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EMERGENCY RESPONSE FOR HOMELAND SECURITY: LESSONS LEARNED AND THE NEED FOR ANALYSIS

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Emergency Response for Homeland Security: Lessons Learned and the Need for Analysis

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Preface

This report addresses response preparedness for large-scale emergency incidents, be they acts of terrorism, acts of Mother Nature (e.g., earthquakes, floods, tornadoes, hurricanes) or human-caused accidents. We call such events ***major emergencies***, in which local first-responder resources are overwhelmed. There simply are not enough local resources to do the many jobs at hand. Response to a major emergency requires careful planning and professional execution. Decisions involve the deployment of people, equipment and supplies. Peoples' lives are at stake. Proper planning for a major emergency can save many lives, perhaps thousands.

Our role is to discover decisions that have to be made before and during a major emergency and to develop quantitative tools to assist local planners and decision makers to assure that their emergency response plans are as effective as they can be. Our approach is quantitative, systematic, based on data and past experience. The tools of systems analysis, statistics and operations research are those that we apply to the problem. For the sake of brevity, we will just refer to the methodology as *operations research*, or simply "O.R."

This report, the first in a series, is organized in three sections. The first, Chapter 1, reviews O.R. approaches to emergency response up to the present time. Much of this extends back to the 1960's, when 'crime on the streets' led analysts to study emergency response of our cities' first responders, i.e., police, fire and emergency medical. The 40 years of cumulative research provides a sound foundation for going forward with emergency response within a Homeland Security context. The second section, Chapters 2 through 7, provides an historical review of six well-publicized major emergencies that have occurred in recent years. These include acts of nature, industrial accidents and terrorist attacks. In this section, we are particularly concerned with 'lessons learned' and with recurring decisions that must be made and may become better informed with quantitative decision support tools. The third and final section is Chapter 8, which extracts from the historical analysis and from the review of research to date, the need for additional O.R. research needed to move forward with new planning models in emergency response for major emergencies.

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CHAPTER 1: APPLICATIONS OF OPERATIONS RESEARCH IN EMERGENCY RESPONSE

Operations research (O.R.), born during World War II, has for 65 years proved invaluable as a decision-planning tool. O.R. is an empirical science that uses the scientific method to assess the consequences of alternative decisions, be they long-term strategic planning decisions or shorter-range tactical or operational decisions. Since a decision can be viewed as an allocation of resources, Operations Research is the science and technology of resource allocation. In WWII, O.R. helped guide the allocation of scarce resources against the enemy. Today O.R. is ideally suited for evaluating and guiding our operational strategies and actions with regard to large-scale emergency incidents, be they acts of terrorism, acts of Mother Nature (e.g., earthquakes, floods, tornadoes, hurricanes) or human-caused accidents. We call such events major emergencies, in which local first-responder resources are overwhelmed. There simply are not enough local resources to do the many jobs at hand.

In this first chapter, with an eye toward future contributions in homeland security, we review briefly major O.R. work done to-date in emergency response. Some of this work is quite recent and aimed directly at homeland security issues. Most has evolved over the past 40 years, motivated by other emergency applications, especially operation of municipal first responders – police, fire and emergency medical. The new threats posed by terrorists present myriad new problems for O.R. analysts. In some ways, today we stand at a place analogous to the place that Philip M. Morse, George Kimball, Bernard Koopman and other O.R. pioneers stood near the beginning of WWII. There are numerous new O.R.-related problems to identify, frame, formulate and solve. Since these methods also apply to emergencies created by Mother Nature and by human accident, let us hope that the huge majority of major emergencies in which these methods are applied are from these latter two categories.

First Responders

The O.R. work on police, fire and emergency medical systems started with the Science and Technology Task Force of the President's Commission on Law Enforcement and Administration of Justice in 1966. It led directly to the national implementation of the three-digit emergency number "911," and it sparked a generation of important O.R. emergency services research. When New York City implemented its 911 system in 1970, managers there discovered how useful queueing theory is in the scheduling of 911 call-takers. Their original call-taker scheduling yielded intolerable 30+ minute telephone queue delays. An O.R. queueing analysis quickly showed how rescheduling available personnel – without additions – brought the delays to within acceptable limits. The management of queues will be vitally important in the governmental response to any future terrorist attack or other major emergency.

Queues occur when the available resources are not adequate to handle real time demand for those resources. Queueing is a type of rationing of resources. Sometimes the rationing and delays are deliberate, as with some private sector call-in complaint centers. In a major emergency, queues are endemic and must be managed aggressively by using techniques such as prioritization and triaging. Triage classifies those who are injured into various priority categories, and acts with urgency on the highest priority categories first, trying to save as many lives as possible with the limited resources at hand. Without triage, queues would grow without bound, and few would be treated in a timely manner. Sometimes triaging requires very difficult deferral decisions, such as occurred on December 7, 1941 at Pearl Harbor: triage nurses deciding against medical treatment other than morphine for those who had been so severely injured that near-term death is a certainty regardless of medical intervention. Such difficult decisions may be required to save scarce medical expertise for treatment of those whose lives can be saved. Modeling work on 'cut-off priority queues" provides a methodology of setting priorities and predicting system performance under alternative triaging schemes [10 11]. In [8] we show how this would work with data from the Hartford Connecticut Police Department.

The first author, a member of the Science and Technology Task Force, wrote a book based on the experience, *Urban Police Patrol Analysis* (MIT Press, 1972). The book offered a variety of O.R. models to examine police response times, patrolling patterns, impact of new technologies, personnel scheduling and more. This effort led to a four-year NSF-funded research program at MIT, the "IRP Project," Innovative Resource Planning in Urban Public Safety Systems. That project led to many graduate theses and computer-implemented models related to police and emergency medical operations.

A key model from the IRP project was the "Hypercube Queueing Model." The model is an equation-based model that uses various analysis tools from the technical field known as 'stochastic processes.' It is a multi-server queueing model that reflects the unscheduled nature of 911 calls by modeling them as a Poisson process. The service times of different servers (i.e., police patrol cars or ambulances) are uncertain (i.e., probabilistic) and have different average values, reflecting differing workloads and travel times in their areas of responsibility. The Hypercube model depicted the detailed spatial operation of urban police departments and emergency medical services. It found application in police beat design, dispatcher car-picking strategies, allocation of patrolling time, evaluating automatic vehicle location systems, and more. The Hypercube Queueing model has been implemented in many cities, including New York City; Boston; Hartford, Conn.; Orlando, Fla.; Dallas; and Cambridge, Mass.

Various vendors have commercialized the Hypercube model, and its full impact is difficult to determine. From the perspective of homeland security, the analytical structure of the Hypercube model offers promise in guiding response resources depleted in the event of a major emergency. But the model needs to be generalized in order to include the impact of second- and third-tier responders, from regional, state and federal agencies, and of specialized responders such as HAZMAT and bio-terrorism units. It also needs a time-dependent solution structure, fed with (potentially massive) data from the field. The authors, with other colleagues at Structured Decisions Corporation, are building from the Hypercube model a new deployment model for response to terrorist attacks and other major emergencies.

In 1969 New York City commissioned the RAND Corporation of California to open the New York City RAND Institute (NYCRI). Over the years, NYCRI's award-winning O.R. work on emergency services has stood the test of time. An example is the NYCRI's fire department relocation model. When there is one large fire or a collection of smaller fires in geographic proximity, the firefighting resources near the vicinity of the fire (or fires) become depleted. Most fire departments try to re-balance protection by moving some of the still-available fire companies from more distant firehouses to occupy temporarily some of the firehouses left vacant by the busy companies. But this in turn creates new relative vacancies at the more distant firehouses, which in turn require reassignment of even more distant firefighters into the newly vacated firehouses. This wave-like cascading process, if not carefully managed, can create conditions in the city in which certain neighborhoods are left uncovered, should a new fire occur there.
The number of ways to implement relocations is in the hundreds of billions, and no human can contemplate the consequences of each option and pick the best. But O.R. optimization models such as the NYCRI relocation model are perfect for the job at hand. Remarkably, 30 years after the NYCRI was shut down due to New York City's 1975 budget crisis, the NYCRI fire relocation model lives on in the New York Fire Department (NYFD). It proved invaluable on Sept. 11, 2001, in managing the relocations of NYC firefighters on that infamous day. With the help of that model plus implementation of a "Fallback 3" response strategy (meaning a less-than-usual number of units initially dispatched to an incident), the NYFD managed to keep its average response times to other fire incidents to an average of 5.5 minutes, only about one minute above the usual average.

The NYCRI relocation methodology is most relevant in planning response to a terrorist attack. The New York City 9/11 case is an “existence proof." Any other terrorist attack is also likely to overwhelm nearby first responders, thereby putting the entire city or region at risk, if resources are not managed carefully. According to Peter Kolesar, co-inventor of the NYCRI relocation model, in the event of terrorist attack,

> "Several core principles underlying the NYFD version would probably be appropriate. First, solve the problem as it occurs rather than trying to plan in advance since you probably cannot anticipate the dimensions of the attack and following crisis. Second, use some politically acceptable mathematical measure to define when coverage is inadequate and to evaluate alternative relocation options. Third, employ a computer-driven optimization algorithm to generate actual solutions. Fourth, allow the actual decision-makers to modify or override the algorithm's suggestions" [Peter Kolesar, private communications, Aug. 10, 17, 2004].

Hazardous Materials
The transportation of hazardous materials on trains, trucks and vessels exposes the public to risks of environmental catastrophes, even in the absence of terrorist threats. The possibility of a terrorist attack on hazardous materials in transit only increases the risk. As one example, currently there is much debate about using deep caves at Yucca Mountain in the Nevada desert for long-term storage of radioactive waste from nuclear power plants. Should that or another location be selected and operations started, there would be a massive transportation effort throughout the United States, hauling spent fuel

rods and other radioactive wastes to the selected location. Each city, town, village or farm that is passed by the train or other conveyance carrying the hazardous materials is at risk of an accident and severe contamination.

Because of these threats, various O.R. studies have focused on the routing of hazardous materials in ways that mitigate the risk and/or spread it equitably. The work has shown that there are tradeoffs between efficiency and equity. The lowest total system risk routes trains (or other conveyances) along the same path each time. A more equitable policy employs various routes, with more people sharing the risk, at a modest increase in total risk exposure. For the nuclear waste problem, the selected routes are of course yet to be decided, but the O.R. analyses point to the ways in which efficiency and equity can be addressed in an integrated fashion.

Bio-Terrorism

Carefully planned detection of and response to any bio-terrorism attack is crucial in terms of saving lives. This new area of concern has only recently been the focus of O.R. analyses.

The models developed by David Craft, Ed Kaplan and Larry Wein provide a consistent framework for considering operations following a bio-attack. With regard to a possible anthrax attack, their conclusions were based on a set of mathematical models that included an airborne anthrax dispersion model, an age-dependent dose-response model, a disease progression model and a set of spatially distributed two-stage queueing systems consisting of antibiotic distribution and hospital care. One of their most controversial recommendations is to have non-professionals disperse antibiotics very soon after an attack and/or have those antibiotics in the hands of citizens at all times – pre-positioned at the points of need in case of such an attack. Based on these recommendations, the US Postal Service has announced that its mail carriers will help to distribute antibiotics if a large attack occurs in the Washington D.C. area[1].

The same three co-authors studied response to smallpox attack. The initial federal policy had been to isolate the symptomatic victims, trace and vaccinate their contacts, quarantine others, and hope that the spread of disease could be limited by these measures. The O.R. analysis indicated that the initially selected policy would result in many deaths. Instead, O.R. analysis suggested a different response: As soon as the attack is recognized, undertake mass vaccination across the entire population. This recommendation caused quite a stir nationally, but now has been adopted as official U.S. policy.

Should a major bio-terrorism event occur at one identified location or limited region, getting timely appropriate medical care to those exposed is critical for their survival. One can imagine scenarios in which victims are first triaged, those identified as needing immediate transport are taken to nearby hospitals, initial treatments are administered, and then many patients at the nearby hospitals are moved out to more distant locations. If

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[1] United States Postal Service. *U.S. Postal Service may deliver medicine in the event of a catastrophic incident.* News release no. 04-015, February 18, 2004.

such outward movements are not done, the nearby hospitals become queueing choke points in the system, with their own limited resources totally overwhelmed. The cascading wave-like movement of patients out of nearby facilities to more distant ones reminds one of the inverse of NYCRI's fire relocation model. Creating such hospital "surge capacity" certainly warrants further O.R.-oriented research.

Private Sector Response

Emergency response is not limited to public sector agencies. In the event of a major emergency, it is important that private firms whose operations have been interrupted resume normal operation as soon as possible. O.R. can play a role in that normalization process.

There are few companies whose operations are more complex than airlines. With thousands of flights scheduled each day, the efficient matching of planes and crews to schedules and airports is an intricate, carefully choreographed optimization problem. When unplanned events occur, myriad decisions must be made. But imagine what happens when all planes are unexpectedly grounded, as happened on Sept. 11, 2001. Planes that had been in the air at the time of the 9/11 emergencies were directed to nearby airports for landing. At the end of the day, the airlines and their passengers found themselves literally all over the country and even outside of the country, often at locations far from the intended destinations. The state of each airline was very far from what had been carefully planned. Yet, as described in award-winning work, O.R. optimization resulted in Continental Airlines having the "best" recovery of any major airline in terms of percentage of delays/cancellations during the restart phase that followed the nationwide grounding of commercial aircraft. The O.R. methodology determined the least-cost sequence of decisions to get the airline up and flying again, consistent with the thousands of constraints dealing with matching crews to planes, getting each plane back on schedule, adhering to maintenance schedules, obeying FAA rules, etc. Since that time, many other airlines have adopted this O.R. methodology to assure their swift recovery from major disruptive events.

Implementation

Many of the O.R. methods discussed herein are implemented and used in command and control systems on a daily basis by first responders throughout the U.S. The end user probably does not even know that "O.R. is inside" the computer programs she is using. This is as it should be, just as the user of an Internet search engine such as Google does not care about the mathematical or logical details of Google's search engine, only in the usefulness of the results. The final proof of the value of O.R. is in the quality of decisions made by those who benefit from its use.

With computer computation and storage being exceedingly inexpensive these days, we are seeing more databases being assembled that will assist the O.R. planner in preparation for emergency response. An example is New York City's Citywide Assets and Logistics Management System (CALMS). CALMS, set up for disaster response, cuts across jurisdictional lines and retains knowledge of the whereabouts of supplies, equipment and personnel from many different agencies. It is organized according to asset types: fleet, equipment and supplies, facilities, contracts, personnel and donated goods. Eventually we see systems such as CALMS instilled with intelligent O.R.-based models and algorithms that would recommend the best movements of men, women and materiel in response to an emergency event. A similar inclusion of O.R. may be expected in now widely implemented Emergency Incident Management Systems, computer-based systems to coordinate the management of resources in response to an emergency.

Summary

O.R. helped immensely during WWII. Today we face a different set of threats, a new type of warfare labeled asymmetrical. This type of threat creates the possibility for large-scale devastation similar to that caused by Mother Nature and by man-made accidents. Planning appropriate societal responses to such major emergencies can save many lives. Hardware technology alone, without careful systems planning, is not sufficient. And there is not enough money in the public coffers to think that simply “throwing money at the problem” will solve it. O.R. offers a scientifically valid, integrated framework for considering all aspects of the problem and for assessing the consequences and tradeoffs associated with alternative decisions.

We turn now to a sequence of historical reviews of well-known major emergencies that have occurred in recent years. Our focus is to extract from this history the needs for new quantitative planning tools for Homeland Security.

This chapter was adapted from a chapter to appear in "The McGraw-Hill Handbook of Homeland Security," David Kamien, editor. The contents of the chapter are also to appear in the INFORMS magazine, OR/MS Today, October 2004.

References.

(1) Blumstein, Alfred, *et. al*, 1967, "Task Force Report: Science and Technology, A Report to The President's Commission on Law Enforcement and Administration of Justice," prepared by The Institute for Defense Analyses, U.S. Government Printing Office, Washington, D.C., 1967.
(2) Green, L.V. and P.J. Kolesar, 2004, "Applying Management Science to Emergency Response Systems: Lessons from the Past," *Management Science*, August 2004, Vol. 50, No. 8, pp. 1001-1014.
(3. Kaplan, Edward H., David L. Craft and Lawrence M. Wein, 2002, "Emergency Response to a Smallpox Attack: the Case for Mass Vaccination," *PNAS*, Aug.6, 2002, Vol. 99, No. 16, pp. 10935-10940.
(4) Kolesar, P. and W.E. Walker, “An Algorithm for the Dynamic Relocation of Fire Companies,” *Operations Research*, Vol. 22, No. 2 (Mar. – Apr., 1974), 249-274.
(5) Larson, Richard C., 1972, "Urban Police Patrol Analysis," Cambridge, Mass.: MIT Press.
(6. Larson, Richard C., 1974, "A Hypercube Queueing Modeling for Facility Location and Redistricting in Urban Emergency Services," *Journal of Computers and Operations Research*, Vol. 1, No. 1, pp. 67-95.
(7) Larson, Richard C., 2002, "Public Sector Operations Research: A Personal Perspective," *Operations Research*, Vol. 50, No. 1, pp. 135-145.
(8) Sacks, Stephen R., Richard C. Larson and Christian Schaack. 1993. "Minimizing the Cost of Dispatch Delays by Holding Patrol Cars in Reserve," *Journal of Quantitative Criminology*, 9 (2) pp. 203-224.
(9) Sacks, Stephen R., Grief, Shirley, "Orlando Magic: Efficient Design of Police Patrol Districts," *OR/MS Today*, 21 (1) February 1994.
(10) Schaack, C., R. C. Larson. 1986. "An N Server Cutoff Priority Queue." *Operations Research* 34(2) pp. 257-266.
(11) Schaack, C., R. C. Larson. 1989. "An N Server Cutoff Priority Queue Where Arriving Customers Request a Random Number of Servers." *Management Science* 35(5) pp. 614-634.

(12) Walker, W., J. Chaiken, E. Ignall (eds.), 1979, "Fire Department Deployment Analysis," North Holland Press, N.Y.
(13) Wein, Lawrence M., David L. Craft and Edward H. Kaplan, 2003, "Emergency Response to an Anthrax Attack," *PNAS*, April 1, 2003, Vol. 100, No. 7, pp.4347-4351.
(14) Yu, G., M. Arguello, M. Song, S. McCowan, and A. White, 2003, "A New Era for Crew Recovery at Continental Airlines," *Interfaces*, Vol. 33, No. 1, pp. 5-22.

Authors' note: A full set of references for this chapter is found in the book chapter by the first author of this report, "Decision Models for Emergency Response Planning," in *The McGraw-Hill Handbook of Homeland Security*, David Kamien, editor (in press).

Chapter 2: OKLAHOMA CITY BOMBING

We start our case studies with one of the most well known terrorist attacks that occurred on US soil. The Oklahoma City bombing took place in 1995 and remained active in the US media well past the end of the decade. In this chapter we describe the bombing and evaluate the emergency response effort that took place almost immediately following the bombing. Several of the ideas in this chapter are derived from a recent interview we conducted with Mr. Sam Gonzales who served as Oklahoma City Police Chief at the time of the bombing.

Overview of Event

Prior to 9-11, the Oklahoma City bombing of 1995 was considered one of the major terrorist attacks on American soil. Response to that bombing is the focus in this chapter, our first case study. The case highlights emergency response focused on a single region (the bombing site). We review the response, discuss some of the problems that were experienced during it, and follow up with lessons learned.

The story behind the Oklahoma City bombing began on April 19th 1993 in Texas. On this date in Waco Texas, the heated standoff between FBI agents and a cult led by David Koresh took a turn for the worse. When FBI agents tried to get the cult members to retreat by using gas, the cult set the entire complex on fire killing over 80 people. Many bystanders blamed the US government for these actions. One of these people was Timothy McVeigh. McVeigh decided to get retribution on the FBI. He decided to target the Oklahoma City Federal building since a number of government offices were housed there. He, his friend, Terry Nichols, and several others devised a plan to get revenge. The group bought large amounts of fertilizer and built a bomb. On April 17th 1995, McVeigh and his group decided to rent a Ryder truck to house the bomb. In the early morning of April 19th, McVeigh drove the truck to the Oklahoma Federal Building and lit the bomb's fuse. The time when the bomb exploded was 9:02:37am. Tragically, 168 people were killed and hundreds more were injured. An hour and a half after the explosion, McVeigh was pulled over for driving without a license plate. Police soon discovered he had an unregistered gun. After being detained, it was discovered that he was linked to the bombing. After an investigation, he was indicted on the charge. He was convicted of murder on June 2, 1997 and executed on June 11, 2001. This chapter outlines the events and reviews some of the problems with the response and offers lessons learned.

First we start with a chronology of events on that fateful day, April 19th 1995:

- **9:02 am** The Alfred P. Murrah Federal Building is bombed.
- **9:03 am** The entire north side of the building collapses.
- **9:04 am** The first police units arrive on the scene.
- **9:05 am** The explosion is reported to the Oklahoma Department of Civil Emergency Management.
- **9:20 am** The first fire department personnel arrive on the scene along with the disaster manager.

- **9:27 am** The first wounded are transported to a triage unit.
- **9:30 am** State and Federal authorities arrive.
- **9:45 am** Governor Frank Keating declares a state of emergency.
- **10:00 am** Ambulance priority is given to the most severely injured.
- **10:15 am** A bomb scare is reported.
- **10:30 am** 200 Patients are being treated in hospitals at this time.
- **11:00 am** Network news (NBC/ABC/CBS/CNN) goes live on-site.
- **11:50 am** Military medical personal arrive to help assist triage unit.
- **1:30 pm** Bomb threats called to other federal offices throughout the nation. This results in evacuations or closings for the day, as well as sealing off the access streets to some federal offices.
- **2:00 pm** Rescuers have to move away from the building due to another bomb threat. The threat turned out to be an ATF training rocket launcher that was totally harmless.
- **2:10 pm** Only three survivors extracted from this point on.
- **4:30 pm** President Clinton signs emergency disaster declaration.
- **6:00 pm** Rescuers have to stop searching for survivors due to a thunderstorm. Building is given supports in fear of the floors pancaking on each other and/or collapsing.
- **6:10 pm** Last survivor is located.
- **7:30 pm** Rescuing continues.
- **11:05 pm** Last survivor is removed from the rubble.

Overview of EMS Response to Bombing
According to an interview with then Police Chief Sam Gonzales, although a fully integrated response was administered, each branch was assigned a specific focus point for the response. The police were assigned to handle perimeter security. The fire department handled rescue and recovery. Since the police department was so busy, Chief Gonzales asked the FBI to handle the criminal investigation (10).

The EMS[2] response to the bombing was divided into three phases: the first of those was the immediate response. Before the first 911 phone call was reported at 9:03am, the first EMS vehicles in the area whose drivers heard the explosion responded to the scene. By 9:07am, 24 EMT's[3] and seven ambulances were on-site. A few minutes later, an EMS command vehicle responded to the scene. At 9:09am, EMS operations shifted from normal to disaster mode. At the command headquarters, three people were appointed to head the response effort. A disaster coordinator was appointed to be responsible for all communications coming from the disaster site. A transportation coordinator was appointed to determine and keep track of bed availability and patient coordination with the city's hospitals. Before 9:10, the first triage unit was set up next to the bombing site. Rescue workers decided to classify patients in two categories based on the severity of their injuries. A *one* was assigned to patients who were in severe need of medical attention, while a *zero* was assigned to all others. By 9:25 there were more than 30 ambulances on-site. At 9:27 the first patient was transported from the site. Within an

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[2] EMS = Emergency Medical Services.

[3] EMT = Emergency Medical Technician.

hour after the bombing, 139 patients had been transported to hospitals. Before 10:00am, more than 50 ambulances had arrived on-site helping transport victims to hospitals. When officials recognized that many victims were going directly from the site to hospitals, they decided to move the triage unit closer to the bombing site. However, at 10:30am, a bomb threat occurred and forced officials to move the site farther away, frustrating many victims (1). By the time the bomb threats were cleared, most of the victims had already been extracted from the building and there was little use for the triage unit (indicating the importance of timeliness of set up of the triage unit) (1). By the end of the day, approximately 450 people had been treated at area hospitals for injuries. Fully 355 were released that day, while the rest were required to stay overnight. Ten people died after being admitted to a hospital. Overall, the response was considered to be a “success.” The main reason for this success was the inter-agency preplanning, training, and interaction that helped to lead, for the most part, an integrated response (2).

Two keys to the rescue operation were the establishment of a Multi-Agency Coordination Center (MACC) and the use of an Incident Command System (ICS). Due to the excellent working relations between the various public services, a plan for a MACC was developed to streamline the rescue process (4). This central unit housed representatives of most of the major agencies and it should be noted that most significant decisions went though this center. Since each agency was aware of the other agencies’ actions, as well as problems, an integrated response was developed where shared resources were used and each unit helped and received help from the others when in need. Also, activities that could be accomplished by any of the agencies were efficiently assigned based on current workload numbers. It is important to note that such an integrated center cannot be set up spontaneously, without careful pre-planning. The only way a center like the MACC will work is if there are good relations and constant interactions among the various public service branches in a given city, and a center is planned for prior to the disaster.

The other major tool that was employed was the ICS. This facility is used to manage all personnel and to develop and plot out rescue plans. This system helps log, track and maintain an overview of all rescue operations that are simultaneously occurring. The system is also used to plan rescue routes and allocate supplies. The key to this system is that it integrates the different rescue units into a single ‘mega-unit’ that helps to increase the productivity of the process.

Lastly, in our interview with him, Chief Gonzales stressed that one of the most important criteria for having a successful integrated response is well-developed relationships among the heads of the branches. The chief reported to us that he and Fire Chief Marrs were very good friends, which led to them to work together successfully on emergency response delegation and planning. One of the most important factors in order to have these integrated responses be successful is to have interagency training exercises on a regular basis so that team skills and coordination can be developed and enhanced (10).

The following section outlines the nine major problems with the response effort and offers lessons learned and recommendations for improvement.

Problems with the Response Effort

Problem 1: Intake and Storage of Donated and Requested Goods

One of the major logistical problems that occurred during the rescue effort involved the prioritizing and tracking of supplies that were ordered (2). While there wasn't a problem getting the equipment needed for the effort, there were major problems with locating and tracking supplies. Multiple staging areas were set up to which supplies were delivered, thereby exacerbating the logistical headaches. For example, if the Red Cross ordered more rain coats, rescue leaders at the scene would have no way of knowing where and when they were delivered, without going to each of the staging stations and looking for the supplies by asking volunteers or by searching. Commercial tractor-trailers donated for storage were literally filled with everything from football helmets, to wheelbarrows, to search-and-rescue gear. Due to the enormous amount of goods that was donated and to the rate at which supplies arrived, it could not be verified what was on scene at any given time. Another major problem with inventory control was that different personnel did all documentation manually, each with his/her own system of recording supplies (2). With no electronic tracking system in place, rescuers had to physically go to the staging areas and ask volunteers or rummage though piles in order to determine if the supplies they requested had been delivered. This took significant amounts of time, often delaying the search and rescue effort.

Part of the problem with the staging areas, in addition to their multiple locations and lack of coordinated information sharing, was that each was operated by a different agency – implying differing 'ownerships.' The Oklahoma City Fire Department set up a staging area that they thought would be the only location for delivered goods. However, as the day went on, other agencies including the American Red Cross, Feed the Children, and the Oklahoma Highway Patrol, set up their 'own' staging areas in other locations around the Federal building. Multiple staging areas resulted in numerous problems in trying to locate supplies. When delivery trucks tried to drop off supplies, they did not know which staging area to bring them to. These problems, combined with a lack of an electronic inventory system, resulted (for example) in supplies intended for the Red Cross being dropped off at the Feed the Children staging area. This further delayed the process of getting much-needed supplies to rescuers. As a result, the rescue effort was slowed, due to the numerous logistical problems.

Lessons Learned/ Recommendations. The logistics behind the intake and storage of supplies are vital for a rescue effort to be a success. The first lesson learned is that there should be one single computer system keeping track of the entire inventory. This system would incorporate a database that would track the time of arrival and the precise location of each item. While it will be necessary to have different staging areas, linking them though a computer system will solve the problem of not knowing at which staging areas particular supplies are located. The second important lesson is that all supplies need to be tracked electronically through an inventory manager. It is crucial that each emergency response plan have an inventory management system set up and ready to be put into action if a terrorist attack occurs. This system should track the arrival time and location of each item donated so that rescuers can easily access goods that are needed. Also a priority system needs to be put into place indicating which items are more important and need to be readily available. This priority system will help streamline the process and allow access of crucial items to rescue workers. Lastly, all workers need to be trained so that they know how to use the inventory management system

Problem 2: Telephone Communications

One of the major problems we have seen in many disasters involves telephone communication or, more precisely, the lack thereof. This instance was no exception. One of the critical problems was communication among the different resource branches (Police, Fire, EMT, 911). One of the main reasons for this problem was that soon after the explosion, telephone lines became jammed (2). However, unlike the sarin attack in Japan (see Chapter 4), officials in Oklahoma City had a list of key contact names and their cell phone numbers. When officials tried to turn to cellular phones to communicate, they soon realized that these lines were jammed as well. This made communication almost impossible for some time (2). However, the cell phone service provider Cellular One came to the rescue in this case. According to Chief Gonzales, Cellular One donated over 1,500 cell phones for officials to use during the response. He said without these donated cell phones, effective communication would have been nearly impossible (10). Also, Cellular One had in their supply warehouse additional mobile equipment to help increase cellular system capacity. When this effort failed to free up phone lines, the government officials requested that priority be given to rescue officials and staff. This request was granted and helped to free-up phone lines.

Lessons Learned/ Recommendations. The key lesson learned is the need to maintain an accurate cellular phone directory of all rescue officials and staff so that when a network is jammed after an incident, priority is given to officials' calls (2). A key to achieving this is to include members of the cellular providers in the disaster planning team. It is also vital to have a prioritization system set up with the local providers to give access to emergency but non-911 calls during post-disaster periods. The reason for this is that a pre-planned agreement is needed in order to effectively execute this service in as little time as possible. Creating these preplanned agreements is significantly harder now than in the past. Around the time of the bombing, almost all residents in Oklahoma who had cellular service used Cellular One (now ATT Mobile). However, today's cellular market is flooded with a number of different providers; reaching an agreement with each of them is a much more daunting task. Also, calls between different providers may have priority issues and technical limitations.

Problem 3: Problems with Radio Communications

Radio communications created other problems. In Oklahoma City, the hospitals have had a system for many years known as The Hospital Emergency Administrative Radio (HEAR) System (1). This system features a common radio frequency shared among all area hospitals to be used during a time of disaster. The main purpose for the system is to provide inter-hospital communication. While the intention of having a system in place is excellent, in reality the system, which is rarely invoked, had unfortunately seldom been tested. Thus when it came time for hospitals to use the system, only three of fifteen area hospitals found their system working (1). As may be expected, this caused major operational problems. One of these was determining which hospitals were at capacity and which had room in their ER's. With the HEAR system down and the phones as congested as they were, it took a lengthy amount of time to receive this critical information (1). As a result, law enforcement officials who were busy with other critical activities, had to travel to hospitals to determine bed availability, thus significantly wasting resources.

Another major problem with radio communication was the problem of operating on a common frequency. Similar to what happened during Hurricane Floyd (see Chapter 5), each branch of service was operating on a different radio frequency, making shared radio communication very difficult (10). Thus, according to Chief Gonzales, it is important to have a common emergency frequency that each branch can tune into to be able to communicate during disaster response. Luckily, cell phones were donated and used in this disaster response, thus overcoming the problem.

Lessons Learned/ Recommendations. A result of the failure of the HEAR system, a test of the communication systems between hospitals is now performed on a daily basis. The lesson to be learned from this is that it is not enough to have an emergency system in place; but rather it is necessary to maintain the system and train personnel through drills.

Problem 4: Identification of Workers and Volunteers.
One of the major problems with the initial phases of the response was the lack of identification for rescuers (10). Since the Federal Building was declared a *crime scene* immediately after the attack, law states that anyone entering the building must be approved and possess verifying identification (4). As a result, there was significant delay in the rescue operation until volunteers could be slowly issued identification to assist with the process. The police had great difficulty protecting the perimeter of the building. Everyone from doctors, volunteers, to insurance adjusters, wanted to gain access to the building (10). Since it was a crime scene, the FBI imposed its own elaborate procedure for issuing temporary identification to those wishing to gain access. Fire Chief Marrs asked if a more expeditious photo ID-based system could be implemented to which the FBI consented. However, problems with the access procedures arose with every personnel change which led to numerous discussions before the problems were resolved.

Lessons Learned/ Recommendations. The recommendation here is that a system should be in place to give rescue workers and volunteers temporary identification as rapidly as possible. However, the system needs to be developed and tested prior to an incident's occurrence so that personnel have control and are trained to issue identification only to those who require access to the site.

Problem 5: The Operation of a Triage Center
One of the first centers established after the explosion was a triage center, which was located less than a block from the explosion site. The triage was set up to evaluate patients and classify them based on the nature and severity of their injuries. One of the fortunate aspects of the response was that the Federal Building was close to a dozen

hospitals. Thus, according to the disaster plan, different hospitals would be equipped to treat different patients based on their ER (Emergency Room) capacity, specializations of staff physicians, and proximity to the triage unit. While a sophisticated system was in place, an acute failure resulted (1). The main reason this system failed is that due to the proximity of the Federal Building to hospitals, over 300 of the 600 victims bypassed the triage unit and went directly to hospitals via volunteer transport or other means. Part of the reason for this failure was that rescue workers were unaware of the center and thus did not inform rescuers about the necessary service. Another reason few went through triage is that the center was moved many times. At first it was located too far from the Federal Building, causing many to miss it. However, after it was moved closer to the building, another bomb threat was issued. Due to the bomb threat, the center was moved farther away again. However, at this point, most still waiting to see a nurse became frustrated and went directly to hospitals instead of moving with the triage. By the time the center was moved back near the building, most living victims had already been transported to hospitals (1). While this may not seem like a huge problem, it caused a tremendous waste of resources. Many doctors were called to attend to victims needing treatment before being transported to hospitals. As a result, only seven intravenous infusions were performed at the triage center.

Lessons Learned/ Recommendations. The key lesson learned here is the importance of the triage center. However, in order to use the center to its full effectiveness, it is vital to locate it in an area that is adjacent to the area of the attack. Also, in order to increase its effectiveness, rescue workers need to be telling victims about the triage center and leading them to it. If this does not happen, the triage unit is a waste. Such malfunction also results in the inefficient use of doctors and nurses because each hospital then has to have a separate triage unit set up. All of this greatly detracts from the care the hospitals can provide patients due to inefficient use of resources.

Problem 6: Accountability of Backup Personnel and Volunteers

One of the major problems encountered during the Oklahoma City bombing rescue involved management and control of an influx of back-up personnel and volunteers. The disaster centered on a small piece of property in a very fragile state, so the number of rescuers that could enter the building at one time was small. However, immediately after the attack, the local media took it upon themselves to issue a call for medical volunteers and personnel at the scene. This call turned out to be a major mistake, resulting in increased management and coordination of well-meaning volunteers but took certified rescuers away from their primary job (10). Hundreds of volunteers responded to this call – some coming from as far away as California. The presence of volunteers on the scene soon became a major problem for the Oklahoma City Fire Department. Many became frustrated because they were not given assignments, so – wearing little or no protective gear – they took it upon themselves to go directly into the Federal Building and tried to rescue trapped victims (1). This resulted in the Oklahoma City Fire Department taking on the additional responsibility of monitoring the safety of and removal of medical volunteers from the building, thus further distracting them from the primary rescue effort. It was reported that there were more volunteer nurses than victims at the bombsite. Perhaps the true risk of medical volunteers was exemplified when a 36-year-old nurse, attempting to rescue a trapped victim, was hit on the head with a piece of debris and died. When we asked Chief Gonzales to identify the major problem with the response effort, he reported it to be the caring folks of the city who poured out trying to help, not realizing that many of them were not needed and in fact they were distracting from the response effort (10).

Lessons Learned/ Recommendations. The key lesson to be learned here is the importance of recognizing that "the more is better" phrase is not always true. In order for volunteers to be effective, they need to be trained, organized and have a clear objective and assignment in terms of the rescue. In future efforts, it is important in a response plan to have a strategy for managing volunteers. It is important to have a staging area to which all volunteers are directed. This did not happen in Oklahoma City and as a result volunteers started to assign themselves. At the staging area, there should also be a place where volunteers can comfortably await their assignments so they do not get frustrated. It is also necessary to alert the media not to issue unsolicited open calls for medical volunteers. Requests should be made for a certain number of volunteers and these requests should go through hospitals and other local medical authorities. Lastly, just as there is a response procedure and computerized system for EMT and fire responses, it is recommended that volunteer responses be integrated with the incident management system and be taken as seriously as the other three.

Problem 7: Importance of Compatible Medical Records

Another more general issue that became very problematic during the response was the lack of compatibility and availability of medical records (5). Due to the large volume of patients skipping the triage unit and arriving directly at hospitals, many problems arose in trying to discover and share patient information. One of the main problems encountered was trying to determine how many had been rescued and where relatives could find their loved ones (5). The lack of information caused a large amount of anxiety. Another major problem was that when patients were transported to hospitals that they had never been to before, doctors experienced communication problems obtaining their medical records and therefore could not determine if they had any special needs.

Lessons Learned/ Recommendations. The ability to share medical records over the computer is imperative during a disaster like Oklahoma City. However, due to the different types of hospitals (public, private, etc.) there was no centralized record-tracking system to be used in these types of situations. Treatments would have been administered more quickly and easily if doctors had had access to this information. Also, a centralized tracking system would have helped hospital officials track capacities at other hospitals to better allocate and share resources and to provide the necessary inter-hospital transfers that needed to take place. Such a tracking system would have also enabled family members to locate loved ones as opposed to searching from hospital to hospital. This may not seem like a significant problem, however the hundreds of family members distracted hospital workers from dealing with the emergencies at hand. Another reason that the lack of computerized record tracking made the process very inefficient was that after the incident, many medical personnel needed copies of the records. If sharing information over a central system had been possible, the time wasted on duplication could have been saved.

Problem 8: Problems with the Media
Many public officials underestimate the power the American media has over a response effort. This was particularly evident in Oklahoma. The majority of people get most of their information directly from the media (2). This can be very problematic. One example of this had to do with supplies. As stated before, supplies were coming in so fast that workers could not keep track of inventory. One rescue worker commented to a media person that he couldn't find gloves when 100 boxes were actually on hand. Thus the media issued a plea to the public to supply gloves. The next thing inventory workers knew was that there was truckload after truckload of gloves coming in, and the glove traffic prevented critically supplies needed from being dropped off, causing major delays in the rescue effort. Another problem with the media was trying to limit reporters' access. Many media personalities tried to enter the restricted area to get better shots. These media personalities soon became liabilities and forced a number of rescuers to be reassigned to controlling the media people as opposed to rescuing victims. Lastly, the media reported that all doctors in the area needed to report to the bomb site. This became very problematic since all doctors were not needed, but rather the request was for trauma specialists to report to the bombsite as opposed to ear, nose, and throat doctors.

Lessons Learned/ Recommendations. Every emergency response plan must outline a method and a model to deal with the media. Without control, the media will cause tremendous confusion and turmoil and can add additional responsibilities to already overburdened rescuers. Thus, it is paramount that we have a way of evaluating whether a city has adequately planned to deal with the media influx that will follow a major attack.

Problem 9: Priority Queueing of Victims
Prior to 10:00am, there was a continuous transport by EMS workers of victims from the triage site to hospitals. The goal was to transport victims to the hospitals at as fast as possible. But, despite triaging at the site, the EMS workers did not take into account the severity of injury or any other priority scheme. Until 10:00am, a "load-and-go" policy was in effect, under which the most critically injured received priority and were taken from the triage (most of the time without even seeing a nurse) directly to the ER of a private, well-equipped hospital a number of miles away.

Lessons Learned/ Recommendations. The lesson to be learned here is that a well-structured prioritization process needs to be part of any response plan, which allows those who need immediate medical attention to receive it, while not neglecting those who are stable, but whose conditions are deteriorating. Thus it is recommended that a mixed dynamic strategy be incorporated, where those who need immediate transportation have it available, but the number kept waiting should be minimized to allow transportation for those who are not in critical condition, but yet are in significant need of medical attention.

References

(1) Maningas P., Robinson M., Mallonee S. The EMS Response to the Oklahoma City Bombing. Prehospital and Disaster Medicine, 1997, Madison, Wisconsin
(2) The Oklahoma Department of Civil Emergency Management. After Action Report Alfred P. Murrah Federal Building Bombing 19 April 1995 in Oklahoma City, Oklahoma, 1995 Oklahoma City, Oklahoma, http://www.odcem.state.ok.us/archives/fema/1048/aar-cove.htm
(3) Oklahoma City National Memorial Website: http://www.oklahomacitynationalmemorial.org/
(4) Marrs G. Alfred P. Murrah Federal Building Bombing, April 19, 1995: Final Report, 1995 Oklahoma City, Oklahoma
(5) McLain S. The Oklahoma City Bombing: Lessons Learned by Hospitals, 1995 Oklahoma City, Oklahoma
(6) Washington Post Site on Oklahoma City Bombing: http://www.wahingtonpost.com/wp-srv/national/longterm/oklahoma/stories/chron.htm
(7) Oklahoma City National Memorial Institute for the Prevention of Terrorism, Oklahoma City Seven Years Later Lessons for Other Communities, 2002, Oklahoma City, Oklahoma, http://www.mipt.org/pdf/MIPT-OKC7YearsLater.pdf
(8) Manzi C., Powers J., Zetterlund K., Critical Information Flows in the Alfred P. Murrah Building Bombing: A Case Study, 2002, Washington D.C.
(9) U.S Department of Justice, Responding to Terrorism Victims: Okalahoma City and Beyond , October 2000, Washington D.C.
(10) Interview (by M. Metzger) with Chief Sam Gonzales, August 26th, 2004

Chapter 3: UNITED FLIGHT 232

Overview of Event

The next disaster we look at is a plane crash, United Flight 232, July 19th 1989, Sioux City, Iowa. Some of the interesting response aspects of a plane crash have to do with the uncertainty of the time and place of any crash, an extremely low probability event. In this chapter, we review the history of Flight 232, along with the emergency response. Unlike other chapters, most of the discussion here praises the excellent Sioux City emergency response plan and its execution.

On July 19th 1989 at 14:09pm, United Flight 232 took off from Denver bound for Chicago. The equipment for this flight was a DC-10, a large, three-engine, dual-aisle plane. Today, the only domestic airline that operates the DC-10 is Northwest Airlines (3). On board the flight were 15 United crewmembers, along with 285 passengers (1). The flight had an inordinate number of minors, due to a midweek youth special that United was running at the time (2). The flight departed Denver's Stapleton Airport at 14:09 CST and after passing over Iowa, the flight turned toward Chicago. All was normal during the flight until 15:17 when a loud bang was heard which shook the aircraft. The bang was due to the disintegration of the tail engine fan's rotator, which caused *all three* of the aircraft's hydraulic flight control systems to fail (1). The probability that three fully redundant hydraulic systems would fail was considered to be so minute that there was not even a page in the safety manual explaining how to respond to such a problem. At this point, almost all control of the aircraft had been lost, so instead of straightening out after turning, the plane continued back toward Iowa, and an emergency warning was issued. The crew contacted ground control in Minneapolis and was directed to land in Dubuque, Iowa, which was over 300 miles from the then-current position of the aircraft. However, based on the extent of the damage, the flight crew received permission to land at the Sioux City airport, which was less than 70 miles from their current position. This left the Sioux City fire and police with about 40 minutes to prepare for the response to the plane crash. The plane crash-landed at 16:01; however, immediately after landing, the left wing hit the ground causing the aircraft to split in two and catch fire. The emergency response to this incident was almost perfect. In this chapter, we summarize the excellent preparation and response effort that helped to save 186 lives.

Here is the chronology:

- **13:45** Flight 232 departs from Denver to Chicago with 285 passengers.
- **15:16** A loud explosion is heard on board the aircraft.
- **15:17** Pilot reports complete hydraulic failure.
- **15:20** Pilot declares an emergency.
- **15:21** Controllers reroute flight to Sioux City, Iowa.
- **15:23** Minneapolis Controllers turn flight controller responsibility over to those in Sioux City.
- **15:26** Sioux City Airport contacts its emergency communications center to inform them of the Alert 2 that was in effect.
- **15:34** Alert updated to Level Three.

- **15:35** Hospital helicopters placed on ground alert.
- **15:40** Trauma surgeons are assigned to stations in anticipation of crash.
- **15:40** Captain informs passengers that the plane has lost an engine.
- **15:54** Captain informs passengers to prepare for an emergency landing.
- **15:55** Disaster plan initiated at hospitals and staff begins mobilization.
- **16:01** Plane crashes on runway in Sioux City.
- **16:15** 40 Physicians lined up in emergency room.
- **16:17** First injured patient arrives at hospital.
- **16:40** Last injured patient arrives at hospital.

Reasons for Response Success

Reason 1: Upgrade to a Level Three Emergency before the Crash. Prior to the Flight 232 incident, in Sioux City the highest level of emergency alert that could be issued before a plane actually crashed was Level Two. This level of alert indicates that all emergency operations branches need to start preparing for the emergency, but normal operations need not cease. At 15:26, when it became evident Flight 232 was going to make an emergency landing, tower personnel contacted the Sioux City communications center and issued an Alert 2. This meant that as a precautionary measure, a limited number of ambulances and police units were dispatched to the airport. By 15:34, the ground control at Sioux City decided to up the level of emergency to a Level Three before the plane crash actually occurred. Normally a Level Three is only allowed to be issued once a crash occurs. Realizing the imminent danger, however, this level was issued early which, in turn, gave many agencies an extra 20-30 minutes to prepare for the crash (1). A Level Three alert allowed emergency vehicles to all but cease other operations and focus directly on preparing for the crash. This also allowed a mutual aid agreement between Sioux City and neighboring communities (Ida and Buena Vista Counties) to be activated giving Sioux City the capacity to tap into their neighbors' resources (2). Thus, there were extra ambulances (29 in all) and other emergency response vehicles sent to Sioux City to help prepare for the disaster, along with helping to maintain normal operations. When the plane crash-landed, most of the ambulances in Sioux City were assembled next to the runway ready to transport patients to the hospital.

Reason 2: Efficient Ambulance Transportation/Triage Center
One of the main reasons for praising the response to the plane crash was the set up of a two-class triage center *before* the crash occurred. The purpose of this center was to determine whether each victim's injuries were life threatening or not. If they were, the victim was immediately transported in the next ambulance to the hospital; if not, the victim was transported immediately as long as there wasn't someone with life threatening injuries ahead of him/her. This is known as the "scoop-and-run" method (2, 4). The idea behind this method, which was developed during the Vietnam War (2), is to get victims to the emergency room as quickly as possible and not provide any on-site medical attention (4). The rationale behind this method has to do with the concept of a "golden hour." More specifically, the probability of saving a critically injured person decreases exponentially with time if the patient is not treated in an emergency room within an hour of the disaster (5, 6).

Another innovative idea used to increase the rate of transporting victims was to place a roadblock on the major highway that connected the airport and the hospital. In the absence of traffic, ambulances could travel much faster to the hospital and back, resulting in one of the fastest transport rates ever observed (2). The first victims arrived at the hospital less than 16 minutes after the plane touched down (2), while the last victim arrived within 40 minutes of the crash. One of the reasons the response worked so efficiently was that separate ambulances were dedicated to transporting victims from the runway to the hospital, while others, that neighboring cities had provided, were reserved for patrolling and assisting with normal day-to-day operations. The objective for each EMT was clear; get the victim from the runway to the hospital and return to the scene in as little time as possible. The ability to refuel on-site made the task even easier. All in all, 88 victims were transported from the crash site to the hospital within 40 minutes. Of the 88 transported, 78 were treated and eventually released (2).

Reason 3: A Living Integrated Emergency Response Plan

Another reason for the success of the response to the crash of Flight 232 was a well thought out and consistently rehearsed response plan. The Sioux City emergency response plan is one that should be awarded a gold star. In 1987, officials decided that they needed to better integrate their disaster plan among the various rescue agencies. They also decided to make the plan document a living one that is updated frequently to reflect problems and innovations identified through technology, practice, or the response to other incidents (2). Also, the entire plan was jointly authored which may be unique for an emergency response plan (2). Usually, separate sections are assigned to the respective agencies; however, this plan was totally integrated from the start. Also, unlike most other cities, all rehearsals and practice runs were performed jointly by the different branches. This helps to prepare for an effective integrated response. The plan was rehearsed once a year, using a different disaster scenario each time. According to rescuers, the yearly drill helped them to discern the weaknesses in their coordination efforts and also helped them get to know one another (1). This process established a level of trust among the different branches, which many believe resulted in a more effective response when Flight 232 crashed. Rescuers were trained so well that when interviewed after the disaster, they said they knew the plan and did not ever refer to it during the response. Another reason integration helped was that a central command center was set up, and the heads of each department reported there to coordinate the response. This greatly enhanced the collaborative effort and made the response effort much more effective.

To illustrate the importance and benefits of preparation, the year 1987's training exercise simulated the crash of a large dual-aisle plane. The Director of Emergency Services realized that the prep time needed before the first responders were ready was too long and as a result, there were changes made to the patrolling of the ambulances in order to make the response quicker should an actual emergency occur. As reported, the response effort on the crash day was very similar to the one practiced in the drill (1). The only exception noted was that there were 285 people on board instead of 150, the number in the drill. As another direct result of the drill, the mutual aid program was expanded, which in the end proved to be vital in helping to save lives.

Reason 4: Medical Assembly Line Program

Another response component deserving praise was the treatment assistance of the medical teams. Fortunately, Flight 232 crashed just as the hospital day shift nurses and doctors were leaving and the evening shift staff was arriving. As a result, no orders to come in were needed as the day shift remained on duty (2). The way the triage at the hospital worked was when a patient arrived, doctors were paired with nurses and each two-person team waited until they were assigned a specific patient. These two medical professionals stayed with the patient and were responsible for treatment until the patient was stabilized. The only exception to this was a separate pool of surgeons who, along with teams of nurses, were assigned to arriving patients in immediate need of surgery (2). Thus, when a victim arrived, he or she was either assigned a treatment team or sent directly to surgery. As United Captain Al Hynes reported:

> "As an ambulance drove up and a patient was removed from it, the next available group went with the patient into the emergency room; and they stayed with the patient until he or she was admitted to the hospital or discharged. That is just the way I met my doctor; he was next in line when my ambulance drove up. There were all kinds of doctors there, it did not matter what their specialties were. This efficient and intensive level of care is one of the reasons why so many of those who made it to the hospital survived, and did not succumb while they were in the hospital (1)."

Reason 5: Mutual Aid Contract

One of the primary reasons for the success of the response effort was the mutual aid contract between Sioux City and the neighboring areas (1). Unlike many cities, a signed agreement was in place so that any time a Level Three emergency was in effect, even if only in anticipation of a potential disaster, the neighboring districts would dispatch additional required resources. As a result, well before Flight 232 crash-landed, the crews were ready at the runway for the potential disaster.

Reason 6: Pre-Positioning Ambulances for the Disaster

Another step Sioux City took in preparation for the crash was the positioning of ambulances to minimize travel time to the expected crash site. This procedure was developed during a training exercise. The idea is that many times when a plane crashes, it does not make the runway it is intended to land on and instead crashes somewhere in the surrounding area. What the city found was that if they positioned a number of ambulances on the areas' highways, they maximized the response effort if the plane crashed before it reached the runway. Thus, with the support of the mutual aid contract, additional ambulances were positioned on highways; this decreased the response time when the plane crashed away from the runway.

References

(1) Haynes A., Eyewitness Report: United Flight 232, http://www.airdisaster.com , 1989
(2) Charles M. and Settle A., United Flight 232: Sioux City's response to an air disaster, Industrial Crisis Quarterly, 1991, Industrial Crisis Institute, New York
(3) Northwest Airlines http://www.nwa.com
(4) Somerville J., Providing Care in the Aftermath of Tragedy, American Medical News, 1989, Chicago IL
(5) Greco D.I., Interview, 1989

(6) Wolpert M.I., Interview, 1989
(7) Kilroy, K., Special Report: United Airlines Flight 232, http://www.airdisaster.com, 1997.

Chapter 4: TOKYO SUBWAY SARIN ATTACK

The next disaster we explore is a deliberate terrorist chemical attack, known as the Tokyo Subway Sarin Attack. Based on the use of the chemical agent, twelve people died. In this chapter we review the history behind the disaster and focus on the response to the attack. Of particular importance are the events that transpired at the hospital and the problems hospitals experienced as a result of the attack.

Overview of Event

In the early morning of March 20th, 1995, a terrorist group (members of "AUM Shinrikyo") launched a sarin nerve gas attack in Tokyo. The attack targeted the Tokyo subway system. The result of this attack was that twelve civilians were killed and more than 5,000 were injured. This disaster is noted as the largest nerve gas attack in peacetime history. This chapter presents the historical background of the events, a chronology of what occurred, an overview of the emergency response, the shortcomings of the response, and concludes with what we can learn from this attack and apply to the emergency response mathematical model we are developing.

History

The subway sarin attack was not the first sarin attack that Japan had experienced. In order to understand what prompted the subway attack, it is necessary to outline the actions of a certain cult. In 1984 Shoko Asahara started a small publishing house in Japan, which later evolved into a cult (1). The cult became increasingly popular and started to attract members from many nations. The group's main focus was to achieve supremacy in Japan. To that end, in the early 90's, the group began developing chemical and biological weapons (1). The expense of this program amounted to more than 30 million dollars.

The group's first attack using sarin occurred in 1994. The group was in a court dispute over a land purchase that Asahara had made. Late in the trial, the group anticipated an unfavorable ruling and decided to seek revenge (1). They released vaporized sarin into the court using a fan and some other household items. However, since the sarin was in a very diluted state, the judges survived while seven civilians lost their lives (1). However, the authorities had no evidence linking the group to the attack and thus could not take action against the them.

About a year later, the police were uncovering mounting evidence against Asahara, so the group decided that they needed to take action fast if they were to achieve their goals before being arrested (1). On the morning of March 25th 1995, the group hastily put together a subway attack plan. The plan was that each of five teams of two people would release a can of sarin in a different subway car headed for the city center. Their strategy was based on public records showing that in the morning subway, the number of riders can exceed official capacity by 200%, making it almost impossible to move around in the subway car. The terrorists picked five subway lines that converged at the Kasumigaseki station. This station is located near many government buildings and police department headquarters. Each can contained 20 ounces of sarin; however, the sarin was only 30% strong (1).

According to police records, the attack was launched at 7:55am on the morning of March 20^{th} 1995. At 8:09am the first emergency call was received and by 8:40am the first ambulance arrived on scene. The following time line tells the events of the day.

Chronology:

- **7:55am** Terrorists board subway cars.
- **8:00am** Attack is launched.
- **8:09am** First emergency call is received.
- **8:16am** Tokyo fire department is informed of attack.
- **8:25am** First Victim arrives at Hospital by foot.
- **8:40am** First ambulance arrives on scene.
- **10:00am** EMT's misclassify agent as acetonitrile.
- **11:00am** Police identify agent as sarin.
- **12:00pm** Hospitals learn agent is sarin.
- **12:45pm** On-site triage and decontamination centers are set up.
- **6:00pm** Germany, France, and England offer to send dispatch teams.

About Sarin

Sarin is a human-made chemical weapon (3), known to be a nerve agent. It was first developed in 1938 for use as a pesticide (3). The agent is used both as a liquid and as a vapor. People are exposed to sarin by breathing it in or through contact with the skin. After coming into contact with sarin, a person's clothing can spread the gas for about 30 minutes. The symptoms of sarin appear a few seconds after being exposed to the vapor form and up to 18 hours after being exposed to the liquid form. Sarin is the most volatile of nerve agents as it evaporates very quickly and thus can spread easily (3). It causes severe eye burn. The following is a list of symptoms a person exposed to sarin might experience (3):

- Runny nose
- Watery eyes
- Small, pinpoint pupils
- Eye pain
- Blurred vision
- Drooling and excessive sweating
- Cough
- Chest tightness
- Rapid breathing
- Diarrhea
- Increased urination
- Confusion
- Drowsiness
- Weakness

- Headache
- Nausea, vomiting, and/or abdominal pain
- Slow or fast heart rate
- Low or high blood pressure
- Loss of consciousness
- Convulsions
- Paralysis
- Respiratory failure possibly leading to death

Antidotes are available to treat sarin and are sold by most pharmaceutical companies. The earlier the person is decontaminated, the less harmful the effects of the agent. The earlier the person is given the antidote, the less the chances of severe health-related problems.

Problems with the Response Effort

Problem 1:Communication and Coordination within the Tokyo Metropolitan Ambulance Control Center (TMACC)

One of the major problems that occurred during the initial stage of the response effort was a lack of communication between TMACC operators (2). Within the first hour following the incident, calls from fifteen different subway stations came in reporting emergencies. The TMACC computers and operators, however, initially failed to link the fifteen calls to a large single attack and thus dispatched different EMT teams to each station to attempt to determine the emergency at each station. Since these teams were unaware of the possible linkage among events, the EMT teams failed to coordinate and work together to identify the cause of the attacks. This lack of communication during the first one to two hours caused many civilians to suffer needlessly (2).

Lessons Learned/Recommendations. The lesson learned is that of communication (which we see many times in this report). It is vital to keep a log and have constant interaction among emergency operators. Coordination between callers should have been able to link these events as a single event in much less than the actual time it took. A feature that could help link the attacks would be a system to log calls and identify linkage between calls. For example, a computer model within 15 minutes of the first few calls should have flagged the trigger words, *subway station*, or *burning eyes*. These were two phrases that almost every emergency call featured.

Problem 2: Timeliness of a Triage Setup

One of the salient characteristics of a nerve gas attack is that the earlier a victim receives medical treatment the less ill he will become. A civilian who is exposed to sarin requires endotracheal intubation as soon as possible (2). After the sarin nerve gas attack, the EMT's primary goal was to "transport as many victims as quickly as possible to the nearest hospital." This reasoning was again due to a lack of communication where most of the EMT's were not instructed to set up a triage center until over 2 hours after the incident took place. Thus, many victims' conditions worsened due to the lack of on-site treatment, and a small number died on the way to the hospital. By the time the TMFD decided to set up a triage center and send 47 doctors and 23 nurses to the 15 stations to provide on-site treatment, almost all of the victims had either been transported by ambulances to hospitals or had fled the area by foot in search of medical treatment (2).

Lessons Learned/Recommendations. A major result of the lack of a triage was confusion about whom to transport to hospitals. The purpose of the triage was to separate victims based on severity of injury. However, this was not accomplished and as a result, victims who were in critical condition were not given priority transport, while mildly affected victims were immediately transported in some cases. Thus, it is important to incorporate triage with an optimal ambulance response strategy. Therefore, some method must be created which determines which victims are transported first and to where, based on the severity of their condition. The only way this classification can be accomplished is if a triage center is immediately set up on-site.

Problem 3: Information Overflow at the TMACC

The decision to set up a triage center was late. Further delays in the process occurred due to an information overflow at the TMACC. The doctor on call at the TMACC lost radio contact with the EMT's due to the overflow of information. The result of the large number of people trying to pass information to each other caused radio frequencies to become jammed and the doctor on call could not contact the TMACC. Thus, very few victims received medical treatment from the EMT's until arriving at their respective hospitals (2). Also, due to the mismanagement of incoming information, the attack was declared after around two hours from onset to be the largest disaster since World War II. This gross exaggeration, due to mismanaged information, caused terror and panic in Tokyo.

Problem 4: Identification of Sarin/More Communication Problems

A major issue with the Tokyo attack and many other chemical attacks is the timeliness of identification of the agent that is used in the attack. In the sarin attack, delay proved to be deadly. The TMFD first thought that the victims were suffering from acetonitrile[4]. (7) When the police finally identified the agent to be sarin, around 11am (3 hours after the attack), they failed to immediately inform the TMFD and hospitals of their findings; rather, they first informed the media Thus, hospitals continued treating patients for acetonitrile until they were finally informed that the agent was sarin. One questions who in the police force decided to contact the media before the TMFD. It is also a problem when medics have to rely on clinical observation to treat chemical attacks, since many attacks requiring vastly different treatments present similar symptoms.

Lessons Learned/Recommendations:

Unfortunately, in the sarin attack, the EMT's were not equipped with detection devices, which could have detected sarin as the agent. The detection would have been easy since the amount of sarin most of the victims were exposed to was huge, 'off the charts'. As further evidence, a study recently done in the Netherlands was able to detect sarin still in the blood of 10 out of 11 victims of the Tokyo sarin attacks, fully nine years after the attack.

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[4] More information about acetonitrile is available at: http://www.nsc.org/library/chemical/Acetonit.htm.

In these uncertain times, it is crucial for the agent in chemical attacks to be identified as quickly as possible. A false identification or lack of one causes the numbers of lives lost to increase exponentially. Thus, it is crucial that EMT's be equipped with agent detectors. If this is not financially possible, detectors should be at least kept in some central locations. Then when such incidents occur, detection devices would be readily available. These devices are easy to obtain and are not very expensive. In fact, a cursory web search found that detectors are available for approximately 100 dollars or less[5]. Secondly, it appears that in many cases of terrorist attack or natural disaster, there is a 'brick wall' between the different response departments (fire, police, ambulance and hospital). The lack of communication seems to be one of the most detrimental mistakes made during emergency responses. Inter-communication between these tightly linked branches of response is vital. There needs to be a common communication system or at least one in place for when these events occur.

Problem 5: On Site Decontamination Facilities/Protective Gear

One of the major problems with the response to the sarin attack was a lack of on-site decontamination centers. The TMFD failed to set up a single decontamination center. Victims who are exposed to sarin need to be moved to fresh air immediately. Following this they need to be administered the antidote atropine sulfate. Also if the victim experiences seizures then the agent diazepam must be administered. It is also important during the decontamination process that one does not induce vomiting with the victims nor provide mouth-to-mouth resuscitation. For more serious cases it may be necessary to administer pralidoxime or obidoxime. No decontamination was preformed on victims until they arrived at hospitals (2). This was a major error. If the chemical agent is present on one's clothing and that person comes in contact with someone else, the probability that it spreads to the other person is very high. It should be noted that sarin can vaporize and spread through the air. Thus it should not be spread through human-to-human contact. As a result, there were second-, third- and fourth-order effects from the attack. Of 1,364 EMT's, 135 or approximately 10% became ill and needed to be checked into the hospital after transporting victims (2). It was reported that the EMT's were wearing street clothing and had no protective gear to guard against the spread of sarin. The result of this has a second-order effect. Since 10% of the EMT's were checked into the hospitals, the number of ambulances available to transport victims still on sight needing medical attention decreased by approximately 10 percent. Another second-order effect was that 110 doctors became ill after treating patients that had not yet gone through the decontamination procedure. In the absence of an optimized transport method, many victims arrived at hospitals via taxi and by foot. Thus, even with decontamination centers on-site, it is vital that hospitals also be equipped with decontamination centers, since people arriving on foot and by taxi will not have been decontaminated and the possibility of a second-order effect will still exist. Due to the large number of victims, hospitals did not have enough decontamination facilities to decontaminate all victims. Thus victims who were mildly affected by the attack were not decontaminated and spread the agent to doctors. It is also vital in these situations to make sure all decontamination centers and treatment rooms are well ventilated. If this is not the case, the gas can build up and spread to doctors and nurses treating patients.

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[5] http://www.arrowtechinc.com/ap2c.htm.

Lessons Learned/Recommendations. It is vital to set up decontamination centers near the site of the attack as soon as possible. The decontamination procedure is very similar for different agents. Victims exposed to sarin require immediate treatment with atropine sulfate. This agent helps victims by opening up airways allowing them to breathe more easily. Atropine also helps stop many of the other side effects of exposure to a poison such as nausea, vomiting, abdominal cramping, low heart rate, and sweating. However, atropine, which is administered through IV or injection, does not prevent or reverse paralysis. Pralidoxime chloride is also administered[6]. In order to protect EMT's, it is necessary to provide them with gear that acts as a blocking agent to sarin. Lastly, hospitals and hospital staff need to maintain proper decontamination equipment and procedures. However, it is also important to note that while having protective gear is vital, the amount of protective gear that is used should be in proportion to the strength of the attack. The reason for this is that excessive protective gear can cause many ergonomic problems, which can increase both the time frame and difficulty of treating and transporting patients.

Another important safety measure is to have EMT's travel with some of this protective gear in case such instances arise. It is a question of space and economics which dictate the amount of supplies and protection that can be on-board. A model should be constructed which determines what supplies are most necessary to be on-board and where to locate the back-up supplies. It is also vital that there be some form of communication that lets EMT drivers know how serious an attack is and what types of gear they must wear during the rescue so they are protected, but not overly protected and thus decreasing efficiency.

Another way to improve the decontamination process is to have what are known as mobile decontamination centers (8). These centers can be attached to ambulances when being transported to the site of an attack. They are fully ready to be put into service after an attack occurs. This helps to eliminate much of the time wasted on setting up a decontamination center. These operational centers allow more rapid on-site decontamination and will greatly reduce the amount of second- and third-order exposure that occurs. An important question a planner has to answer is how many centers are appropriate for a small community. This answer will be based on population and economics. A final important decision problem is where to locate these centers to minimize travel times to the incidents. Solving this optimization-location problem would help to decontaminate victims as quickly as possible.

Lastly, one possible solution for hospitals that cannot afford additional decontamination facilities is to construct temporary ones outside the triage entrance in the parking lot. These temporary facilities would help decontaminate more victims and minimize the second-order effects of the attack.

[6] http://www.emedicine.com/aaem/topic547.

Problem 6: Ambulance Transportation Problems and Communication
The ambulance transport system experienced many problems after the sarin attack. According to reports, EMT workers transported a total of 688 out of the more than 4,000 victims who received medical attention. Taxis transported more victims than ambulances did, corresponding to over 25 per cent of all victims, which helps to explain the magnitude of the second- and third-order effects (2). Part of the reason for this inefficiency was a lack of communication between the EMT's and the hospitals. According to sources, radio channel overload prevented communication between EMT's and their supervising hospital-based doctors. This lack of communication can be considered part of the cause for not having on-site treatment for victims. The assignment of victims from respective site to respective hospital was grossly inefficient. Many EMT's took victims to hospitals far from where they were picked up when hospitals much closer still had vacancies (2, 4). Due to a lack of communication, information about what hospitals were at capacity and what hospitals could accept more victims was inaccurate, leading to a lack of efficiency and effectiveness in the process. Many ambulances had to travel from hospital to hospital in search of vacancies, while other less-caring EMT's would drop patients off at hospitals that were at or above capacity. Due to such misinformation, one hospital that was not particularly close to any of the subway stations received a disproportionately large fraction of the victims of the attack.

Lessons Learned/Recommendations. Clearly one needs a systematic way to deploy ambulances to different sites after a disaster like this occurs. One of the major problems was that ambulances were allocated based on the relative density of daily population near the subway stations. The attacks, however, occurred in the morning when most people were moving into Tokyo, and thus, these local population numbers bore no relationship to need. Also, one of the terrorists used two cans of sarin, thus causing much more damage to a subway station near a relatively under populated neighborhood. Thus, the victims at this station did not receive a proportionate level of EMT's and support, and the majority of them had to travel by foot or via taxi to the closest hospital they could find. Once the first EMT's arrived on-site, they reported to the TMACC their initial analysis to determine the allocation of EMT's to subway stations. Finding a reasonable procedure to determine which stations EMT's should report to is crucial in large-scale events like this. This type of procedure should be included in any response plan. The plan should also be dynamic; as time progresses these proportions might change. A second feature that should be included is a rational assignment of EMT's to hospitals. As stated above, the Tokyo procedure was grossly inaccurate leading to both overcrowding in some hospitals and underutilization in others. In order to optimally allocate patients, a method must be created that assigns each patient to a hospital, and takes into account the location of the patients, the current hospital occupancy, and the severity of the patients injuries.

A second-order response method should be implemented that utilizes non-emergency response vehicles to help with the response effort. Thus there should be a model which allocates non-emergency response vehicles to take part in transporting victims to hospitals. Efforts on the part of the taxi drivers in Japan saved numerous lives. Taxi drivers acted because of a severe shortage of ambulances. Following the attack, the

Japanese instituted a disaster reporting system in all taxicabs that directs the drivers to desired locations if their assistance is needed in case of a disaster.

Problem 7: Inter-hospital Ambulance Transfer/ Communications Among Hospitals
Due to communications problems, there were few EMT's stationed at hospitals waiting to perform inter-hospital transfers (2). When officials at one hospital contacted the TMFD about providing hospital transfers, the TMFD said that they did not have the capacity to provide these transfers, since all vehicles were dealing with the rescue efforts and thus they were in a shortage situation. As a result, some hospitals were working over capacity, while others were nowhere near capacity. Also, due to the lack of inter-hospital communication, doctors at under-capacity hospitals, who were not swamped with patients, were not transferred to over-capacity hospitals. (Note: These doctors did not need ambulances and could have driven themselves, while the reverse was not possible).

Lessons Learned/Recommendations. Inter-hospital transfers are required during events like this, otherwise reasonable allocations are not likely to take place. Thus, it is crucial to keep a number of EMT's stationed at hospitals to support the process of inter-hospital transfers. Ideally one would reallocate patients that are movable based on current hospital capacities, distance between hospitals, and doctor-to-patient ratios.

If there are no ambulances available for hospital transfers, there needs to be a back-up system in place to perform these transfers. Whether such a system utilizes taxis, buses, or military vehicles, one needs to be included in the planning; otherwise medical officials run the risk of filling hospitals to levels dangerously over capacity, resulting in loss of life.

Problem 8: EMT Restrictions/Communication with Doctors
Restrictions on EMT on-site actions created problems. One of the initial acts medical responders can perform to help sarin victims is to insert an endotracheal tube to maintain a breathing airway. However, in Japan without the consent of a doctor, this act is illegal (2). Thus, when EMT's and doctors lost contact during the information overload, they were unable to provide doctors on-site fast enough to get consent so that the EMT's could perform this possibly life saving procedure.

Lessons Learned/Recommendations. EMT's must be educated on how to provide the very basics of medical care to on-site victims. In cases of extreme emergency, there should be provisions that allow trained EMT's to perform basic treatments without consent of a physician.

Problem 9: Antidote Supply and Storage
Another major problem concerned the demand for the antidote to sarin. Hospitals had a limited supply of the antidote stored on-site. When the agent was finally correctly identified, many hospitals were running low on or out of the right antidote and needed to order more. However, due to processing and travel time, it took a significant amount of time until many hospitals received their back-up orders.

Lessons Learned/Recommendations. We need an inventory policy, that is a set of decision support tools, to determine the optimal amounts of antidote to have on hand at local hospitals in the event of a chemical attack. The inventory levels will be functions of the population, number of hospitals, assessed risk, and other economic factors. It is also important to structure and solve a facility location problem to determine where back-up supplies of the antidote should be stored. It is vital that the storage points be close to the respective hospitals, while at the same time having the supplies dispersed enough to reduce vulnerability to a terrorist attack.

Problem 10: Back-Up Support

In the Tokyo sarin attack, the Japanese national government played little role. One of the main reasons for its lack of participation had to do with Japan's *Fundamental Law of Disaster Management* (2). The main idea is the official in charge of the geographic region where the disaster occurs is responsible for initiating the response effort. Thus the national government did little in responding to the attack. However, after a long delay, some members of the Japanese Self Defense forces arrived on scene to assist (2). It was clear in the case of the sarin attacks that the Tokyo response system was overloaded, as many victims arrived at hospitals via foot or taxi.

Lessons Learned/Recommendations. When developing a model, it is critical to identify when and to what extent the system is overloaded. When overload occurs, it is necessary to have back-up support on-call to aid in the response effort. The disaster response plan needs to identify this and have back-up provisions to aid in the response effort. This back-up support can be in the form of taxis, national guardsmen, neighboring personnel, or civilian help. Lastly, if back-up support is called away from a local city, that city needs to reallocate their personnel in order to guard against a second attack and/or to maintain an adequate level of usual emergency response services.

References

(1) Chemical Terrorism in Japan: The Matsumoto and Tokyo Incidents, http://www.opcw.org/resp/html/japan
(2) Okumura T., the Tokyo Subway Sarin Attack: Disaster Management, Part 1: Community Emergency Response, Academic Emergency Medicine, 1998, Lansing, MI
(3) CDC Sarin Emergency Response Card, 2004, http://www.bt.cdc.gov/agent/sarin/erc107-44-8.asp
(4) Okumura T., the Tokyo Subway Sarin Attack: Disaster Management, Part 2: Hospital Response, Academic Emergency Medicine, 1998, Lansing, MI
(5) Okumura T., the Tokyo Subway Sarin Attack: Disaster Management, Part 3: National and International Responses, Academic Emergency Medicine, 1998, Lansing, MI
(6) Ishimatsu S., Takasu N., The Tokyo Subway Sarin Attack: Medical Care at St. Luke's Intl Hospital. Kyukyu-Igaku, 1995
(7) Cox RD, Decontamination and Management of Hazardous Materials Exposure Victims in the Emergency Department, Ann Emerg Med, 1994, Irving, TX
(8) Okudera H., Unexpected Nerve Gas Exposure in the City of Matsumoto: Report of Rescue Activity in the First Sarin Gas Terrorism, Am J Emerg Med, 1997, Philadelphia, Pennsylvania

Chapter 5: BHOPAL GAS TRAGEDY

The next disaster we explore is the Bhopal Gas Tragedy. This disaster is perhaps the most tragic of all of the disasters reviewed in this report. Yet, this is our shortest chapter. This is because the response to this disaster was almost absent. We review what happened on the night of December 2nd, 1984 and outline the limited emergency response.

Overview of Event

The Bhopal gas tragedy is one of the worst known industrial accidents in modern history (3). The small town of Bhopal India was home to the Union Carbide C plant. The plant had a license to manufacture methylisocyanate (MIC). This toxic chemical was commonly used in pesticide production. When vaporized and exposed to the skin, methylisocyanate is deadly. On the night of December 2nd, 1984 water got into MIC storage tank #610 (2). Around 11pm that night, the tank expanded and caused a safety valve to release and caused the deadly substance to expand and vaporize, allowing vaporized gas to escape the tank. Between 12:45am and 1:45am, wind spread 40 tons of released MIC gas (1). This caused over 10,000 people to die and injured more than half a million others (3). There was little or no escape for the local residents, as most of them were sleeping. There was also no signal to alert residents to the escape of the gas. Thus many died in their sleep, while those who awoke tried to escape and died on the streets. When the dust cleared the next day, investigators discovered the cause of the disaster. A long legal battle ensued which continues to this day (in 2004) (4)

Lessons Learned

There were numerous errors made that resulted in the deaths of over 10,000 people. The main error was the lack of a well thought out safety plan. As the result of not having a planned evacuation system, workers were trapped in the factory and failed to alert the community about the gas release. The main reason the community was not alerted about the disaster was simply because the emergency sirens had been switched off; some contend this was done to save money while others contend that regular safety checks were not performed and thus the problem was not detected (3). Thus, due to poor communication systems in India, it was not until morning that ambulances were sent out to rescue those still alive. As a result, over half a million people were severely injured.

Another major issue was the lack of safety equipment available on-site for workers. If the workers who first identified the agent were not susceptible to the agent, they could have alerted disaster authorities and prevented the tragedy. However, the way they identified the agent was from exposure and thus most of them died on exposure (2).

The main lesson to be learned from this disaster is that with a well thought out disaster evacuation and notification plan, far fewer people would have lost their lives. It also offers a stark illustration of the importance of early detection of an agent is in preventing a massive disaster. Thus it is crucial that EMT's and authorities have detection devices with them that will identify killer agents. It is also vital for workers always to have substantial protective gear to prevent potentially fatal exposures. Perhaps the most important lesson is the need for pre-planning and to have safety measures implemented to minimize the chance of such a disaster occurring in the first placed.

This chapter's brevity is indicative of the fact that little to no response occurred immediately afterwards.

References

(1) http://www.corrosion-doctors.org/Pollution/bhopal.htm
(2) http://www.Bhopal.net
(3) http://www.Bhopal.com
(4) TED Case Studies: Bhopal Disaster http://www.american.edu/projects/mandala/TED/bhopal.htm

CHAPTER 6: HURRICANE FLOYD

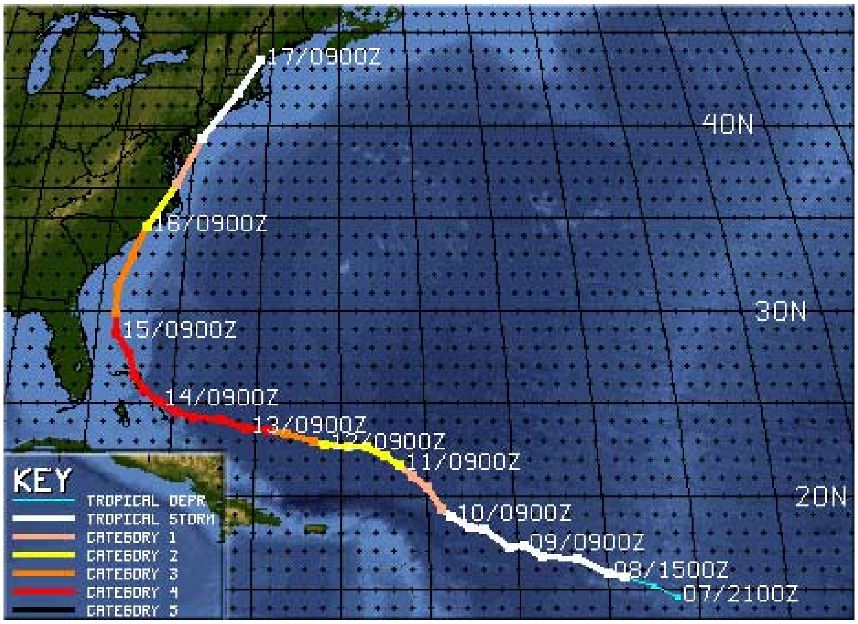
In this chapter we explore the response to Hurricane Floyd (1999). We highlight the major problems with the response, along with the lessons learned from responding to this disaster. Perhaps the importance of false evacuations and fast response cannot be stressed enough.

Overview of Event

Hurricane Floyd is notable for the largest peacetime evacuation in the history of the United States (9) up through the end of the 20th Century. On September 2nd 1999, the hurricane started in West Africa due apparently to a series of large ocean waves. It then traveled across the Atlantic to the Bahamas. At this point, the storm reached its most severe level; a category 4 hurricane, meaning sustained winds of 131 to 155 miles/hr and a storm surge of 13 – 18 feet above normal (see appendix), potentially devastating for Florida. Experts thought the storm was going to hit central Florida with extreme force (9). Due to this fear, a large portion of the east coast of central Florida was evacuated on September 12th or 13th. However, hours before the hurricane was projected to strike, a gale-force wind originating in Canada caused the storm to turn east and move back over the Atlantic Ocean, thus missing the Florida coastline. The total economic loss caused by Hurricane Floyd is estimated to be 3.4 billion dollars. A significant portion of this loss is attributable to the evacuation which took place (10). However, the real shame of the Florida evacuation was that it caused other states to become much more wary of evacuations in planning for the hurricane, which ultimately proved deadly (2). Unfortunately, the storm turned back west on September 15th and headed for Georgia and the Carolinas. Floyd made its landfall[7] on Thursday the 16th of September near Cape Fear, North Carolina. This chapter chronicles the hurricane, followed by some commentary on the North Carolina response effort, and concludes with lessons learned.

Chronology. The below map tracks the position of Hurricane Floyd day-by-day (1):

[7] The landfall of a hurricane is the point at which the eye of the storm first crosses a landmass.



Hurricane Floyd Timeline

The below timeline overviews the response effort in North Carolina:

- **Tuesday September 14th** As the storm moves north offshore the Florida coast it is classified as a category 4 hurricane.
- **Tuesday September 14th 4:30pm.** Potential flooding off I-95 in North Carolina is predicted.
- **Wednesday September 15th** First Evacuation Notice is issued.
- **Wednesday September 15th** The Southeast River Forecast Center in Atlanta predicted 6-12 inches of rainfall in North Carolina.
- **Thursday September 16th 2am** Floyd comes ashore in North Carolina.
- **Thursday September 16th 5am** Floyd drops to a Category 2 hurricane.
- **Thursday September 16th 11am** The storm falls in North Carolina near I-95.
- **Thursday September 16th 2pm** The storm moves north and the skies begin to clear over North Carolina.
- **Thursday September 16th 5pm** The rescue effort begins with a few firefighters.
- **Thursday September 16th 6pm** A Maine helicopter is flown in to help with the rescue effort but arrives after dark providing little help for Thursday's effort.
- **Thursday September 16th 11pm** The inland rivers in North Carolina rise dangerously.
- **Thursday September 16th 11:30pm** Evacuations are issued to those living near fresh water.
- **Friday September 17th 4am** The inland rivers crest.
- **Friday September 17th 1pm** Military helicopters arrive.
- **Friday September 17th 1pm** An Estimated 1,500 people are still trapped.
- **Saturday September 18th** 420 people rescued by military helicopters.
- **Saturday September 18th 3pm** All rescues completed.

Overview of the Emergency Response Effort
Many experts concluded that while South Carolina did an especially good job with their evacuation and rescue efforts, the same could not be said for North Carolina (4). One facet many do not realize about the tragedy of Hurricane Floyd is that more than 90% of the resultant deaths were not caused by salt water drowning stemming from oceans overflowing. Rather, 50 out of the 57 deaths were due to fresh water drowning. Kent Frantz of the Southeast River Forecast Center found it hard to get past the focus on the coast even though he predicted extensive inland flooding. "We tried to tell everyone that the main problem was going to be inland flooding, but no one seemed very interested." (6). When examining the emergency response efforts it is imperative to look at what happened before the hurricane landfall in order to understand how the response efforts unfolded. In fact, in the past 30 years, over three-fifths of hurricane deaths have been caused by freshwater flooding (11).

<u>Problems with the Response Effort</u>

Problem 1: Prediction Probabilities
One of the main problems with being prepared for a large hurricane is the inability to predict with high accuracy where it will strike land. If officials err on the side of greater caution and issue a false evacuation warning, their credibility suffers and the economic losses can be large. Based on weather observations, the National Weather Council (NWC) uses *strike probabilities* to determine the chance that a hurricane will strike within 65 nautical miles of a certain point. The 65-mile radius is used to estimate the area of damage and determine if an evacuation will be necessary based on the hurricane category. The main problem with the NWC's prediction is that the highest probability of an accurate prediction two days in advance is a mere 25% (2). Thus given the current position of a storm and the ability to track it, the maximum probability that it will strike a given region conditioned on this information is 25%

The prediction probabilities are shown in the below table (2):

Forecast Period	Maximum Probability
72 hours	10%-15%
48 hours	20%-25%
36 hours	25%-35%
24 hours	40%-50%
12 hours	75%-85%

It is difficult to make the decision to evacuate an area two or more days in advance since the probability of a hurricane striking a region is at most 25%. Only within 24 hours of expected strike time can the updated probability exceed 50%. Given all the uncertainty, the decision to evacuate is a very hard call to make (2). However, the amount of resources and crews that will be needed in the response effort varies significantly with the amount of time people have to evacuate. Other major factors include the topography of the region, the strength of the hurricane, the evacuation plan, and the population density.

Problem 2: Fresh Water Flooding

One of the major concerns when planning the emergency response effort is to take into consideration the fresh water areas in the region. If there are relatively few, the rescue effort can be focused just on the coastline. If, however, there are many rivers in the area, the damage can be widespread. A major reason for this is that many people who are significantly inland do not realize the potential risk of freshwater flooding and thus choose to ignore evacuation warnings, leaving families trapped. Freshwater flooding was a major problem during the Hurricane Floyd rescue mission. Evacuation became a major problem when the river levels in North Carolina rose. Rainfall amounted to over 20 inches (6). Many of the evacuation routes were too close to freshwater and ended up becoming flooded and closed, which caused people to seek alternate routes (6). Major highways (e.g., IS 95, US 70, 64 and 264) were supposed to be part of the evacuation route, but were closed. However, freshwater flooding did not become a major problem until a day *after* Hurricane Floyd hit North Carolina, that being Thursday, September 16. When Floyd hit, authorities predicted that the rivers would not crest for 24 hours, some time on Friday, September 17. They also cautioned against driving on flooded roads. At one point, over 1,000 roads were closed due to flooding.

When the rescue efforts began on Friday, it was decided that helicopters were the best way to rescue those trapped on flooded roadways. However, a primary problem was that all of the state's helicopters were down for scheduled maintenance; thus, the use of Air National Guard helicopters was required. The first persons rescued were two drivers of an 18-wheeler that was stuck on 1-95. Late Thursday night, the rivers began to crest. This river overflow caused even more civilians to become trapped in unstable conditions (6). However, that Thursday night water levels continued to climb, causing panic. Some inland counties then issued evacuation orders (after the hurricane hit!), but as stated above, the roads were flooded and this is how many of the people became trapped. (The rest were those who ignored orders or became stuck in traffic.) Federal agencies criticized public officials for underestimating inland flooding.

An important lesson to be learned when planning evacuation routes is that it is necessary to incorporate the possibility of inland freshwater flooding. If this possibility occurs, then in addition to evacuating those residing on the coastline, it will also be necessary to evacuate those living inland. Also, when planning coastal evacuation routes, one must be sure that the routes avoid all freshwater areas. Lastly, since it may be necessary to evacuate inland residents living near freshwater, when planning evacuation routes one must be certain that the two routes do not intersect and become severely congested at that point. Due to local topography, some regions may find it impossible to consider simultaneously all of these restrictions, in which case they should err on the side of caution when ordering evacuations.

Problem 3: Communication Problems/Evacuation Planning
In terms of evacuation, fewer emergency supplies/officials will be needed if a well-planned evacuation strategy is in place prior to the incident. The better thought out the strategy, the fewer the number of trapped civilians that will result and thus fewer rescuers will be needed. One of the main things North Carolina was criticized for was not having a well thought out plan when Floyd hit (6). Part of the problem with the plan was specifically identifying which residents needed to evacuate. It is estimated that most civilians, as well as officials, learned about emergency announcements through the local media (8). When emergency reports are issued through the media, they are often too brief and announced too rapidly, causing many residents to become unsure of whether they were supposed to evacuate or not. As a result, many inland residents, not living near freshwater, thought that they had been told to evacuate and did so, causing the evacuation routes to become clogged with traffic, trapping many inlanders. This also caused a number of people living on the coast to be "trapped" on the highways when flooding started. Another major concern was that residents did not know which evacuation route they were supposed to take and most headed toward the same major highways resulting in even more traffic congestion.

In the immediate future, the local media will most likely remain as the primary method to communicate evacuation orders to civilians. Thus it is of the utmost importance to develop a good relationship with the local media. When it comes time for an emergency evacuation, disaster preplanning should involve the local media and educating them on how to make effective emergency evacuation announcements, as well as expressing to them the vital role they play in the overall success of the response effort.

Problem 4: Optimization of Evacuation Traffic
One of the major problems with the Hurricane Floyd evacuation efforts in North Carolina had to do with evacuation traffic. Some roads became so congested that bumper-to-bumper traffic resulted. Officials were criticized for not anticipating the traffic flow and not using additional routes to ease traffic (1).

Reverse traffic lanes refer to changing the direction of one side of a highway so that all lanes flow away from the disaster area. During an evacuation period, virtually no people other than rescuers are traveling toward the coast. Thus, reversing all traffic lanes to travel outward from the coast can almost double the capacity of the highways. This was not done sufficiently in North Carolina, a point raised in subsequent public criticism. If more had been done, it would have greatly reduced, if not eliminated, much of the evacuation queuing.

Problem 5: Overseeing the Evacuation Process, Role of Public Officials
Local officials were not overseeing the evacuation in some areas. While it may appear they could do very little, they can help with traffic management. Before the hurricane hit, at one intersection in Cape Verde a major traffic light failed, causing panic and gridlocked traffic. A key lesson learned from this is that public officials should be monitoring the situation whenever possible. It is always sound practice to have a back-up power supply at major intersections (1). At many points along the evacuation route

where roads were closed, there were no officials to direct evacuees to alternate routes (6). This caused people to travel far beyond the destinations they had been directed to. This occurred because there were no public officials around to indicate that people had evacuated as far as they needed to go; as a result they kept moving farther and farther from the coast until they felt safe. This caused others – who were supposed to travel farther – to become trapped again.

In terms of evacuation routes, one of the main lessons learned was that a statewide transportation management center would greatly improve the effectiveness of the evacuation effort. Also learned from Floyd is that public officials must be able to act quickly and adaptively when roads are closed. The emergency services and the weather authorities must be better prepared to inform the public who needs to evacuate, where they need to go, and what routes they should take. Of course, possible detours should be considered ahead of time for the case when road flooding occurs.

Problem 6: Damage to Rescue Supplies

In the affected areas, significant damage occurred to local resources and facilities such as police stations, cars, ambulances, and other rescue supplies. The result of this was a lack of supplies and equipment to conduct the rescue effort. With the extensive damage to rescue equipment, back-up supplies had to be called in which delayed the rescue effort.

The lesson to be learned from this is that when a hurricane warning is issued, it is imperative to mobilize local rescue personnel and equipment so that after the hurricane, the rescue effort can commence immediately as opposed to having to wait for back-up supplies to arrive. When the probability of a hurricane's striking becomes significant, public officials must mobilize a certain number of their units so that should the disaster occur, the rescue effort can commence immediately.

Problem 7: Radio Communications

Since more than 1,400 roads were flooded, almost all of the rescuing had to be done from the air using helicopters. When the flooding worsened, the state called in supplementary military helicopters. However, these helicopters used military radio frequencies, which were incompatible with civilian radio frequencies (5). Therefore, it was extremely difficult for the different rescue groups to communicate with one another. This caused the rescue process to slow. After the flooding increased, a day went by with an estimated 1,500 people still trapped; the next day, with the crisis escalating, 60 additional helicopters were flown in along with 4,000 National Guard troops. An additional 750 people from the military were also flown in to help with the rescue. Bringing in these additional helicopters and troops slowed down the rescue process. Authorities estimated that 420 people were rescued by helicopters overall. By Saturday, September 18th, the flood levels had diminished and the rescue effort was completed.

The lesson to be learned here is that pre-planning is essential to a successful rescue. The problem with communication would have been discovered if practice runs had been conducted and could have been easily corrected by finding a common communication frequency. Also stronger pre-arrangements should have been made with neighboring counties to help assist by donating helicopters, should a hurricane strike. This would have eliminated the delays that caused many to die.

Problem 8: Managerial Problems
According to published reports, some of the problems with the rescue effort were management-related. One of these was that rescuers did not arrive promptly enough, and it took a long time before personnel started to act (1). Many criticized the state for not having a planned emergency recovery outline for when regional disasters like this occur (1). With 37 different counties affected, incredibly, the event was responded to as though it were 37 separate cases of flooding, as opposed to a single regional disaster. In some cases, local officials did not communicate well or at all with neighboring districts and towns. There was also little pre-planning and a lot of bureaucracy when determining when and where to send rescue crews. Moreover, authorities underestimated the potential for freshwater flooding and were unprepared for the river flooding that took place after the hurricane's landfall.

Conclusion
The major shortcoming was the design and extent of the rescue efforts on Thursday before the river flooding occurred. Many experts feel that if the rescue effort had been greater and better planned the Thursday before the river flooding occurred, many of the 57 lives lost could have been saved. Thus, for freshwater areas, it is imperative that rescue efforts get underway before additional river flooding occurs and inhibits ground rescue. Being prepared and having a rescue plan before the landfall, is probably the most important lesson of the event. Others say the damage could have been a lot worse if it had not been for North Carolina's good fortune to have a large number of military bases in the area to assist with the air rescue.

Appendix to Chapter 6.
The following appendix is included as reference material for those who are unfamiliar with the hurricane classification system. The information was abstracted from the National Hurricane Council (2).

Background on Hurricane Classification (2)
Hurricanes are classified by their wind speed. Currently there are five categories, which indicate the strength of a hurricane. This scale is known as the Safier Simpson Hurricane Scale. Details of the classification system are listed below. It is worthwhile to note that Floyd was classified as a Category 4 hurricane.

- **Tropical Storm**
  Winds 39-73 mph
- **Category 1 Hurricane** — winds 74-95 mph
  No real damage to buildings. Damage to unanchored mobile homes. Some damage to poorly constructed signs. Also, some coastal flooding and minor pier damage.
  - Examples: Irene 1999 and Allison 1995
- **Category 2 Hurricane** — winds 96-110 mph
  Some damage to building roofs, doors and windows. Considerable damage to mobile homes. Flooding damages piers and small crafts in unprotected moorings may break their

moorings. Some trees blown down.
- Examples: Bonnie 1998, Georges(FL & LA) 1998 and Gloria 1985

- **Category 3 Hurricane** — winds 111-130 mph
  Some structural damage to small residences and utility buildings. Large trees blown down. Mobile homes and poorly built signs destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain may be flooded well inland.
  - Examples: Keith 2000, Fran 1996, Opal 1995, Alicia 1983 and Betsy 1965
- **Category 4 Hurricane** — winds 131-155 mph
  More extensive curtain wall failures with some complete roof structure failure on small residences. Major erosion of beach areas. Terrain may be flooded well inland.
  - Examples: Hugo 1989 and Donna 1960
- **Category 5 Hurricane** — winds 156 mph and up
  Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Flooding causes major damage to lower floors of all structures near the shoreline. Massive evacuation of residential areas may be required.
  - Examples: Andrew (FL) 1992, Camille 1969 and Labor Day 1935.

References

(1) Batchelor J, Hurricane Floyd Lessons Learned, North Carolina Department of Transportation, April 2000, Raleigh, North Carolina
(2) National Hurricane Council Website, http://www.nhc.noaa.gov
(3) Zacher J., Hurricane Evacuation Plans Untested, The Greenville News, 6/16/04
(4) Moore R., Barnes J., Faces From the Flood: Hurricane Floyd Remembered, The University of North Carolina Press, 2004, Chapel Hill, North Carolina
(5) Dow K., Cutter S., South Carolina's Response to Hurricane Floyd, University of South Carolina Draft, 2000, Columbia, South Carolina, http://www.cla.sc.edu/geog/hrl/Quick%20Response%20Report.htm
(6) Ray S., Overwhelmed: North Carolina's Response to Hurricane Floyd, 911 Magazine, 2003, Tustin, CA
(7) Pasch R., Storm of the Century, http://www.FirstScience.com
(8) Dumont R., The Legacy of Hurricane Floyd-Inland Flooding and a Massive Evacuation, OFCM, 2000, http://www.**ofcm**.gov/fp-fy01/pdf/
(9) http://www.disastercenter.com/hurricf9.htm
(10) http://www.ofcm.gov/risk/presentations/day%202/2_agency_briefings/beafaumani.pdf
(11)http://hurricanewatch.mgnetwork.com/index.cfm?SiteID=TFP&PackageID=9&fuseaction=article.main&ArticleID=66&GroupID=17
(12) http://www.newmediastudio.org/DataDiscovery/Hurr_ED_Center/Hurricane_Science.html

CHAPTER 7: HURRICANE CHARLIE

The final disaster we will discuss is Hurricane Charlie, August 2004. At the time this paper went to publication, Hurricane Charlie had hit Florida less then a month earlier. Where Hurricane Floyd hit the more affluent North Carolina coast, Hurricane Charlie hit a very poor area of west central Florida. Since the homes were better constructed in North Carolina, Hurricane Charlie destroyed many more homes and businesses. What is remarkable when comparing the two is that Hurricane Charlie killed many fewer people then Hurricane Floyd. The reasons for this are discussed in this chapter along with the evacuation of the Tampa area and some preliminary lessons learned.

Overview of Event

With this paper's focus on emergency response and management of past disasters, the authors thought the paper would not be complete without a section discussing a recent disaster that occurred during its publication: Hurricane Charlie. In this section we attempt to outline what happened during mid-August 2004 in Florida and discuss its implications. While it is too early to determine the problems with the response and flesh out the lessons learned, through reading many news articles it is possible to identify a few key issues with the evacuation and offer some opinions.

Chronology (1):

- **Wednesday 8/11/2004**
  - 2:05 pm Tropical Storm Charlie is upgraded to Hurricane Charlie
  - Storm is currently located near Jamaica
  - Late afternoon evacuation order is issued for Monroe County, Florida
- **Thursday 8/12/2004**
  - 9:00am Storm is upgraded to a Category 2 hurricane
  - Storm center moves north toward Havana
  - One million people are evacuated from Key West (Counties: Charlotte, Sarasota, and Manatee)
  - 6:00 pm Storm is again upgraded to a Category 3 hurricane
- **Friday 8/13/2004**
  - Charlie is upgraded to a Category 4 hurricane
  - Hurricane hits Florida
    - 5:00am Hurricane 85 Miles southwest of Key West
    - 1:00pm Hurricane moves inland toward central Florida
    - 3:45pm Eye passes over Captiva Island
    - 4:15pm Hits Punta Gorda and Arcadia, four people are killed
    - 4:42pm Storm crosses Port Charlotte
    - 5:00pm Hurricane travels through state's center
    - 7:00pm Storm passes and cleanup begins
  - Potential Damage is estimated at 15 billion
- **Saturday 8/14/2004**
  - 15 People are confirmed dead
  - 16 counties are declared disaster areas

- Excess of 9,000 homes are reported destroyed
- 2,000 National Guardsmen are headed to the area
- 400 State law enforcers are assigned to the area
- 300 of these officers are housed at a local high school
- A curfew from 8pm to 7am is instituted to help stop looting, an activity detracting from the rescue effort

- **Sunday 8/15/2004**
  - Officials estimate 80% of buildings were destroyed
  - 5,000 emergency workers continues to lead the rescue effort
  - Death toll reaches 18 in the U.S. plus four others

SOURCE: Federal Emergency Management Agency, AP MSNBC

Hurricane Charlie started out as a mere tropical storm that was spotted in the Caribbean. Like most hurricanes, it took some time for it to develop into a more powerful storm (2). It was not until Wednesday August 11th that the storm was even upgraded from a tropical storm to a hurricane. At that point, it was a Category 1 hurricane, which rarely requires evacuation. As the storm strengthened, weather forecasters gradually upgraded it to a category 4 storm (3). At this point, however, weather officials thought the storm was going to hit the southern tip of the Tampa area (1). Residents from some of the coastal counties north of Key West to Tampa were told to evacuate their homes. Many residents who lived on the water were given mandatory evacuation orders while those inland were mostly given optional ones. It is currently estimated that 1 million people took part in the evacuation. The call for evacuation, however, turned out to be a false alarm for many of the evacuated areas.

Friday morning is when the unexpected occurred. Instead of hitting the Tampa area, as presumed, the storm turned 15 degrees to the right and headed northeast, away from the tourist-filled affluent Tampa-St. Petersburg west coast of Florida to what is known by Florida residents as the “other” Florida, referring to the areas of Florida where migrant workers live and are not frequented by tourists. The storm ended up hitting the cities of Punta Gorda, Port Charlotte and Arcadia. Chances are, prior to this incident, you hadn’t heard of these inland cities. This area of Florida is accessible mainly through US-17, an old, two-lane highway. The region is filled with RV parks, mobile homes, citrus groves, and cattle ranches. Most of the area’s residents are poor migrants. An estimated 25% of DeSoto County (where Arcadia is the only incorporated city in the county) is made up of Hispanics (3).

Tampa residents, however, were upset about having to evacuate. Many residents reported being sent away from safety and into the storm’s path. Locals complained about being told to leave when the hurricane did not hit. The question that remains is, based on this experience, if asked again to evacuate, will they? Logic suggests that fewer of them will evacuate once they experience a false alarm. The question in the long run is, "Was the evacuation necessary?" Local officials and meteorologists agree that the evacuation was the right call. The hurricane was expected to hit Tampa and if that had happened, many more in this coastal area would have died. Based on this experience and its future implications, and what happened during Hurricane Floyd, it is clear that the decision to evacuate or not is a very complex problem (6).

When category 4 Charlie hit the inland county, it ripped through flimsy, mobile homes and destroyed numerous businesses in the area. Weather forecasters did not foresee the hurricane's turn until the morning of the 13th, the day the storm hit (3). Before forecasters knew the storm was going to turn, a voluntary evacuation was issued to residents of the county. However, when the storm's path was understood and disseminated, residents had only two hours of advance notice to evacuate their homes. The reason why so few residents actually evacuated was because many, as stated previously, were uneducated migrant workers, who did not understand the necessity or have the means to comply with a mandatory evacuation warning.

While it is too soon to perform a full critique of the response effort, one of the major problems with the evacuation was traffic. When the first evacuation orders were issued Wednesday night, it took motorists more than 10 hours to evacuate on routes that would normally take 2 to 3 hours. Then a key event occurred that made matters much worse. Sometime on Thursday morning, a tractor-trailer jack-knifed on US 1 after hitting two cars, and the back-up caused a massive delay. A major problem, as identified in the Hurricane Floyd chapter, was that reverse traffic lanes were not used sufficiently which could have helped to clear the back-up. As a result, the road was closed for a few hours, which prevented many from evacuating and caused a major back-up.

Officials made one very important decision that speeded up the evacuation process. They decided to suspend all tolls on I-95 Thursday night. Preliminary reports offer a range of rates by which traffic sped up from this effort; however, all acknowledge that it greatly helped to ease traffic congestion.

At this point, major problems with the response effort seemed to stem from ancillary activities. Illustratively, although extra back-up help had been sent in, many officials were forced away from the rescue efforts to deal with price gouging and looting. A number of Florida residents attempted to loot local stores and even remove property from other residents' lawns. This forced officials to have to protect residents from the theft of items such as cars, lawn mowers and furnishings.

Officials reported that many hotels, convenience stores, and gas stations raised normal prices by over 200%. Such activity is illegal and can be accompanied by fines of up to $25,000. Officials found this activity rampant, especially with hotel chains. Thus, officials decided to survey the area to try and put a stop to the gouging. Although taking advantage of consumers during emergency times is nothing new, officials found the price gouging more rampant than during other disasters. All of this took away from the rescue effort since a number of police who would have been assisting with the rescue were forced to monitor theft and price gouging instead.

Another reason for delays to the rescue effort is that it was unclear who resided in the mobile homes in the inland county at the time of the storm. Since many of the workers are migrants, it was estimated a sizable percentage of them were further north harvesting crops. Officials knew that many did not understand the evacuation orders and might still be trapped in their trailer homes. Thus, officials had to search many overturned or destroyed trailers to try and locate trapped victims. This effort was time consuming and added to the rescue burden.

Why were there fewer victims who died during Hurricane Charley than during Hurricane Floyd? One of the main reasons is the lack of freshwater flooding as result of Charlie. People being trapped in unsafe structures, as opposed to drowning, caused most of the deaths.

References:

(1) Hurricane Charlie, before and after, Miami Sun Herald, 8/21/04
(2) Kaye K., Hurricane Charley could pack 120 mph winds, New York Newsday, 8/13/04
(3) McCarthy M., Storm's course, force catch many Floridians unprepared, USA Today, 8/15/04
(4) Allen K., Hurricane Charley could be one of Red Cross' costliest relief efforts, Herald Tribune, 8/24/04
(5) Charley targets Havana, Tampa Bay, Washington Post, 8/12/04
(6) Helfand L., Union says first responder policy murky, St. Petersburg Times, 8/26/04
(7) Hurricane Charley Response Reaffirms Amateur Radio's Value, ARRL Web, http://www.arrl.org/news/stories/2004/08/16/100/?nc=1
(8) Charlie charges across Florida, leaving damage in its wake, Atlanta Journal Constitution, 8/14/04

CHAPTER 8: NEEDED NEW OPERATIONS RESEARCH FOR EMERGENCY RESPONSE PLANNING

Our review of well-known major emergencies has provided us with important perspective on the needs for additional quantitative analysis to assist planners and other decision makers. In this concluding chapter, we attempt to extract from the history, priority problems that require further analysis, leading eventually to improved decision support. Since there are literally hundreds of decision problems that must be addressed in planning for and executing an emergency response, we only touch on some of the important systemic issues.

Since our discipline is O.R. we over-select from O.R. types of problems. This is not meant to imply that other problems are less important. For instance, good personal relationships and communications among response groups are vitally important, as we have seen from the case studies. Compatible radio frequencies are absolutely required. Having standing agreements with local radio and TV media are vitally important. Having a plan and periodically testing it are necessities. Our focus in on the quantitative, model-oriented issues that need to be addressed in creating and executing any plan.

Pre-positioning of Supplies and Equipment

Preparedness for major emergencies requires careful consideration of risks of possible types of emergencies that might be experienced in one's local community. For those types of events for which the risk is sufficiently high, that being a subjective quantity, planners must consider the needs for supplies and equipment, appropriately spatially dispersed in anticipation of an emergency. We have especially seen the need for this in biological and chemical attacks, though many acts of nature and industrial accidents also require spatially dispersed supplies and equipment.

The field of O.R. analysis most closely associated with these types of problems is 'location theory.' One usually models the transportation medium as a network or graph, representing streets of a city or perhaps flight paths of aircraft. The idea is then to find one or more 'optimal locations" of facilities on the network. Here 'optimal' is an overly strong adjective that implies maximizing or minimizing the value of some *objective function*, such as minimizing travel time from the located facility or facilities to the scene of the need for service from that facility. The siting of fire station houses is a good example, where response time minimization is key.

Substantial new work in location theory is required for application in emergency response in a Homeland Security setting. The following new elements need to be incorporated in the analysis:

- Possible destruction of one or more of the located facilities.
- Possible inaccessibility of one or more transportation pathways.

- Proximity of the placed facilities to other facilities (such as hospitals) that are likely to be used during the response.

The resultant 'good' locations would be robust in the presence of possible damage done by the original emergency event, suggesting that they would be spread out over the jurisdiction and not concentrated at one or even a few points. And they might lie on transportation routes used by ambulances or other emergency response vehicles, thereby minimizing 'detour time' associated with collecting the supplies and equipment. All of this implies the need to develop a new robust class of location models.

911 Inference Algorithms

Emergency call takers initially interpreted the Tokyo sarin attack as an unrelated series of local emergencies in different subway stations. This lack of 'connecting the dots' created substantial delay in assembling the appropriate master response to what turned out to be a coordinated massive chemical attack. One can imagine the same incorrect inference occurring in other cities, with other planned attacks. Even certain acts of nature and some industrial accidents may be reported by numerous people from various locations, perhaps again making it difficult to connect the dots – that the collection of reported incidents is in fact one large major emergency. Until a major emergency is identified for what it is, requiring a substantial coordinated and massive response, potential victims may be injured or even die needlessly.

We propose research on creating a *'data trawling algorithm'* for 911 call centers. Such an algorithm would be continually scanning and analyzing 911 calls as they arrive and are logged onto the 911 computer system. It would search for calls that may be reporting on one large incident rather than separate smaller incidents. It would incorporate probability and Bayes theorem, data mining techniques and expert systems ideas to do its work. We are not aware of such a system existing today. But if one were created, tested and perfected, it could be installed on all 911 computer call-taking systems. It would act as a silent background processor, continually looking for that major emergency event that is being reported by several callers who perhaps only see one small part of 'the elephant' that is the major event. Had such a tested system been installed in Tokyo, it is highly likely that lives would have been saved.

The Evacuation Decision

We have seen Hurricanes Floyd and Charlie create demands for major evacuation of thousands of residents who may be in the direct path of the storms. But hurricanes are not the only possible major emergencies that could create the need for evacuation. Others include risk of volcanic eruption, nuclear power plant malfunction or impending terrorist attack, to name a few.

The decision processes leading to the evacuation order are complex and involve numerous risk and probability calculations. While national weather forecasters have created an evacuation prediction science for hurricanes, it is not clear that the science cannot be improved. For other types of major emergencies there is usually much less of a science currently developed. Hurricanes are notoriously fickle, meaning that they can change paths seemly at will. As a result, reliable probability estimates of the location of landfall may only be available after the time to evacuate safely has passed. So, forecasters tend to be risk averse, meaning that they may call for an evacuation with only a 25% chance of a direct hit. But evacuations that turn out to be false alarms can cause citizens to become complacent and skeptical, as could occur in the Tampa area in the aftermath of Hurricane Charlie, similar to those who heard the little boy ‘cry wolf’ one too many times. A false alarm also creates major financial and emotional costs for the evacuated jurisdictions and their citizens. Tragically, a false alarm may also route citizens from places of relative safety right into the path of the storm. Even a correct alarm may route people into harm’s way, if the paths, destinations and sequencing of evacuees are not properly managed. Think of those evacuees who died in fresh water flooding in North Carolina as a consequence of Hurricane Floyd.

We propose additional decision-theoretical research on the evacuation decision process. The resulting decision model would be transparent to all and would reflect all relevant issues discussed above and much more. The decision would not only be ‘to evacuate” or ‘not to evacuate,’ but would also consider the possible logistics of evacuation – should an evacuation order to issued.

Triage

In the majority of cases we have examined, we have seen the strong need for triaging. Recall that a triage unit prioritizes victims (i.e., prospective medical patients) into various urgency categories. This should result in the most critically injured patients getting medical attention first. It should also result in transportation of each patient to the most appropriate medical facility, matched by specialty and availability. Where local triage fails or does not exist, hospitals need to establish their own triage units, thereby sapping scarce medical personnel. Lack of proper triage can cause needless suffering and sometimes deaths of victims.

Additional O.R. research is needed in developing the rules for triaging, the queueing delay consequences of any proposed set of rules, the likely medical outcomes of any set of rules and the optimal placements or locations of triage units. There exist some priority queueing models that address components of these problems, but we are unaware of any comprehensive O.R. analysis of the constellation of triage issues and problems listed above.

Second- and Third-Tier Responders

By definition, a major emergency is one in which local first responders are overwhelmed – there is simply more work to do than there are resources to do the work. Additional personnel must be brought in – from surrounding communities, from the state and perhaps even from federal agencies. Depending on the type of emergency, some of these other responders may be specialty units, such as ‘bomb squads,’ HAZMAT, bio-terrorism, nuclear specialists, etc.

We need dispatching and deployment algorithms and models to make this process as smooth and coordinated as possible. In Chapter 1 we described briefly the Hypercube

Queueing model that aids dispatchers in routine 911 call dispatching. We need to significantly expand and generalize that approach to incorporate second and third tier responders. Questions to be addressed in the new analysis would include:

- When and under what circumstances to call in a response unit of type "X" (where X could be specialists, generalists, off-duty personnel, or citizen volunteers).

- Determining the site(s) to which to dispatch the new unit(s).

- Managing the coordination of all the dispatched units.

- Predicting the response times of the new units and the risks/benefits associated with those response times.

Use of Volunteers and Off-Duty Personnel
Rules and policies need to be established with regard to use of off-duty personnel and citizen volunteers. We saw that with the Oklahoma City bombing, the massive volunteerism of the local citizenry, while very much a sign of strong community spirit, may have been a net detriment to effective response – due to large time demands on skilled personnel in managing and controlling the volunteers. We saw that use of soon-to-be off-duty medical personnel in the United Flight 232 response greatly improved the quality of the response. In New York City on 9/11/01, numerous off-duty firefighters and other emergency workers came in to volunteer their time and efforts.

Asset management models for emergency response must include off-duty personnel and citizen volunteers. Ideally, the models could predict the response consequences to victims of employing alternative policies with regard to these types of volunteers, thereby aiding in selecting the best policy. Then, of course, steps would have to be taken to implement that policy when needed. This may require labor-management negotiation in the case of off-duty personnel and citizen and media education/training in the case of citizen volunteers.

Near-the-Scene Logistics (for Personnel and Donated Goods)
In the Oklahoma City case, we have learned of problems with locating sites for receiving and distributing donated goods, for receiving volunteers and for locating triage centers. Triage center creation and location was also a problem with the Tokyo sarin attack. Triage site creation and location were very well performed with United Flight 232.

Additional decision support is needed to help planners and on-the-ground decision makers manage the process of logistics near the scene. Of special interest is the siting and communication/coordination between and among the (up to) three types of sites/facilities mentioned above. The most important is the location of one or more triage units. Learning from our cases, it would appear that one wants it conveniently near the scene of the emergency event and in the general direction of nearby hospitals. And it must be set up quickly. If out of sight, it may also be out of mind, as victims may try to transport themselves, by walking, taking taxis, using public transportation or driving their own vehicles.

Siting of donated goods locations presents additional problems related to perceived 'ownership' of the sites by the respective volunteer agencies. Without prior planning and agreement, each appears to want 'its own' donation and distribution center, creating a type of supply chain management problem for emergency workers. Recall the cry for gloves in Oklahoma City when gloves were already present at the scene, unbeknownst to scene managers.

Due to the uniqueness of each major emergency, it is doubtful if a tight, closed-form solution to these facility location problems can be derived. But various scenarios could be studied and general principals could be found – thereby helping to direct and inform cooperative planning discussions among agencies. Agreements could be forged among the various agencies and guidance for site locations could be provided to emergency managers on the scene.

Handling of Routine 911 Calls from the Rest of the City

In New York City on September 11, 2001, citizens benefited from a computer-based algorithm created by the New York City Rand Institute (NYCRI) 30 years earlier. That investment paid off handsomely as the New York City Fire Department (NYFD), despite unprecedented demands on their personnel and horrific tragedy to their firefighters and to citizen victims, managed to retain average response times to other 911 calls for fire service to within one minute of long-term averages. The NYCRI algorithm is a fire resources repositioning model. That model still lives in the NYFD. The algorithm suggests how available fire units far away from the major emergency are to be directed temporarily into now-vacant firehouses in anticipation of possible new fire calls that may or may not occur. This operational policy, in conjunction with a modified first response commitment of resources, can assure that routine 911 calls still enjoy satisfactory response service levels.

The NYCRI fire resources relocation algorithm is one example of planning models useful to jurisdictions for operating the rest of their emergency response systems to handle routine 911 calls while also managing a major emergency. Additional research needs to be done to supplement the arsenal of planning tools available to manage such reduced resources situations. This research should include policies for on-the-phone prioritization and triaging; for citizen education; for temporarily altering traffic flows on major thoroughfares to speed response of emergency units, and more.

Reducing Traffic Congestion on Telephones and Radios

Several of our cases dramatically demonstrated that major emergencies generate so much telephone and radio traffic that the communication circuits become almost always busy. Getting through to emergency response colleagues becomes nearly impossible. Such total lack of communication capability at the very time that is needed most can create havoc in response. Ambulance drivers do not know which hospitals still have room for new patients, resulting in imbalances of patient distribution among hospitals and unnecessary delays in patients receiving medical treatment. Many other problems develop as well.

Research is needed to find ways to solve this queueing congestion of communications systems. Oklahoma City invented a solution on the fly. Most of the time, we should not expect such good fortune. Tokyo had severe problems. Our belief is that a type of prioritization scheme should be negotiated with radio and telephone service providers *prior to* any major emergency, so that when it is need, the system can switch into emergency mode, a mode of operation that gives first preference to the emergency response professionals and second priority to everyone else. Queueing-type O.R. models, perhaps within the context of communication networks, would seem to offer a promising line of analytical attack to this class of problems.