O.R. Models for Homeland Security

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Emergency Response

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*Decisions involving deployment of people, equipment and supplies serve as ideal setting for operations research to create better emergency response plans.*

By Richard C. Larson

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. 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.

Response to a major emergency requires careful planning and professional execution. Decisions involve the deployment of people, equipment and supplies. This setting is nearly perfect for O.R. — to create better emergency response plans.

Here, 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.

The 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." This 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
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 U.S. Postal Service has announced that its mail carriers will help to distribute antibiotics if a large attack occurs in the Washington, D.C., area [reference: United States Postal Service, "U.S. Postal Service may deliver medicine in the event of a catastrophic incident," news release no. 04-015, Feb. 18, 2004].

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 such outward movements are not done, the nearby hospitals become 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" 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 from 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.

The need for O.R. talent is demonstrated by the U.S. Department of Homeland Security's listed job openings for O.R. professionals.

**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 response to such major emergencies can save many lives. 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. 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 expect to see many more O.R. results 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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Author's Note:


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Operations Research," Prentice Hall, 1981, now available on the Web as part of MIT's OpenCourseWare project. He served as president of ORSA, (1993-4), and is currently president-elect of INFORMS. Larson invented the Hypercube Queueing Model and the Queue Inference Engine. He has served as consultant to many organizations. He is a member of the National Academy of Engineering and is an INFORMS Founding Fellow. He has been honored with the INFORMS President's Award and its Kimball Medal. He is founder of LINC, Learning International Networks Consortium, an MIT-based international e-learning project.