush declares State of Emergency in Mississippi, Florida, and Alabama.

3:00 PM Superdome has 10,000 people inside. 150 National Guardsmen stationed (2/3 unarmed).

6:00 PM Nagin orders a curfew of 6 PM.

7:00 PM National Weather Service predicts the levees may be "overtopped" due to storm surge.

Mon 29-Aug

6:10 AM Katrina becomes Cat 4 storm with 145 mph winds. Makes landfall.

9:00 AM Lower 9th Ward Levee reportedly breached. Floodwaters 6-8 feet in this area.

11:00 AM FEMA Director Michael Brown dispatches 1000 employees 5 hours after landfall - gives them 2 days to arrive. Brown arrives in Baton Rouge at the State Office of Emergency Preparedness.

2:00 PM City Hall confirms 17th Street levee breach. Floods 20% of the city.

Afternoon: FEMA issues statement asking first responders to only come to the city if there was proper coordination between the state and local officials.

1:45 PM President Bush declares Emergency Disaster for Louisiana and Mississippi. Frees up federal funds. Superdome damaged (with 10,000 people inside). Refineries damaged, and eight refineries closed. Airports close. Coast Guard rescues 1200 from flood; National Guard called in.

Tues 30-Aug

Second levee in New Orleans breaks. Water covers 80% of the city (20 feet high in some places). FEMA activates the National Response Plan to fully mobilize federal government's resources. FEMA stops volunteer firefighters with hurricane expertise due to the insecurity of the city. Asks them to wait for National Guardsmen to secure city first. An estimated 50,000-100,000 remain in New Orleans on roofs, the Superdome, and the convention center. The convention center was discussed as a possible option for refugees by New Orleans officials, but it was never officially chosen as a place of refuge. It was not a shelter listed in the New Orleans Comprehensive Emergency Management Plan. Unclear as to why it became a shelter.

4:30 PM Officials call for anyone with boats to help with rescue mission.

5:50 PM President Bush announces that he will cut vacation short.

6:30 PM Nagin issues urgent bulletin that waters will continue to rise - 12-15 feet in some places. He reports that pumps will soon fail.

8:10 PM Reports suggest looting is widespread.

8:55 PM Army Corps of Engineers begin work on 17th St levee.

10:15 PM Gov. Blanco orders an evacuation of the Superdome. She sets no timetable.

Wed 31-Aug

President Bush authorizes draw of oil from Strategic Petroleum Reserve. Gas prices rise above $3/gal (from average of $2.60 to $3.20).

Morning: Gov. Blanco requests more National Guardsmen from President Bush. Orders total evacuation of city.

10:00 AM Texas Governor spokesperson says that Superdome refugees will be put in Astrodome. HHS Secretary declares federal health emergency throughout the Gulf Coast. Sends in medical supplies/workers. Buses begin arriving to evacuate Superdome. 25,000 people in Superdome. 52,000 people in Red Cross shelters.

12:30 PM Refugees begin arriving in Houston at the Astrodome. Pentagon sends four Navy ships with emergency supplies. Launches search-and-rescue mission. Water level stops rising in New Orleans. Looting grows exponentially. Police forced to focus on violence/looting rather than search and rescue. London Avenue canal breached. Military transport planes take seriously ill and injured to Houston. FEMA deploys 39 medical teams and 1700 trailer trucks.

Thurs 1-Sep

Military increases National Guard deployment to 30,000. Violence, carjacking, looting continues. Military helicopters shot at while evacuating residents. FEMA water rescue operations suspended because of gunfire. Nagin issues a "desperate SOS" for more buses. President Bush appoints George H.W. Bush and Bill Clinton to fundraise for hurricane victims. Halliburton awarded Navy contract for storm cleanup. Sandbags arrive for levees. Superdome and Convention Center now housing up to 45,000 refugees. Senators return from recess to being work on emergency aid bill. DHS Secretary Chertoff states in an interview that he was not aware of the people at the convention center until recently.

8:00 PM Brown states (on Paula Zahn's show) that he became aware of the convention center problem only a few hours before.

Fri 2-Sep

President Bush tours Gulf area. Acknowledges failures of government. Calls the results "not acceptable." More National Guardsmen arrive; 6500 arrive New Orleans, 20,000 by day's end in LA and MS. Congress approves $10.5 billion for immediate rescue and relief efforts.

U.S. and Europe tap oil and gas reserves (2 million barrels a day). Explosions at chemical storage plant in New Orleans. Scattered fires. Fifteen airlines begin flying refugees out of New Orleans to San Antonio.

Sat 3-Sep

Bush orders 7,200 active duty forces to the Gulf Coast. 40,000 National Guardsmen now on Gulf Coast. U.S. Labor Department announces emergency grant of $62 million for dislocated workers. New Orleans police report 200 officers have walked off the job, 2 committed suicide.

Sun 4-Sep

Superdome fully evacuated (except stragglers). Gov. Blanco declares State of Public Health Emergency. Carnival Cruise offers cruise ships for 7000 victims.

Mon 5-Sep

Gap in levee closed. Still repairing another gap. Bush returns to the region. 4,700 more active duty troops dispatched. Former Presidents George H.W. Bush and Bill Clinton announce hurricane fund. 500 New Orleans officers unaccounted for. Some refineries restart production. Other countries frustrated with relief efforts of their citizens (Europe, Canada, S. Korea, etc)

Tues 6-Sep

Executive and legislative branches pledge separate investigations into federal response. US Army Corps of Engineers begins pumping New Orleans. Now 60% underwater. Less than 10,000 people still in New Orleans. Streets secure. Four fires. FEMA: Victims will be given debit cards for necessities. Labor Department pledges $62 million for Louisiana, $50 million for Mississippi, $75 million for refugees in Texas, and $4 million for Alabama for dislocated workers.

Late Evening: Nagin issued his emergency declaration authorizing police and military to remove anyone who refused to leave their homes. Unclear as to whether force will actually be used at this time (reports suggest not).

Wed 7-Sep

President Bush calls for another $52 billion in aid to compliment the $10.5 billion already approved by Congress.

Thurs 8-Sep

$52 billion in aid approved by Congress

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Chapter 2

Introduction

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Northridge

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