Decision Models for Emergency Response Planning

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Operations Research (O.R.), born in World War II (WWII), has for 65 years proved invaluable as a decision-planning tool. Known as the *science and technology of decision-aiding*, 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 of resource allocation. In WWII O.R. helped guide the allocation of scarce resources against the enemy. Successful applications ranged from finding optimal locations for new and expensive radar installations in Great Britain (in order to detect incoming enemy aircraft and missiles), to the invention of 'optimal search theory,' used to deploy aircraft and ships in search of enemy submarines [32]. The search theory results were deemed so important that the original papers by Bernard Koopman remained classified for 15 years. 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 industrial accidents.

Following WWII, Operations Research found widespread applications in civilian sectors, both in private companies and in the nonmilitary government sectors. The collective result has been savings of billions of dollars from costs of operation and significant increases in the quality of services provided – in both the public and private sectors. The majority of Fortune 500 companies have utilized O.R. inside to help them in their decision making, long, medium and short term. The O.R. civilian sector includes the US Postal Service, which for decades has used O.R. extensively for designing routes, scheduling personnel and designing its national distribution network. It also includes the City of New York, which as a result of 30 years of successful O.R. experience, created its own permanent O.R. group within the City's Office of Management and Budget. And the military has its own Military Operations Research Society, whose 3,000 members must have a security clearance to attend its meetings.

O.R. is in many places where you least expect it. New England Patriots football coach Bill Belichick uses O.R. in the execution of a football game. In a famous incident in 2003, with the ball on the Patriots' side of the 50-yard line, on a fourth down and one-yard-to-go situation, he went for first-down. His decision was viewed as contrary to what 90 percent of NFL football coaches would have done, but was supported by 30+ pages of sophisticated "Bellman equation" O.R. analysis of a Stanford University professor[1]. The decision proved correct, the first down was achieved, the team continued to a touchdown and later in the season to another Super Bowl victory. O.R. is not just an academic discipline, any more than electrical or mechanical engineering are just academic disciplines. O.R. is an academic discipline that continues to have numerous substantial beneficial impacts on organizations, large and small. While football and response to terrorist attacks are very different operations, we cite the football example to show that O.R. can be used to inform and transform decisions in the real world, with all its gritty complexity. One needs that type of down-to-earth practical science to confront the many challenges of emergency response planning and operation. As explained below, that is why O.R. proved invaluable to New York City firefighters on September 11, 2001.

What are the methods of O.R.? The answer is: *any aspect of the scientific method that sheds light on the problem at hand.* Usually but not always mathematics is involved. Usually but not always a mathematical model of the system or problem being studied is created, tested, refined and then implemented on a computer. Once computer-implemented, the O.R. analyst runs the model under alternative assumptions, leading to optimal or near-optimal system configuration or decision policies. But some very famous O.R. studies have involved no mathematics at all, just clever application of 'common sense,' often leading to new and insightful re-definitions of the problem.

Response to a major emergency incident requires careful planning and professional execution of plans, when and if an emergency occurs. Decisions involve the movement ('deployment') of people, equipment and supplies. They also include the development of policies with regard to operation, once men, women and materiel are in place. This setting is nearly perfect for the application of O.R. – to create better emergency response plans and to design better operational policies once the rescue efforts are underway.

In this chapter we review briefly the major O.R. work done to date in emergency response. Some of this work is quite recent and aimed directly at what we now call Homeland Security issues. Most of it has evolved over the past 50 years, motivated by other emergency applications, especially operation of first responders in municipalities – police, fire and emergency medical. The good news is that we are now building from a rich legacy of 50 years of research in emergency response. The bad news is that only recently have we collectively refocused our energies towards catastrophic events

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[1] *New York Times*, David Lionhardt, "Incremental Analysis, with Two Yards to Go," February 1, 2004. Also see http://espn.go.com/nfl/columns/garber_greg/1453717.html.

associated with Homeland Security. But our 50-year's of research and implementation results provide us today with solid platforms for moving forward. Space limitations do not allow us to provide a comprehensive literature review of the field of "O.R. and emergency response." So, we have selected the works that we feel are most important for progressing with emergency response and Homeland Security. 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 Drs. 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, to frame, to formulate and to solve. Hopefully the end result will be the most rational deployment of our scarce national resources, resulting in maximally many lives saved and injuries averted in the instance of another terrorist attack. But since the methods we describe also apply to emergencies created by Mother Nature and by human accident, let us hope that the vast majority of incidents in which these methods are applied are from these latter two categories.

For purposes of this chapter, a *major emergency* is one in which local first responder resources are overwhelmed. There simply are not enough resources to do the many jobs at hand. To read a history of such an event, one that took place across the entire United States, we suggest studying the 'great influenza epidemic' of 1918-1919, a pandemic that took more American lives than all wars of the 20th Century [1]. Nurses, doctors and other resources were simply too few to care for the sick and dying. But more critically, history shows that lack of timely response to events as they unfolded and lack of disciplined management strategies led to many unnecessary deaths. One of our goals here is to show that careful and systematic approaches to the myriad operational problems associated with emergency response can lead to policies and procedures that maximize the effectiveness of the resources available. As a result, lives should be saved, and lifelong debilitating injuries should be minimized.

1. First Responders: Police, Fire and Emergency Medical Services

Perhaps most relevant to emergency response planning is the 40 years of O.R. work focused on urban and municipal first responders, i.e., police, fire and emergency medical. This work started with the Science and Technology Task Force of the President's Commission on Law Enforcement and Administration of Justice in 1966 [6]. 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 and necessary queueing theory is in the scheduling of 911 call takers. Their original scheduling of personnel, without the benefit of O.R. analysis, yielded intolerable 30+ minute telephone queue delays on weekend evenings, with the caller hearing only the familiar and annoying 'electronic ringing sound.' An O.R. analysis quickly showed how rescheduling current personnel – without additions -- brought the delays to within acceptable limits. The recommendations were fully implemented within one month of the study's completion [21].

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 [35, 36]. In [33] we show how this would work with data from the Hartford Connecticut Police Department.

The author of this chapter was a member of the Science and Technology Task Force of the President's Commission, and as a result of that work, wrote his Ph.D. thesis on urban police patrol allocations. This culminated in a book, *Urban Police Patrol Analysis*, MIT Press, 1972 [22]. This book offered a variety of O.R. models to examine police response times, patrolling patterns, impact of new technologies (such as automatic vehicle locations systems), personnel scheduling and more. This effort led to a major four-year NSF-funded research program at the Massachusetts Institute of Technology, 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. It started 'public safety' O.R. careers of at least five doctoral students [27].

The key model from the IRP project was the "Hypercube Queueing Model." This mathematical model depicts the detailed spatial operation of urban police departments and emergency medical services [23, 25]. 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 has found application is police beat design, dispatcher car-picking strategies, allocation of patrolling time, evaluating the response time reduction value of automatic vehicle location systems, and more [28]. By combining the spatial and temporal aspects of police and ambulance operations within one unified probabilistic framework, the Hypercube model was the first to be able to predict the operational consequences of alternative police deployments over space and time. It illustrated the inadequacies of some deeply rooted beliefs that had become folklore in police deployment [24]. In contrast to popular wisdom at the time, it predicted a large number of inter-beat dispatches of police cars, a forecast later verified in the field [20]. It showed that a police car may have an above-average workload even if its 'own beat' had virtually no internally generated workload. The Hypercube Queueing model has been implemented in many cites, including New York City [30]; Boston, Massachusetts [7]; Hartford, Connecticut; Orlando, Florida; Dallas, Texas and Cambridge, Massachusetts. The Orlando Police Department, for instance, in 1992 essentially redesigned the police beat layout of the entire city, in order to create a new central city precinct [34]. Without the model, the city's police planners would have had no scientific basis for making such a dramatic change in deployments. But with the model, they could be confident that the new allocation scheme would satisfy all performance standards set by the department [26].

Various vendors have commercialized the Hypercube model, and its full impact is impossible to determine since not all implementations have been documented in the open literature. 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 author, with research colleagues at Structured Decisions Corporation of West Newton, Massachusetts, is building from the Hypercube model a new deployment model for response to terrorist attacks and other large emergencies. The desired result is a model that will guide event managers in the dispatch and routing of heterogeneous responders on a regional interagency basis. The effort will also help local emergency planners to identify and correct weaknesses in their response plans for major emergencies. This effort is part of the CREATE project at the University of Southern California, funded by the U. S. Department of Homeland Security.

In 1969 New York City commissioned the RAND Corporation of California to open the New York City Rand Institute (NYCRI). The NYCRI assembled a team of analysts to examine a wide variety of operational problems of the City [13, 17, 18]. Over the years, their award-winning O.R. work on emergency services has stood the test of time. Some of this work is still the best available today. An example is the NYCRI's fire department relocation model [19, 41]. When there is one large fire or a collection of smaller fires in geographic proximity, the fire-fighting 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 fire fighters 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 literally in the hundreds of billions, and no human can contemplate the consequences of each option and pick the best. But computer-implemented mathematical models such as the NYCRI relocation model are perfect for the job at hand. The NYCRI was shut down in 1975 due to New York City's severe budget crisis. Remarkably, 30 years later, the NYCRI fire relocation model lives on in the NYFD. In fact, it proved invaluable on September 11, 2001, in managing the relocations of NYC fire fighters on that infamous day. With the help of that model plus implementation of a "Fallback 3" response strategy (meaning far less than usual number of units initially dispatched to an incident), the NYFD managed to keep its average response times to other more routine fire incidents to an average of 5.5 minutes, only about one minute above the usual average[2].

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 Dr. Peter Kolesar of Columbia University, 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."[3]

University students are becoming increasingly interested in research on emergency response. For example MIT doctoral student Michael Metzger has recently completed a Masters thesis on deployment of rescue and recovery resources in response to an earthquake [31]. He used data from the world's most earthquake-prone country, Iran, to illustrate the results of his O.R. analysis. Among other measures, his model predicts the number of hospital admissions, and fatalities over the hours and days following the earthquake. The results depend on the response strategy selected. Particularly important are the strategies to select when more than one populated community is affected by earthquake damage. The results are important, controversial and counter-intuitive. For example, he shows that to save the maximum number of lives in *all* affected communities, it may be necessary to dispatch 'local' responders from one of the affected communities to travel to a more distant damaged community, in order to save lives there. The result might be the saving of 100 or more lives in the more distant city 'at a cost' of not saving some fewer number of lives in the 'home city.' Such sharing of resources may be politically difficult and would require considerable citizen education prior to any event in which it is implemented. Metzger's methodology, which will appear soon in a published article, demonstrates how one can model the temporal allocation of resources following a catastrophic event, thereby finding ways to deploy personnel to save lives and reduce occurrence of debilitating injuries.

We have given a very brief sampling of the many O.R. contributions to analysis of first responders. For those who want additional detail, there are review papers available [13, 17, 18, 27], as well as summary books [29, 41]. And, there is prize-winning work in the

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[2] McKinsey Report, Increasing FDNY's Preparedness.
http://www.ci.nyc.ny.us/html/fdny/html/mck_report/index.shtml

[3] Peter Kolesar, private communications, August 10, 17, 2004.

scheduling of police personnel [37]. We feel that the entire 40-year body of emergency response O.R. work will prove invaluable in building the next generation of emergency response models and methods, ones that are applicable to response to terrorist attacks and to other major emergencies.

2. 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, there have been O.R. studies focusing on the routing and scheduling of hazardous materials, point to point on a transportation network such as the national railway system, in ways that mitigate the risk and/or spread it equitably. The work has shown that there are tradeoffs between efficiency and equity [2, 3, 5, 10, 14]. 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 analyses point to the ways in which efficiency and equity can be addressed in an integrated fashion.

Risk reducing routing of hazardous materials is an example of pre-event O.R. analysis. By making improved decisions based on such analysis before a major emergency event occurs, one can reduce the damage caused -- should the event occur -- and on occasion even reduce the chance of the event ever happening. Of course, the ‘nonevent’ is the best one for saving lives and property!

3. 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. But the work has been widely reported and has had major national impact. The developed models provide a consistent framework for considering operations following a bio-attack. The work has changed our national policies with regard to immunizations and medications following a bio-terrorist attack.

With regard to a possible anthrax attack, the co-authors Lawrence Wein and Edward Kaplan state,

> Two pounds of weapons-grade anthrax dropped on a large American city could result in more than 100,000 deaths, even if early cases were successfully diagnosed,

> antibiotics were distributed broadly and drug adherence was high. The reason for the catastrophic death toll: Not enough people would receive antibiotics quickly enough to prevent symptoms from developing, and those who developed symptoms would overwhelm the medical facilities.
>
> Any plan to cope with this scenario must include (1) immediate intervention, (2) rapid distribution of antibiotics to everyone in the affected region, (3) aggressive education to ensure adherence to the full course of treatment and (4) creation of "surge capacity" to treat the sudden influx of patients. [43]

Their conclusions, together with their colleague David Craft, were based on a highly sophisticated 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 [42]. 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 [15]. 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[4].

The same three co-authors also used O.R. methods to study response to smallpox attack [16]. 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, again based on a highly complex but compelling set of models, indicated that the initially selected policy would result in many deaths. Instead, the 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, in the press, among physicians and with policy makers, but now has been adopted as official US policy.

O.R. is playing major roles in other aspects of medical response to major emergencies as well. For instance, Linda Green has shown how usual efficiency measures defined in terms of bed occupancy in hospitals cause large queueing delays for beds even in the presence of routine demand; demands caused by major emergency events would overwhelm such hospitals [11, 12]. Bravata *et. al.* extend the policy conclusions of the anthrax and smallpox work described above to examine regionalized or local stockpiling of drugs and response to bio-terrorism events [8, 44].

One can see here the need for additional O.R. research on optimal locations of drug and equipment stockpiling. Traditional location theory seeks global optimal solutions that minimize some measure of total system travel time or distance [29, Chapter 6]. Usually one or a small number of carefully positioned facilities accomplish this travel time

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[4] 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.

minimization goal. Within an environment of a major emergency, the traditional formulation of the facility location problem may be highly inappropriate. Instead, one has to consider that one or more of the stockpiled facilities may be destroyed by the emergency event and/or travel paths leading from them may be damaged or inaccessible. In such cases, one may want to position more than the usual number of facilities, each containing fewer medications and supplies, in order to increase the probability of survivability of the drug and supply distribution system. This version of the problem is somewhat similar to the so-called the *p*-dispersion location problem, where *p* is the number of facilities being dispersed. These issues are addressed in new papers by Gong *et. al.* [9] and Berman *et. al.* [4].

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 or other medical facilities, initial treatments are administered, and then many patients at the nearby hospital are moved out to more distant locations. For if 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 reverse of NYCRI's fire relocation model. Creating such hospital "surge capacity" (in the words of Kaplan and Wein) certainly warrants further research.

Effective responses of healthcare systems are essential to the total societal response to major events, be they terrorist attacks, acts of nature or man-caused accidents. The number of components of these systems can be large, the relevant factors many, and their interactions complex. Mathematical models are essential in order to understand all of the complexities and tradeoffs, ultimately leading to more informed decisions and allocations of scarce societal resources.

4. Private Sector Response

Emergency response is not limited to public sector agencies. In the event of a major emergency such as a terrorist attack, it is important that private firms whose operations have been interrupted by the emergency resume normal operation as soon as possible. Operations Research 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. "Usual events" in the airline industry are "Chicago O'Hare closed due to snow" or "Miami closed due to a hurricane." These Mother-Nature-caused events are difficult enough to handle, as hundreds of flights and thousands of passengers may be affected. But imagine what happens when all planes are unexpectedly grounded. And, on September 11, 2001 all civilian airlines were grounded. 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 [38, 39, 40], 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 computer-implemented 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 to which they are qualified, getting each plane back on schedule, adhering to maintenance schedules, obeying FAA rules with regard to maximum allowable flying times of crews, etc. Since that time, many other airlines have adopted this proprietary O.R. methodology to assure their swift recovery from major events to resuming regular operations.

The events of 9/11 affected many industries in addition to airlines. For instance the mantra of ‘just in time’ supply chain management was tossed out the window on 9/11 due to a lack of redundancy and slack in ‘just-in-time” systems. Hundreds of trucks were lined up on the Canadian border on September 12, 2001, awaiting customs and immigration clearance into the USA. As a result of these delays, factories in the US began experiencing parts and supplies shortages. This has led to a new type of supply chain analysis, one that requires robustness in case of emergencies, one that trades of just-in-time efficiencies with redundancies needed to maintain normal operations in case of interruption from a major event. This is another area for the analytical, model-based approaches.

5. Implementation

Many of the models and methods discussed herein are being used on a daily basis by first responder emergency services throughout the United States. As discussed, the NYCRI ‘fire department relocation model’ was used extensively and successfully by the New York Fire Department on that fateful day, September 11, 2001. Private firms have implemented and often extended the methodologies discussed here into real-time command and control systems, such as computer-aided dispatch systems and regional emergency management systems. The end user in such circumstances 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 from those who benefit from its use.

With computer computation and storage being exceedingly inexpensive these days, relative to the past, we are seeing more and more databases being assembled that will assist the O.R. planner in preparation for emergency response. One of these is New York City’s Citywide Assets and Logistics Management System[5] (CALMS). CALMS, set up for disaster response, is the only New York City system that cuts across jurisdictional

[5] http://www.nyc.gov/html/oem/html/response/calms.html

lines and retains knowledge of the whereabouts of supplies, equipment and personnel from many different agencies. It is organized according to six asset types: fleet, equipment and supplies, facilities, contracts, personnel and donated goods. CALMS automatically gets periodic uploads, to refresh its databases. And, its spatially oriented data can be displayed on maps of the appropriate parts of the City via a Geographic Information System (GIS) mapping tool. 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 and one in which there is now an effort to standardize nationally[6].

The need for O.R. talent in the domain of Homeland Security is apparent. The U.S. Department of Homeland Security has job openings for professionals with O.R. training. The City of New York has hired such people. Even the taxicab system of New York City has sought such professionals, as needed talent to interact with consultants who are examining the consequences of using GPS vehicle positioning technology on New York City taxicabs. O.R. professionals often have undergraduate degrees in electrical engineering, computer science or mechanical engineering, so they can integrate technical engineering knowledge into the systems framework of Operations Research.

A growing new professional career is that of *emergency services manager*. Emergency services managers may also be called emergency program managers or directors, operations center chiefs and risk management experts. They are professionals who coordinate equipment, emergency workers and volunteers who move into action following any disaster. They make sure that government, volunteer and medical personnel work together cohesively and effectively during an emergency. Knowledge of operations research is increasingly a job requirement.[7] Universities such as Virginia's University of Richmond offer certificates and degrees in Emergency Services Management.

The public, in weather forecasts, has been exposed for many years to the types of probabilistic analyses we have discussed. We are all accustomed to hearing that, "…the probability of rain tomorrow is 0.4." Quantified uncertainty has become a part of our daily lives. More critical to Homeland Security, the public is also aware of probabilities associated with hurricanes, particularly where and when they will achieve landfall. Public preparedness for and response to hurricanes are important components of Homeland Security, as a Category 3, 4 or 5 hurricane making landfall of the United States certainly conforms to our definition of *major emergency.* The types of analyses we have been discussing are used today to create the 'probability risk profile' of approaching hurricanes. They are also used to make decisions on evacuations. Here additional O.R. analyses may be valuable on the detailed planning of evacuations, to minimize false alarms and the public apathy that may result and also to minimize the

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[6] See http://www.dhs.gov/dhspublic/display?content=3259.
[7] http://www3.ccps.virginia.edu/career_prospects/briefs/E-J/EmergencyManage.html

chance that evacuees could end up in congested roadways subject to local flooding. There is still much to do.

6. Summary and Conclusions

Operations Research, the science and technology of decision aiding, helped immensely in 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 response to such large-scale emergencies, should they occur, can save many lives and reduce extent of injuries. Hardware technology alone, without careful systems planning is not enough. And there is not enough money in the public coffers to think that simply 'throwing money at the problem' will solve it. Operations research 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 expect to see many more new results from Operations Research in the years ahead, as the nation comes to grip with the new threats from terrorists and the old threats from Mother Nature and industrial accidents.

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