Evacuation planning is a key component of emergency planning. Originally a requirement for the nuclear power industry, evacuation planning has extended into other venues, involving, for example, chemical plants and military installations charged with destroying chemical or biological weapons.

Evacuation planning emphasizes the development of scenarios. The emergency planning staff works out procedures and selects the most appropriate response to a hypothetical emergency. The process itself is conducive to training. In addition, simulators can be used for evacuation training in real time within a closed-loop system.

**Evacuation Time Estimates**

The general public and some professionals misunderstand the nature and meaning of evacuation time estimates (ETEs). An ETE is a criterion in a protective action recommendation (PAR) addressed to emergency decision makers by the technical staff evaluating the emergency. A PAR generally presents three choices for public action: do nothing, shelter in place, or evacuate the area. To the public, ETEs become indicators of risk.

The ETE is the time required to move the at-risk population out of the evacuation area. It is an aggregate measure and should not be confused with individual evacuation travel times. The ETE does not represent the time for an evacuee to travel to a final destination—for example, to a congregate care center or a relative’s home.

Before beginning the evacuation trip, an evacuee must mobilize, or prepare for the journey. Preparatory activities vary depending on the person’s needs and situation.

Evacuation time and mobilization time start with the release of a public advisory to evacuate. Mobilization and evacuation are processes that occur over time and space—they are not events that take place at a point in time.

Figure 1 presents the relationship between ETE and the average evacuation travel time. The ETE is the time elapsed from the public transmission of an evacuation advisory to Public at Time = 0.
advisory until the evacuation is complete. The average travel time for an evacuee is the time elapsed from the start of the evacuation trip to the time that the evacuee leaves the affected area. Figure 1 shows that the average evacuation trip is shorter than the aggregate ETE.

The evacuation travel time depends on traffic demand and highway capacity. When demand exceeds capacity, travel speeds decline, and the traffic begins to queue—that is, becomes stop-and-go—which is a characteristic of congestion. The traffic moves, but slowly. Under these conditions, the ETE can exceed the time required to mobilize the population.

If an area to be evacuated does not generate traffic with a high ratio of demand to capacity, then the evacuation travel time will approximate the travel time at free-flow speeds. The ETE therefore is closely related to the population mobilization time.

Human Factors
To develop ETEs for an emergency planning zone (EPZ), an analyst must identify the travel patterns, the car ownership, and the household size characteristics of the population. Demographic information may be available from countywide census data.

Census data, however, have several drawbacks for emergency planning. First, the data do not encompass the range of information needed to calculate the time required for the mobilization. Second, census data may not focus on the specific population of the EPZ and consequently may not represent accurately the characteristics of the evacuating populace.

Telephone surveys have been used successfully to address these concerns. The surveys ask respondents about family demographics and elicit estimates of response times to well-defined events. The surveys avoid asking “What would you do if …?” but ask specific questions instead about familiar activities: “How long does it take you to …?”

Mobilization Time
Mobilization time consists of a sequence of events and activities. Each event occurs at a point in time and is the outcome of an activity. The principal focus of family activities before evacuation is gathering members together to evacuate as a group. For example, a resident of the area to be evacuated who is at work at the time of an emergency may engage in the following activities:

1. Becoming aware of the emergency condition. Notification may arrive via media announcements, sirens, alert systems, or other means.
2. Preparing to leave work. Office workers may require less time to prepare for leaving work than would merchants or farmers who must secure the property before leaving.
3. Traveling home. Employees who want to gather their families together before evacuating will have to travel home from work.
4. Preparing the home for departure. Before beginning the evacuation trip, families secure their homes and pack bags for the journey.

Figure 2 presents the results of this analysis for four EPZs surrounding nuclear power stations in the northeastern United States. The EPZs at Vermont Yankee, in southern Vermont, and at Nine Mile Point, outside Oswego, New York, can be characterized as low-population rural environs. The other two sites, Pilgrim, about 35 miles southeast of Boston, and Indian Point, about 30 miles north of New York City, are characterized as medium- to high-density suburban areas.

Figure 2 presents the evacuation mobilization times for households with commuters who will return home to gather the family before beginning the evacuation trip. In both sets of curves, the time required to return home from work is key. Because the work-to-home travel time takes longer in heavily populated suburban areas than in rural areas, suburban sites have longer mobilization times.

Evacuation Response
Figure 2 indicates that more than 80 percent of households with returning commuters are prepared to begin their evacuation trips within 1 to 2 hours after the advisory. One likely result is that during the early phases of an evacuation more traffic may be moving toward the EPZ than evacuating the area. The agencies that provide both the traffic control to assist the evacuation and the access control to deny entry therefore
must not start too early, to avoid impeding return of commuters and delaying the evacuation.

Figure 3 presents the public response to a recommendation for evacuation. In the case of a terrorist scenario or a technological emergency—such as a chemical spill or a radiological release—a map of the evacuation area usually takes the shape of a keyhole: a central circular area determined by the toxic release plus an area extending outward in the downwind direction. The extent of the evacuation area depends on the nature of the toxic release and on the wind conditions, including wind speed and atmospheric stability.

People who live or work in the immediately surrounding region—represented by the middle ring in Figure 3—may decide to evacuate voluntarily, even if they are not at risk. The evacuation region could extend into portions of this area, however, if the wind shifts and puts more people at risk.

Finally, the outermost ring in Figure 3 represents an area called the shadow evacuation area. People here may choose to relocate farther from the source of the hazard. Both the voluntary evacuation area and the shadow evacuation area must be considered in projecting potential traffic congestion that could delay the departure of evacuees from the central area.

Evacuation Planning
Evacuation planning involves an iterative process to identify the best routes and to estimate the time required to evacuate the area at risk. Some of the steps are as follows:

- Identify the region to be evacuated. Is the area circular or keyhole in shape? The EPZ may be subdivided into emergency response planning areas (ERPAs), which are defined by recognizable geographic or political boundaries and are understandable in specific instructions to the public—for example, “People within the town of Plymouth should shelter in place.” Groups of ERPAs that receive the same emergency instructions constitute a region.
- Identify the travel demand in terms of numbers of vehicles, as well as in terms of probable destinations for people from the evacuation area and for people from the voluntary and shadow evacuation areas.
- Use a traffic distribution and assignment model to compute the optimal routing of evacuation trips on the nodes to the specified destinations and to simulate the movement of vehicles during the evacuation. The simulation model should describe traffic conditions under saturated flow, to account for the effects of congestion; the model also should be capable of rerouting traffic from a congested route to one that is less congested, to avoid unnecessary delays.
- Review the simulation results to determine the traffic management needs for the evacuation. Introduce the traffic management tactics into the simulation and repeat the ETE analysis.

Computer Modeling
Evacuation simulation can be performed with microscopic models or with macroscopic models.

- Microscopic models move individual vehicles through a network. The vehicles have their own characteristics and the drivers respond to the presence of other vehicles and to traffic control devices. Micro models provide a detailed simulation at a slow computing speed.
- Macroscopic models describe the overall traffic flow on a link of the network, instead of the movement of individual vehicles. Macro models can simulate quickly the conditions of large areas operating under high traffic demand.

Both classes of models are valuable tools in evacuation planning.

An evacuation study conducted for Nine Mile Point allowed a comparison of microscopic and macroscopic modeling. The evacuation network consisted of 964 route links. Statistics indicated that the ETEs produced by the micro and macro models were similar, with less than a 5 percent difference over a 5.5-hour period. The microscopic model, however, took 300 times longer than the macroscopic model to yield the results.

The PCDYNEV Evacuation Planning System, developed for the Federal Emergency Management...
Agency, has been used in the United States and abroad to conduct evacuation planning studies for areas near nuclear power stations and chemical weapons disposal facilities and for areas subject to hurricanes. PCDYNEV comprises two principal models: TRAD and IDYNEV.  

TRAD is an integrated traffic assignment and distribution model that yields vehicle turn percentages for every node in the network and uses these to guide vehicles along an evacuation route. The analyst specifies the highway network, the volume of traffic generated from all centers of origin, a set of probable destinations on the periphery of the area to be evacuated, and the capacity—that is, the attractiveness—of each destination. TRAD then calculates the optimal trip distribution and the optimal trip assignment or routing of the traffic from each origin to the probable destinations, to minimize evacuee travel times.

The premise is that the selection of destinations and the selection of routes are intrinsically coupled.

IDYNEV is a macroscopic simulation model based on CORFLO, also developed for the Federal Highway Administration. The model describes traffic flow with time-varying statistical histograms for each link. The IDYNEV simulation model employs a dynamic routing feature that overrides the TRAD-generated turn movements under certain conditions, to reflect driver behavior.

For example, if an evacuation route reaches a point on the network where two routes diverge and one of the routes is congested, then vehicles destined for the congested route will divert to the alternate route. The destination on the periphery may change, but the objective of leaving the at-risk area in the shortest time will be satisfied.

PCDYNEV includes a computer graphics display for animated presentations of evacuations (see Figure 4). Highway links are color coded for level of service, with severe traffic congestion shown in red. The analyst then can identify the need for traffic control to support the evacuation traffic flow.

Evacuation Case Study

The Indian Point Energy Center is located on the eastern shore of the Hudson River. The EPZ includes parts of four New York counties: Orange, Putnam, Rockland, and Westchester.

The EPZ is subdivided into 51 ERPAs, defined by a combination of geographical, topological, and political features. Table 1 presents estimates of the peak EPZ population for three categories. The peak population does not occur for all categories at the same time—for example, the employment population would peak on a midweek midday scenario, and transients would peak on a summer weekend.

The study examined 14 evacuation scenarios, each with a different combination of conditions that can affect evacuation demand or roadway capacity. For

![FIGURE 4 Sample animation display showing traffic congestion during an evacuation.](image)

<table>
<thead>
<tr>
<th>TABLE 1 Indian Point Energy Center Peak Population Estimates</th>
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<tbody>
<tr>
<td>Permanent Residents</td>
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<td>Evacuees</td>
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<td>Evacuees</td>
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2 TRAD = traffic routing and distribution; IDYNEV = interactive dynamic evacuation.

3 CORFLO = corridor flow; also known as TRAF Level II.
example, a summer midday weekend scenario would represent a peak transient population, with state and local parks and campgrounds operating at capacity. Winter midweek scenarios would involve schools and would require the evacuation or relocation of schoolchildren.

Weather conditions also affect the capacity of the roadway—for example, rain or snow can reduce free-flow highway speeds, as well as capacities. A full evacuation of the entire EPZ would involve more than 300,000 vehicles, with 239,000 leaving from the area at risk and an additional 63,000 leaving from the shadow evacuation region.

The ETE results for the Indian Point case study vary from slightly more than 7 hours to approximately 12 hours. The ETEs for rain and snow scenarios are higher than for the equivalent good weather scenarios. The differences among the times for public mobilization activities and among the resulting ETEs are directly attributable to the presence of significant highway congestion.

Figure 5 presents a graphical display of the ETE for a given scenario. Each curve represents the time needed to clear the indicated radius. Points on each curve identify the 50th, 90th, and 95th percentiles.

**Improving the Process**

The evacuation planning in the case study involved a fixed infrastructure facility. Federal guidelines define the extent of the EPZ for nuclear power stations. This kind of planning would work for any fixed facility, such as chemical plants, toxic material storage sites, or refineries.

The procedures need to be upgraded, however, to apply to emergencies at other kinds of sites. Transportation accidents can occur almost anywhere; terrorist attacks require fast response from emergency personnel.

A real-time emergency planning system would be needed to respond to these events. Provided with the location and the nature of the threat, such a system would generate evacuation routing and traffic management plans from the database.

The evacuation models would have to be fast enough to operate in real time; PCDYNEV can produce an Indian Point evacuation case in less than 1 minute. The integration of emergency planning functions into ITS technologies also would enhance the real-time utility of the system.

A real-time evacuation planning system, moreover, can become an integral part of an emergency planning training simulator. The model would be able to generate incidents—such as traffic accidents or other events that change the capacity or the topology of the road network—during a simulated evacuation.

The emergency trainee would become aware of the problem and would respond either by changing the routing instructions or by notifying emergency response teams to proceed to the incident. The results of the user-specified mitigation activities would be incorporated by the simulator into the completion of the exercise.

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