Assumptions and Processes for the Development of No-Notice Evacuation Scenarios for Transportation Simulations

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Emergency management agencies and departments of transportation benefit from transportation simulation support when developing their emergency response or evacuation plans. No-notice events are increasingly becoming part of these plans. Few, if any, studies have shown how to operationalize general no-notice evacuation considerations. To fill this gap, this article describes essential features and reasonable assumptions that should be considered in the development of no-notice evacuation scenarios for use in conjunction with transportation simulation models. Although the information presented here centers on a specific location and disaster, the concepts may be generalized and adapted for use in other locations and hazards and are of value to both practitioners as well as researchers seeking to develop similar models.

Keywords: No-notice; Evacuation; Scenario.

Introduction

Events requiring mass evacuations for a given area have low probabilities. The limited history of such events also means that there are few past experiences from which to learn and to improve the methods and systems for moving people during emergencies. This lack of experience also makes it difficult to make confident forecasts of travel conditions during emergencies.

Planning evacuations for no-notice events is even more challenging than planning for more frequent, more predictably located natural events. Hazardous materials events and terrorist attacks, for example can occur nearly anywhere and at any time without any warning. This lack of a controlled set of scenarios creates challenges for agencies developing evacuation plans for all hazards or no-notice events, in particular. Yet, these
plans will be critical should an event actually transpire. This article describes essential features and reasonable assumptions that should be considered in the development of no-notice evacuation scenarios for use in conjunction with transportation simulation models in order to develop evacuation plans applicable to no-notice events, evaluate transportation system performance, develop evacuation management strategies, identify bottlenecks, and identify critical links. Some of the transportation strategies employed for hurricane evacuations can be transferred to the no-notice context, but no-notice events typically affect smaller areas and do not allow as much time to implement manpower- and equipment-intensive strategies. Evacuation plans that can handle large surges of traffic in the no-notice context will also benefit evacuations for events with more notice where demand can be spread over a day or more.

This article outlines the no-notice evacuation scenario development considerations encountered in a recent study which will be useful to other researchers as the desire to incorporate no-notice events and all hazards into emergency plans. The remainder of this paper is organized into four sections. The next section provides an overview of the background pertaining to no-notice evacuation modeling, primarily from the transportation modeling perspective. Then, an outline of the types of information needed for transportation simulation is provided. The following section details the items to consider when developing scenarios for simulation, including examples from a recent study pertaining to a hypothetical terrorist attack and justification for assumptions. The final section offers some concluding comments.

Background

The literature available for no-notice evacuations is considerably sparser than it is for hurricane evacuations, likely due to the typically smaller evacuation area, lower frequency, and/or security sensitivity. Even as recently as 2006, little work focusing on the practice for no-notice evacuations was available (Wilson-Goure, Houston, and Easton 2006). Since then, a few studies (e.g., Auld et al. 2012; Carnegie and Deka 2010; Liu, Murray-Tuite, and Schweitzer 2012) have involved surveys or interviews of residents in the context of hypothetical no-notice events; however, the level of detail provided to the respondents is much sparser than that needed for transportation simulation. Other interviews and surveys were conducted after real events occurred (e.g., Aguirre, Wenger, and Vigo 1998; Cutter and Barnes 1982; Houts et al. 1984; Perry 1981, 1983) but these studies often focused on testing specific theories, hypotheses, or models and did not collect all of the data required for simulation. However, the results of the surveys and interviews for both real and hypothetical events are useful in developing models of citizens’ responses to events and help inform the demand side of future simulation efforts.
Other studies focus on optimization based approaches (e.g., Jabari, He, and Liu 2009; Liu, Murray-Tuite, and Schweitzer 2011; Zhang, Niu, and He 2010; Zheng et al. 2010) and transportation simulation tools, either real-time (e.g., Chiu and Zheng 2007) or off-line. Generally, these optimization based studies are from the perspective of the emergency managers or transportation network operators and assume that citizens follow protective action recommendations, at least at an assumed compliance level. Optimization model results do not necessarily correlate with individuals’ or households’ anticipated behavior (Murray-Tuite, Schweitzer, and Morrison 2012a). Murray-Tuite et al. (2012b) found that hurricane evacuees selected routes based on familiarity and/or because they thought the routes would be the fastest/shortest rather than because a management agency recommended the route. Hsu and Peeta (2011) allowed variation in response in their models, but did not have behavior data to verify their models.

Real-time decision making tools are useful and important during an emergency, but not to the exclusion of pre-event planning and what-if analyses. The two should operate synergistically. The planning phase helps identify the resources that may be required during an actual event, infrastructure locations that should be protected, and locations where particular strategies are consistently beneficial. Furthermore, the potential for power or communication system damage/failures could severely limit real-time tools’ use in an actual event. Thus, their use should not be to the exclusion of, but rather in conjunction with, pre-event planning and scenario testing. Pretorius et al. (2006) cite emergency evacuation plans as one of the key resources during evacuation operations. To make the planned and actual conditions as close as possible, the pre-event planning scenarios should be as realistic as possible.

**Transportation Simulation Needs**

To simulate scenarios, transportation simulation models require a set of supply and demand based inputs. The supply side incorporates the features of the road network, including link characteristics—such as direction, number of lanes, speed limits, and capacities—and node characteristics, such as control operations. At the most basic level, the demand side inputs include the number of vehicles departing at a given time and traveling from a given zone to another given zone. The model operates on a set of embedded rules to move vehicles from their origins to their destinations. Various parameters for the rules and internal models should be calibrated prior to use, as well as demand, which are non-trivial tasks. Simulation scenarios involve variations of the supply, demand, parameters affecting the rules, and/or the rules themselves. Once the simulation is complete, the desired performance measures can either be directly obtained from the tool’s outputs or derived by post-processing the available results.
Developing Scenarios

Both the demand and supply inputs for no-notice evacuations are different from typical travel days and depend on the specified scenarios. Ideally, the scenarios account for the interacting forces of the event, emergency management, infrastructure condition, and citizen response. Figure 1 illustrates how these forces interact to produce the scenario inputs for the simulation model. The interaction of the citizen response (demand) and infrastructure state is simulated within the transportation model.

![Figure 1. Interacting Forces for Scenario Development](image)

Event

The event precipitating the evacuation needs to be considered in detail and at a minimum specify the type, severity, location, and timeline. The type of event helps guide what response would be appropriate – evacuate or shelter-in-place; will decontamination activities be required; will law enforcement investigate the event; will infrastructure be damaged or need to be inspected for safety; will injuries be present; etc. Sheltering in-place, although sometimes the appropriate protective action, is not especially interesting from a transportation simulation perspective and scenarios where sheltering in-place is desired (with full compliance) need not be simulated, unless desired for comparison purposes. The type also indicates whether environmental cues will be present—such as sights, sounds, or smells that alert people to danger and increase the likelihood of
Evacuation (Perry 1983). Finally, the event type helps inform whether transit service will be available; transit agencies will not operate if doing so puts their employees or customers at risk.

Event type, severity, and location determine the amount of infrastructure damage that should be modeled and the size of the area that will require a mandatory evacuation. The size of the evacuation area and its location indicate whether multiple jurisdictions will have to coordinate and how many and where public shelters should be opened. Dunning and Oswalt (2007) add that topography is an important consideration as well. Certain chemicals are heavier than air and evacuating citizens into or through valleys would place them at greater risk than sheltering in-place.

Terrorist attacks are often modeled with a specific target (e.g., Peeta and Hsu 2009). Historical events or other information may help identify impact locations. For example, in a recent study by the authors, the funding agency selected a location based on historical terrorist attacks. Other studies (e.g., Liu 2011) selected locations based on the likelihood of an event according to the locations of hazmat sites and critical transportation infrastructure.

Finally, event timing and the progression of the threat are important considerations for the emergency response plan and evacuation demand estimation. The time-of-year and day-of-the-week determine the estimates of different types of evacuees – residents, workers, tourists, and students. Time-of-day influences how the evacuation notices can be issued, the types of evacuees, and dispersion of the resident population. For instance, citizens cannot be notified of the evacuation order by television if it is the middle of the night. Nighttime evacuation scenarios can assume that most people will be at home whereas daytime evacuations involve greater dispersion of the household. Noh et al. (2009) suggest that the worst-case time-of-day scenario for a downtown area is between 11 AM and noon. Time-of-day also influences the amount of background traffic (non-evacuees) that will be present in the network and their origins and destinations.

In the authors’ project, scenarios were based on an attack involving unspecified hazardous materials at a specific location with no danger of incident escalation or transportation infrastructure damage. Two radii around the target were examined; radii could also be informed by recommended evacuation distance for chemicals (see, for example, USDOT 2012 for hazmat transport incidents). Both scenarios occurred during the evening peak travel period of a weekday to generate the maximum background traffic. Health risks were assumed to be minimal to ensure continuity of transit modes and ease the complexity of trying to model switching transportation modes, which could be especially difficult for those who did not drive to work. These scenarios could be more complex by varying some of these conditions, but at the same time, one needs to limit the number of simulations so that one is not simulating and analyzing indefinitely.
Emergency Management

Zimmerman et al. (2007) point out that for no-notice incidents, emergency managers will not have full situational awareness and will operate on incomplete information and pre-event plans. Quick decision making is critical for saving lives in no-notice events. Without advance information, the emergency response plan will be implemented post-impact. Elements of the plan may pertain specifically to infrastructure damage caused by the event or involve modifications to the network (discussed in the next section) to facilitate evacuation. Safety precautions may call for isolating the directly impacted area from non-emergency traffic and should be reflected in the infrastructure modeling.

Communicating the appropriate protective action to the public is one of the key elements for the scenario modeling. Citizens who receive a clear evacuation notice have higher likelihoods of evacuating (Baker 1979; 1991; Gladwin and Peacock 1997; Hasan et al. 2011; Lindell et al. 2005). If desired, the spread of information over space and time can be part of the scenario modeling. This could be accomplished using diffusion models such as the one by Rogers and Sorensen (1991). In the authors’ study, to manage the overall scenario complexity, the assumption that the evacuation order would be issued 15 minutes after the event and that warning dissemination could be part of the response curve for traffic loading (discussed below) simplified the information dissemination considerations.

Infrastructure Capacity and Configuration

Infrastructure damage or closure by emergency managers is event-dependent (Wilson-Goure et al. 2006). Similarly, transit operations also depend on the event and special transit operations may depend on the evacuation plan. On the other hand, certain capacity enhancements can be implemented, whether by policy or based on the assumption that drivers would use all available capacity. For instance, high occupancy vehicle (HOV) restrictions can be suspended or hard shoulders can be used. In the authors’ study, hard shoulders were already in use due to peak period operations but HOV restrictions were assumed to be eliminated 10 minutes after evacuation starts.

Other traffic management strategies can be resource and time intensive. Zimmerman et al. (2007) indicate that contraflow operations require three to five hours to implement, and thus are not likely to be implemented for no-notice events. However, other possible strategies include modified signal timing, ramp closures, and crossing elimination. The last two strategies require resources and careful planning with respect to demand in order to be effective; however, their operations are more localized than contraflow operations and can be implemented faster.

Information, as available, can be provided to drivers about road closures, incident locations, and congestion conditions. When information provision is included in the
scenarios, the methods should be considered (e.g., 511, radio, Internet, and fixed and portable variable message signs—VMS), as well as updating frequency. As an example, the authors assumed that evacuees would receive new information every 10 minutes through in-vehicle devices. Start and end times of congestion warnings on variable message signs may need to vary by location and can be determined after analyzing initial simulations.

Basic scenarios may be examined in conjunction with traffic incidents. Associated locations, severities (number of lanes closed), and durations can be determined from historical incident records or in conjunction with random incident models. If incident locations are close together and individually would not produce significantly different simulation results, only one of these should be chosen.

Citizen Response

Ideally, behavioral models, such as those that predict evacuation departure times, origins, destinations, and routes should be specific to a particular area, event, and network. However, the data collection efforts for many detailed scenarios can be cost prohibitive and the nuances of the scenario definitions may be lost on the respondents or survey administrators. There is also a question about how well anticipated behavior will match actual behavior. Fortunately, Kang et al. (2007) found that the two are in line with each other over many dimensions.

Estimating the number of different types of travelers is complex. One must consider evacuees who are in the mandatory evacuation area, evacuees who elect to travel but are not required to or ignore advice, and travelers that are not addressed by the evacuation order. Further complicating the issue are special facilities (e.g., hospitals, prisons) and people with special needs who need assistance to evacuate. All travelers need to be defined in terms of their origins, destinations, departure times, modes of transportation, and routes.

Additional considerations may be needed for the traffic mix. For example, trucks do not have the same features as personal vehicles, especially in hilly areas. The simulation model may be able to handle all of these types of demands, but if not, and truck volumes are comparatively small, trucks may be converted to passenger car equivalents using factors from the Highway Capacity Manual. Truck evacuation traffic should also be considered if volumes are substantial, the evacuation area is sufficiently large, and/or a major trucking source is affected.

Evacuee Estimates. Compliance with an evacuation notice has been a concern for hurricanes, among other disasters. This is similarly an issue for no-notice events. If detailed behavior models are available for the event/area, they should be used. In their absence, assumptions regarding the percent compliance may be required. When making conservative estimates for emergency planning purposes a response rate of 100 percent,
which assumes that everyone within the threat area will evacuate, is commonly used. Such an assumption would generate the maximum amount of travel into the system and would also likely result in the most lengthy clearance time.

Identifying the evacuees naturally depends on the event, its timing, and the emergency plan. Evacuees may be categorized in different ways, such as residents and transients (e.g., tourists and business travelers, see Drabek 1996). It may be reasonable to assume that most of the evacuees can transport themselves, but any special populations and their evacuation plans should be incorporated as appropriate. For some cases, special populations may be safer sheltering in-place rather than evacuating due to the time-intensive nature of obtaining transport, preparing the dependents for travel, and then evacuating.

During a nighttime evacuation, most of the resident are likely to be at home and transients will be in hotels. However, during the day, people will be more dispersed, making the estimation of evacuees more challenging. At these times, evacuees may be further segmented into workers, students, at-home residents, shoppers, and tourists, estimates of which will depend on the particular time of day. Calculations for the first four groups may be informed by a transportation planning model. Information for predicting the number of tourists may be obtained from state or local tourism entities.

In the authors’ recent study, estimates of the total number of workers requiring evacuation were based on the evening peak period origin-destination matrix from a local metropolitan planning organization’s (MPO) transportation planning model. MPO travel models, such as the one used from the Metropolitan Washington Council of Governments, are helpful to show normal daily traffic patterns, including origins, destinations, and routes as well as the times during which these trips are taken. In turn, this information can be used for estimating both evacuation trips and the background traffic that would exist in the network at the time of an emergency. From the normal day travel demand calibration effort, an adjusted demand matrix was obtained that included some pre-peak demand, the entire evening peak, and some post-peak demand. This matrix consisted of trips of all types. To separate the work-home trips, the calibrated matrix was multiplied by the planning model’s ratio of work trips to all trips and these ratios varied across time periods. Student trips could be similarly estimated if required by the time-of-day scenario. Shopper evacuees can also be calculated in a similar fashion, but using the planning model’s home-based shopping trips rather than work trips.

To predict the number of at-home residents who would evacuate, information from the U.S. Census can be used. For a worst case demand scenario, the number of retirees and unemployed persons may be assumed to be at home at the time of the event. As an estimate of retirees, the authors used the number of individuals aged 65 and older. These statistics were used in conjunction with the proportion of the Census area within the mandatory and shadow evacuation radii. Other factors in the at-home resident calculation include employed residents who live in the evacuation area but work elsewhere. The
authors assumed that their percentage was proportional to the ratio of the elapsed peak period to the entire peak period. To generate the number of vehicles, the authors assumed a vehicle usage rate (80%) in the range identified by Ewing (2010). Employed residents who were outside the evacuation area at the time of the event were assumed to not return home but follow the destination assumptions discussed below.

Tourist volumes may be estimated from information provided by the state tourism organization, including the total number of annual tourists, the highest percentage for the month of travel, the average number of nights spent in the state, the percentage associated with the cities in the study area, and the percent traveling by personal vehicle/rental car. Depending on the evacuation area, evacuees using aircraft as their mode of evacuation may need to be considered. An airport authority can provide estimates of the numbers of passengers and greeters (e.g., family or friends meeting the passengers at the airport) during a specified timeframe (employees should be addressed in the estimates of the number of workers). Analysts may also assume that, due to the event, some flights would be diverted to other airports and that an estimate of the number of vehicle trips could be based on the airport’s parking spaces. Although not all vehicles in the parking lot would be used, taxis and greeters would provide service.

In addition to all of these considerations for the mandatory evacuation area, researchers should also anticipate shadow evacuees. In the authors’ study, shadow evacuation was assumed to occur in the area with a radius at least double the mandatory evacuation radius. A behavioral study for the area suggested that estimates of 40 percent of workers and 20 percent of residents in the shadow area would be reasonable (Guterbock et al. 2009).

Intermediate Trips. A long history of observations of family gathering during evacuations (e.g., Johnson 1988; Johnson, Feinberg, and Johnston 1994; Killian 1952; Perry 1985; Perry, Lindell, and Greene 1981; Perry and Mushkatel 1984) suggests that this behavior should be incorporated into the demand considerations if the timing of the event warrants. Liu et al. (2012) confirm that parents anticipate gathering their children during no-notice evacuations. Failure to include such behavior leads to overly optimistic evacuation time estimates and traffic patterns that would otherwise not be captured, potentially conflicting with traffic management strategies (Liu 2011; Murray-Tuite 2007; Murray-Tuite and Mahmassani 2004). However, child pick-ups would be negligible at times other than those hours unless there participation in extracurricular activities is high.

Background Traffic. This type of traffic can have a significant impact, especially when the evacuation area does not encompass the entire simulated network. Few empirical studies are available to inform estimates of the travelers not participating in the evacuation. At a minimum for transportation simulation, some pre-event traffic is required to generate realistic network conditions.

The authors created three background traffic scenarios for their study. The first allowed background traffic to follow typical day volumes and departure timing. The
second kept the volumes the same but condensed the departure time span to half of the peak period in order to represent the case in which these travelers would be aware of the event and try to reach home sooner. Finally, for the same volumes, the departure time span was expanded to 1.5 times the peak period to represent the condition in which people might stay at work longer to avoid evacuation related traffic.

Destination Assignment. Based on numerous hurricane related studies (e.g., Drabek and Boggs 1968; Moore et al. 1963; Murray-Tuite et al. 2012b; Wu, Lindell and Prater 2012), the homes of relatives and friends and then hotels/motels are preferred accommodation types for evacuees, compared to public shelters. Public shelters, however, may be used temporarily, depending on the duration for which evacuees anticipate being away from home and the nature and timing of the evacuation (Milet, Sorensen and O’Brien, 1992).

Although many hazards have readily identifiable source locations, directions of movement, and speed of progression, not all do. When the location and movement characteristics of a hazard are unknown or cannot be forecast, one may consider two scenarios for evacuee destinations. One destination assignment scenario may focus on homes and hotels/motels. The authors assumed that evacuees would travel to dispersed locations in proportion with the normal travel, according to a regional planning model. Noh et al. (2009) based the dispersion on social/recreational trips from a planning model. In the other scenario, evacuees can be assigned to public shelters identified by the emergency management agency. For smaller evacuation areas, the local shelters may be able to accommodate all evacuees but larger evacuation areas require travel beyond the regional transportation simulation model. In that case, the evacuees can be assigned to external zones in the direction of those shelters. Reality will likely fall somewhere between these two scenarios, probably closer to the first, but the number of simulations needs to be reasonable.

Other types of travelers should be assigned reasonable destinations. In particular, barring isolation of network components due to the event, background traffic should be assigned to their original destinations. Similarly, workers and shoppers who are evacuees that live outside of the evacuation radius should be assumed to go home. Any intermediate trips considered should have appropriate intermediate destinations (e.g., schools).

Mode Split. The modes available for evacuation depend on the event, its timing, and evacuation plans. Transit may not be available in the middle of the night, regardless of the event’s effects. At a more individual level, if an event occurs during the workday, commuters who used transit will not have access to personal vehicles except by carpooling with co-workers; thus, the number of personal vehicles cannot be increased despite slight mode changes.

Personal vehicle use during evacuations has shown both similarities and differences when compared to regular travel. Generally, vehicle occupancy is higher during
evacuations since families tend to travel together. However, certain types of events—such as floods, fires, and hurricanes—that threaten any vehicles that are left behind may offset the higher vehicle occupancy as drivers seek to avoid their loss.

When personal vehicles are appropriate for the event, they are the preferred mode of transportation for residents and tourists. Hurricane related studies revealed vehicle usage ranging from 72-91 percent of all registered vehicles (Ewing 2010).

In the authors’ study, they made four more assumptions related to modes. First, transit services would operate normally. Second, travelers, particularly background traffic, would use their normal modes of transportation. Third, airport evacuee mode split is 17% transit and 83% personal vehicle; these values are based on normal mode splits provided by the airport authority. Finally, pedestrians would not interfere with vehicle traffic; should this last assumption be relaxed, capacity reductions should be modeled.

Traffic Loading/Departure Times. The loading of evacuation traffic onto transportation road networks is a reflection of people’s decision to evacuate. The speed at which this occurs depends on a range of variables that relate to the dissemination of evacuation information, preparation time, experience, community behavior, and the characteristics of the threat. Although the cumulative time scales differ for different hazards, it is typical to see an S-shaped response curve in which the evacuation begins slowly. Zimmerman et al. (2007) and others indicate that some people may evacuate even before an official evacuation order is issued. Wolshon et al. (2010) found that as many as 10 percent of evacuees depart spontaneously. This pattern of behavior is common especially for with-notice hazards like hurricanes as some evacuees seek to depart the hazard zone as early as possible because they may feel particularly threatened, seek to avoid later traffic congestion, and so on. Then, soon after the order is given, the evacuation response rapidly gains momentum with about 80 percent of the total number of evacuees departing over about a third of the total clearance time. Finally, over the final third of the cumulative clearance time window, the final 10-20 percent clears the risk area. This last part of the evacuation, which is also labeled the “evacuation tail”, can significantly lengthen total evacuation time (Wolshon, Jones, and Walton 2010).

The widely-used logistic curves (Yazici and Ozbay 2008) are characterized by two parameters, one is the half loading time and the other, \( \alpha \), indicates the response rate. Short loading time and high \( \alpha \) values generate concentrated departure times. The authors adopted an \( \alpha \) value of 0.5, which represents rapid response and considered two scenarios for half loading time—30 minutes and 60 minutes. These parameters were selected to be conservative.

Route Selection/Traffic Assignment. The traffic simulation tool will include at least one traffic assignment technique. Often, the method is based on some version of equilibrium. However, a user-based equilibrium requires travelers to have knowledge of the conditions over all possible paths. For normal travel, the knowledge is gained through experience, which is not practical during evacuations (Lindell and Prater 2007). More
realistic assumptions involve evacuees selecting a good, but not necessarily optimal path, especially those going to a non-home location.

Background traffic, on the other hand, especially those far from the impact area, should be assumed to follow their habitual paths, at least initially (Zheng et al. 2010). Their paths may be affected by real time traffic information and delays. Assumptions about the percentage of travelers that will hear the traffic information will have to be made and parameters reflecting delay tolerance will need to be specified.

The authors’ study used the software DynusT, which allowed at least two types of traffic assignment. Background traffic was assigned to their normal paths with a single delay threshold. In the initial scenarios, en-route information was not provided to the background traffic but was provided to all of the evacuees; this was done to facilitate post-processing activities, but should be varied in additional scenarios. Evacuees were simulated with “one-shot” assignment, which provides evacuees with good but not necessarily optimal paths.

A summary of the key scenario elements, considerations, and potential sources of information that may be considered for evacuation simulations is provided in Table 1.

**Modeling Experience**

Based on the examples indicated throughout the above discussion, the authors developed 24 base scenarios (two evacuation radii, three background traffic cases, two destinations, and two departure time/loading curves). Each of these was subjected to four incident locations (temporary capacity reductions) and four traffic management strategies implemented at least 25 minutes after the event occurs. Without interacting the incident and management strategies, this led to 192 scenarios. The simulation input and selected output files required nearly 13 GB for each scenario (2.5 TB total) and approximately 1.5-3.5 hours to run each, depending on a variety of factors, such as the number of simultaneous runs, the processor, information strategies, and number of vehicles simultaneously in the network. The total number of vehicles involved in the scenarios was on the order of 5,500,000 with a network of 5,648 nodes and 12,890 links.

The large number of scenarios is not suitable for presentation to decision makers as the comparisons are difficult to make. Outputs of interest include, but are not limited to, travel time for evacuees overall, travel times for evacuees to reach safety, travel times for all vehicles, and speeds and densities for each link in the network. The last two performance measures vary with time and can be displayed with GIS tools or animations. Instead of presenting all of the results, researchers should select ones that generate significant differences. Naturally, this will require significant effort on the part of the analyst. Detailed results from the authors’ study are not publicly distributable.
Table 1. Scenario Elements and Information Sources

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<th>Sources of Information and Dependencies</th>
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<td>Emergency Response Guidebook (Cloutier and Cushmac 2004); historical records; professional judgment</td>
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<td>Shadow evacuee estimates</td>
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<td>S-curves; Rayleigh distribution (e.g., Tweedie’s approach)</td>
<td>Parameter values</td>
<td>Previous studies (e.g., Noh et al. 2009; Wolshon et al. 2010; Yazici and Ozbay 2008)</td>
</tr>
<tr>
<td>Route selection</td>
<td>Routing models; information response models; behavior models</td>
<td>Behavior assumptions; information updates; response thresholds</td>
<td>Simulation capabilities; historical traffic conditions; behavioral studies</td>
</tr>
</tbody>
</table>
Summary and Conclusions

Emergency management agencies and departments of transportation benefit from transportation simulation support when developing their emergency response or evacuation plans. No-notice events are increasingly becoming a part of these plans. Although a general outline of considerations is available from the Federal Highway Administration (Zimmerman, Brodesky, and Karp 2007), few, if any, studies have illustrated how these considerations can be operationalized.

This study provides details of scenario development based on the general considerations and the authors’ research experience. The scenarios should consider the four interacting components of the event, infrastructure, emergency management, and citizen response. The event should be specified in terms of type, severity, location, and timeline in order to identify infrastructure effects, the need to evacuate, the method of delivering evacuation warnings, whether transit will operate in the affected area, and to some degree how citizens will respond. Infrastructure operability and safety, combined with emergency plans, will determine whether evacuees and background traffic can use the full network. Authorities may also increase capacity by suspending HOV restrictions and allowing the use of hard shoulders. They may also modify the network through traffic management strategies, such as modified signal timings, ramp closures, and turning movement restrictions at intersections. Furthermore, information can be provided to travelers through variable message signs and in-vehicle devices to help them avoid congestion and effectively use the network. The citizen response will be influenced by the event, official warnings, and infrastructure conditions. Estimating travel demand requires consideration of spontaneous evacuation, mandatory evacuation compliance, special populations, and background traffic. This article provides assumptions and methods to compute at-home resident, worker, shopper, tourist, and airport evacuees whose destinations are scenario-based. Modes of transportation, departure times, and routes should also be considered. This paper suggests justified assumptions for these factors.

Although no single hypothetical scenario is likely to perfectly replicate a real event that occurs in the future, the simulations of a variety of scenarios can be useful and informative for emergency management. The scenarios allow for the identification of factors to which the results are sensitive. Little sensitivity allows agencies to be fairly confident with assumptions about those factors but high sensitivity may indicate areas for future detailed study. Such analyses also indicate where traffic management strategies should be consistently implemented, and where a strategy is only effective in certain situations. In some scenarios, implementing a strategy designed for a completely different case, may deteriorate evacuation performance and place evacuees at increased risk.
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