A scientific approach to evacuation planning

Televised images of traffic jams stretching for miles as Hurricanes Rita and Katrina approached the Gulf Coast earlier this year brought home once again the difficulty of evacuating large urban areas. Mass evacuations are among the most difficult challenges faced by transportation professionals, but planning for a complete evacuation of a specific city is difficult because such evacuations are only rarely necessary. As a result, developing evacuation plans has been carried out largely on the basis of engineers’ judgment and “educated guesses” about how to best make use of the road system.

Shekhar points out that no area can afford to ignore the possibility that mass evacuation may be necessary. While Minnesota may be safe from even the largest hurricane, other disasters—some man-made—could threaten our area. For example, the Monticello nuclear power plant is situated a mere 40 miles from the Twin Cities, and while it enjoys an excellent safety record, a terrorist attack aimed at disrupting the reactor could have catastrophic consequences. Shekhar’s research team used a scenario based on just such an event in its research.

In order to develop a better evacuation plan, Shekhar turned to the tools of computer modeling and traffic simulation, which are widely used by researchers and traffic managers to understand and predict the operation of traffic systems under normal conditions. But because evacuations are so radically different from normal traffic flow conditions, modeling them required the researchers to develop new techniques.

In the type of model used in this research, the network of roads and highways is modeled as a “graph” of line segments, or “edges” (roads) connecting “nodes” (intersections). Such a model captures the physical form of the transportation network, but does not take into account the operational differences between, for example, city streets and multi-lane highways—the “logical” transportation network. To model the logical transportation network, with its different traffic capacities, directions of travel, and turning restrictions at intersections, it is necessary to assign different capacities to each edge and node in the network model. Varying distances between nodes, and different speeds possible on different types of roads, are modeled by assigning a travel time to each edge in the network. In addition, each node (an intersection and the area around it) is assumed to have a certain initial number of occupants.

Given such a model, the challenge for evacuation planning is to find ways to direct vehicle traffic to move the greatest number of people from areas designated as unsafe to areas designated as safe. These methods may include modifying the logical transportation network by changing the direction of travel on certain roads, or changing the traffic control at selected intersections using the traffic signal control system or by placing traffic control officers in the field to direct drivers as needed.

Previously, computational techniques for solving evacuation problems often relied on the mathematical programming (MP) approach, which is widely used in optimization problems involving flow within transportation networks. Mathematical programming techniques are proven to produce optimal solutions to network flow problems and are known to work well for computing evacuation plans for smaller networks such as a single building. However, according to Shekhar, the high computational cost associated with current MP methods makes it difficult to scale MP methods up to problems involving extensive urban transportation networks with large numbers of evacuees. In addition, traditional MP approaches require the user to set an upper limit on evacuation time in order to derive a solution; this is rarely feasible in practice, as the goal is to evacuate the area in the smallest possible amount of time.

Shekhar’s research team focused its efforts on the development of a novel and more practical form of heuristic algorithm for evacuation planning—one that would take into account the capacity constraints built into transportation networks.
Improving evacuation traffic operations with adaptive control strategies

In addition to good planning, an effective evacuation requires effective traffic control to respond to changing conditions and ensure that evacuees follow designated routes. Assistant professor Henry Liu of the civil engineering department hopes to improve traffic flow during emergencies by giving evacuation managers better decision-making tools.

Liu argues that evacuation efforts often run into problems despite elaborate scenario-based planning efforts carried out in advance, because planning can’t predict all possible scenarios. Instead of scenario planning, Liu’s work focuses on real-time traffic management, or, as he put it, “how can we respond to this specific disaster, now.”

By their very nature as extreme events, emergency evacuations resist traditional network evaluation methods, because standard assumptions about network use patterns do not apply. Traffic during evacuations is dominated by movement to “safe zones” and fraught with unpredictable behavior by frustrated and panicked motorists. However, emergency situations do provide the authority for strict centralized control of the traffic system, using signals and traffic control officers on the ground to direct vehicles as needed.

These characteristics led Liu to develop an adaptive control approach to evacuation traffic management. Adaptive traffic control systems, which use current traffic data to change their control behavior in response to changing conditions, offer the ability to compensate for disruptions by rerouting traffic along optimal routes. A reference model of the road network and a traffic simulation engine calculate the overall system objective using current data.

Liu has created a stripped-down simulated version of this system (without origin-destination estimation and resource allocation modules) on a simplified road network containing only a few nodes and links. For each node (intersection) in the network, the system calculates the optimal turning percentage to achieve a desired performance measure, such as lowest total travel time or minimum number of “victim vehicles” (vehicles unable to clear the network before a deadline). The system uses a “rolling horizon” approach to estimate traffic flow characteristics every two minutes and update its control strategy accordingly.

Liu, who joined the Department of Civil Engineering as an assistant professor in August of 2005, began working with adaptive traffic control systems before coming to Minnesota; he said he intends to continue his work here at the University of Minnesota.