International Journal of Mass Emergencies and Disasters
November 1994, Vol. 12, No. 3, pp. 327-343

State of the Art In Evacuation Time Estimate Studies for Nuclear Power Plants

Thomas Urbanik II
Texas Transportation Institute
Texas A & M University
College Station, TX 77843

The purpose of evacuation as a protective action at nuclear power plants is to remove people from areas potentially affected by wind-borne radioactive material. A reason for conducting evacuation time estimate studies is to aid decision makers in the selection of appropriate protective actions. Another reason to conduct evacuation time estimate studies is to identify ways to reduce the evacuation time through the development of appropriate plans.

Before 1980, transportation analysis for natural and technological hazards was rare. Most consideration of evacuation times was largely qualitative. Techniques used were devoid of any of the expertise developed in the field of transportation analysis. Increased emphasis on estimating evacuation times for natural hazards and technological hazards began around 1980. The initial guidance issued by the Nuclear Regulatory Commission and the Federal Emergency Management Agency was published as NUREG-0654 (U. S. Nuclear Regulatory Commission 1980). The initial document was for interim use and comment. Planning standards and evaluation criteria were established including those related to evacuation (see section J.8 and J.10). Appendix 4 of NUREG-0654 (U. S. Nuclear Regulatory Commission 1980) provided limited guidance on preparing evacuation time estimate studies.

At about the same time as the initial publication of NUREG-0654, the Nuclear Regulatory Commission examined techniques for estimating evacuation times at nuclear power plants, the results of which are documented NUREG/CR-1745 (Urbanik 1980). NUREG/CR-1745 summarized the state of the art in evacuation time estimate analysis and made recommendations concerning how to conduct evacuation time estimates. NUREG-1745 and work by Federal Emergency Management Agency contractors became the basis for the subsequent revision of Appendix 4 published in NUREG-0654.

Evacuation time estimates are, in fact, only estimates. A wide range of potential accidents is possible, making it impractical to provide estimates for each of the many possibilities. Because of the many possible conditions that may exist, it is appropriate to think of evacuation time estimates for a given site as part of a planning basis. A planning basis is a method for addressing a spectrum of accidents.

Details about using a planning basis for development of emergency response plans are found in NUREG-0654 (Nuclear Regulatory Commission 1980) and NUREG-0396 (Nuclear Regulatory Commission 1978). The standard planning basis includes a plume exposure pathway emergency planning zone of about 10 miles radius, the area within which detailed evacuation planning is considered appropriate. Within the broad context of emergency planning at nuclear power plants, evacuation time estimates are but one part. The goal of evacuation is to reduce radiation dose to the population in the event of a radioactive release. Evacuation time estimate studies provide estimates of the sensitivity of the evacuation time to key variables, including the population of the area to be evacuated and the capacity of area roadways.

Transportation Analysis Considerations

A wide range of factors affect the time required to evacuate a given area. Furthermore, to effectively plan for an evacuation and develop efficient evacuation routings and traffic control measures it is necessary to conduct a systematic analysis of the transportation system under evacuation conditions.

At the most fundamental level, the appropriate analysis is a comparison of evacuation demand (i.e., the number of evacuating vehicles) and available capacity of evacuation roadways. The analysis is somewhat more complicated by the fact that capacity is time dependent. That is, capacity can not be stored for future use. If vehicles are delayed in one portion of the roadway network, it is possible that capacity in another portion of the network could be unused.

Simple analysis techniques exist (e.g., Highway Capacity Manual (Transportation Research Board 1985)) for evaluation of operations along various points along a roadway system. Although not specifically intended for estimating evacuation time, the techniques can be used to estimate roadway capacity. However, as the complexity of a roadway network increases and as the number of evacuees increases, the use of the computer models becomes attractive.

It is important at this point to note the inappropriateness of using level of service analysis in evacuation planning. Level of service analysis is predicated on the desire to provide capacity in excess of expected demand. Providing sufficient capacity to provide a high level of service during an evacuation is not practical in most cases. Only in very low population emergency planning zones will a high level of service be achievable.

The basic methodology for estimating evacuation times is to compare the evacuation demand (in numbers of vehicles evacuating per hour) with available roadway capacity, or transportation service rate. If the transportation service rate (also typically expressed in units of vehicles per hour) is greater than the rate of evacuation demand, then no significant traffic-related delays occur. If no significant traffic-related delays occur, then evacuation time is simply the time required by evacuees before beginning to evacuate, plus the time required to drive out of the emergency planning zone. If evacuation demand exceeds capacity, additional time is required to account for traffic related delays. The following discusses the key factors affecting evacuation time estimates.

Basic Methodology

The basic analysis methodology is to check whether the time-dependent evacuation demand rate exceeds the available roadway capacity. If the evacuation demand rate is less than available roadway capacity, then evacuation time is simply the time required for the last evacuee to begin evacuating, plus the driving time to leave the area. A critical part of evacuation is the trip departure time discussed in Section M below. If the rate of trip departures exceeds available roadway capacity, the time required by the excess vehicle demand must be added to the evacuation time.

A simplistic example illustrates the process. If 1000 vehicles are available to evacuate in a one hour period and available roadway capacity is 2000 vehicles per hour, there is no significant roadway-induced delay. Evacuation time is essentially one hour plus driving time out of the evacuation area. Alternatively, if 3000 vehicles are available to evacuate in a one hour period and available roadway capacity is 2000 vehicles per hour, the evacuation time for the last vehicle to leave is one and one-half hours (which includes 30 minutes delay time) plus driving time out of the evacuation area.

Obviously, a real example is more involved due to the complexities of vehicles leaving many different areas at many different times over many different roads under a variety of weather conditions. Nevertheless, the methodology simply requires an analysis of all the vehicles trip departures and any delay due to an evacuation demand rate more than the rate lat which the roadway can accommodate evacuating vehicles.

Emergency Planning Zone

NUREG-0654 and NUREG-0396 describe the emergency planning zone concept. The guidance specifies a plume exposure emergency planning zone of about 10 miles as the area for which evacuation planning is required. The emergency planning zone boundary is often increased or decreased slightly to conform to the characteristics of a particular site. Factors considered are demography, topography, land characteristics, access routes and local jurisdictions.

Sectors are sub-areas of the emergency planning zone. The sectors are nominally 90 degrees and sub-divided at two and five miles. The sectors provide a convenient means to carry out partial evacuation of the EPZ based on wind direction. The prevailing wind direction at the time of a radiological release determines the affected sectors. The boundaries of these emergency planning zone sectors are also based on demography, topography, land characteristics, access routes, and local jurisdictions.

Scenarios

Scenarios are the alternative sets of input variables that represent combinations of conditions that might occur at the time of a nuclear power plant accident. For purposes of evacuation time estimating, key variables are typically population and roadway capacity. For a given geographic area, the population to be evacuated is highly time-dependent. Therefore, scenarios to be analyzed should reflect different seasons of the year, days of the week, and times of day. Likewise, roadway capacity is highly dependent on weather conditions. Weather conditions to be considered should include good (clear) and adverse (rain, fog or snow) conditions. Adverse weather also reduces vehicle speeds.

The purpose of formulating several different scenarios is to determine if certain combinations of conditions cause evacuation demand to exceed roadway capacity. A range of possible combinations should be considered, however, it is not useful to analyze illogical or mutually-exclusive combinations of conditions (such as a large daytime beach population and snow covered roads). The analyst should attempt to identify that combination of conditions that is likely to generate the highest *typical* demand on a recurring basis. Scenarios to be analyzed should also include periodic events or conditions that generate a large, temporary attendance within the emergency planning zone.

There is a relationship between evacuation time and the advisability of certain protective action decisions Overestimating evacuation time is not desirable because such an estimate might lead the decision maker not to order evacuation as a protective action when it is actually the best alternative. It is also not necessary or desirable to determine a "worst case" time. The worst case would nearly always be one in which evacuation is not possible.

The goal of evacuation time estimate studies is to evaluate the sensitivity of evacuation time at a specific nuclear power plant to likely variables. These variables include evacuating population and available roadway capacity at the time of evacuation. It is desirable for the evacuation time estimate study to provide a range of evacuation times based on the likely ranges of conditions. The evacuation time for any set of conditions not specifically analyzed in the study can be inferred, based on an understanding of the sensitivity of evacuation time to each of the variables.

Demand Estimation

One of the key aspects of the methodology is to define the number of evacuees. Although the object of evacuation is to remove people from the EPZ, it is the number of evacuating *vehicles* that determine if any transportation-related delays are likely. The estimation of the number of evacuating vehicles can be based on several possible data sources. In most cases the number of evacuating vehicles is estimated *after* estimating the number of evacuees. Occasionally, it is more appropriate to estimate the number of evacuating vehicles directly. For example, it may be more accurate to determine the number of vehicles at a beach by counting them in the parking lots than to count or estimate the number of individuals on the beach. Several data bases may be used to estimate of the number of evacuating vehicles. The evacuating population is typically subdivided into three groups. Permanent residents are those who live in the emergency planning zone year-round. Transients are visitors, including tourists and daily employees, who live outside the emergency planning zone. Special facility populations include those in institutions and schools. Some individuals are members of more than one group.

The permanent resident population is typically estimated from census data (often updated for growth), and transient populations are derived from other local sources of data. In some cases special field studies may be conducted to develop better estimates of transient populations. Numbers of tourist vehicles are sometimes counted directly as the best alternative for estimating evacuating vehicles.

Special facility populations, including school populations, are estimated on a facility-by-facility basis because the transportation needs are determined by individual facility characteristics. Some special facility populations may require buses while others may require ambulances. Therefore, consideration of individual facilities is necessary because of the need to identify the specific vehicle requirements.

Evacuation time for special facility populations is determined by the vehicle needs, mobilization time, loading time and travel time. For example, if enough buses are available to evacuate schools in a single trip, then evacuation time is essentially dependent on mobilization time of the buses, loading time, and travel time out of the emergency planning zone. If multiple trips are required due to vehicle limitations, the analysis is more complicated (See section III B).

The issue of double counting makes careful analysis necessary. In some cases, double counting is necessary and does not cause significant problems. For example, school children are counted both as permanent residents and as special facility populations. This is because in some cases the school children may evacuate from school (week-day/winter/daytime) and in others, from home (summer or evening). The school children are counted separately in order to determine vehicle needs for a direct evacuation from schools. This double counting has no adverse effect on evacuation time estimates. Care should be taken to avoid unnecessary double counting.

Returning commuters are permanent residents who work outside the emergency planning zone and return home before evacuating as a family group. Returning commuters move in a direction opposite to the general evacuation during the early portion of an evacuation while the public is preparing to evacuate. Trip generation time, which is discussed in Section M includes the returning commuter trips. Returning commuters are not considered evacuation trips for purposes of estimating evacuation time.

Voluntary evacuation describes those who decide to evacuate without being advised to evacuate. The terms "spontaneous evacuation" and "shadow evacuation" are also applied to this phenomenon. Two alternative means account for voluntary evacuation.

First, voluntary evacuees can be controlled so they do not interfere with other evacuating traffic. In some cases, control is unnecessary because the path of voluntary evacuees is independent from the designated evacuation routes. Voluntary evacuation can also be controlled though appropriate traffic management plans. Control directs voluntary evacuees away from evacuation traffic. The second alternative is to include the appropriate number of voluntary evacuees in the evacuating traffic demand estimate.

There are two different groups of voluntary evacuees to be considered. The first is made up of individuals living within the: planning zone but not within the sector(s) where evacuation has been advised. The second group is made up of those living *outside*, but near, the emergency planning zone who may relocate in response to an evacuation order directed at people living within the emergency planning zone.

Another possible evacuation demand is "background traffic". The term "background traffic" is used to describe vehicles present during an evacuation that are not associated with permanent residents, transients, or special facility populations. The most common example of background traffic would be "through traffic" on major intercity routes such as interstate highways. Access control measures to direct this "through traffic" onto some alternative route outside the emergency planning zone is the preferred method to handle this sort of background traffic. "Through traffic" that is not rerouted before it enters the emergency planning zone boundary must be considered part of the evacuating traffic.

Some individuals may chose not to evacuate. Nevertheless, the planning basis used for evacuation time estimate studies is to assume that all individuals evacuate.

Capacity

Transportation analysts classify roadways using a hierarchy ranging from locals, to collectors, to arterials, to freeways. Local streets primarily provide access to individual residences. Collectors concentrate local traffic and, ideally, provide access to arterials. Arterials are the roads and streets whose principal function is to move traffic. Freeways are a special type of arterial with controlled access.

The primary evacuation roadway system for analysis purposes generally includes arterials and freeways. Occasionally, collectors or even local streets are used to improve the operation of the evacuation roadway system. Opportunities to improve an evacuation by using any roadway that could reduce evacuation time should not be overlooked. That is, through traffic management, a minor roadway such as a local street could be utilized to improve evacuation capacity.

The reason it is unnecessary to analyze all roadways in an emergency planning zone is because the critical elements of the evacuation roadway system are those points where large volumes of traffic converge. Delay on the evacuation roadway network (if it exists) generally occurs at the convergence of two arterials, or at arterial access to freeways.

To determine roadway capacities, the roadway characteristics (number of lanes, lane widths, shoulder widths, grades, etc.) and traffic control (traffic signals, stop signs, lane use restrictions, one-way streets, etc.) must be determined through field surveys. Maps and other available data bases should not be to be relied on without field verification.

The quality or "level of service" of roadways is quantified using a rating scheme to describe the quality of traffic flow on a scale from A (best) to F (worst). Level of service is not particularly applicable to evacuations. The issue in evacuation is how long it will take to clear a given area, not the quality of traffic flow. By definition, where demand exceeds capacity, the level of service is "F", which is breakdown or forced flow. The existence of level of service "F" means the existence of bottlenecks due to evacuation demand exceeding the rate at which a roadway can accommodate traffic without delay. Although level of service "F" conditions exist upstream of a bottleneck, the bottleneck itself is, in fact, flowing at capacity. Vehicles in forced flow conditions are simply waiting for their opportunity to pass the bottleneck at the capacity flow rate.

The points of a roadway with the least capacity typically constrain the capacity of the evacuation network. Typical bottlenecks are intersections, especially intersections with traffic signals. Traffic signals assign right of way and determine the capacity of the intersection for a particular movement (i.e., in a particular direction). The capacity for a given movement is determined by the percentage of time the traffic signal is green. Occasionally sections of a roadway between intersections may be narrower (less lanes) than other portions of the roadway and create bottlenecks at location,s other than intersections. Ramps to freeways may limit the capacity of the freeway to accommodate traffic. A freeway (which would have at least 2 lanes in each direction) with a single one-lane entrance ramp can never reach capacity. Of course, if evacuation traffic has more than one access point to a freeway, then the freeway itself may reach its capacity.

Adverse Weather

Adverse weather conditions (rain, snow, ice, and fog) reduce roadway capacity. In addition, adverse weather also reduces the speed of vehicles. Severe snow or ice conditions can make a roadway impassable. The time required to make a roadway suitable for evacuation must be added to the calculated evacuation time. The impact of adverse weather conditions should be assessed at the time a decision to evacuate is being made.

A few studies (Jones et al. 1969, Hall and Barrow 1988) have addressed roadway capacity under adverse conditions. Rain reduces capacity 10 to 20 percent. Snow reduces capacity 10 to 30 percent. The effect is determined by the intensity of the rain or snow fall. The larger capacity reductions have occurred for rates of sin or snowfall that are likely to be of brief duration. Weather-related capacity reductions of 20-25 percent are typically used in current evacuation studies.

Accidents

Evacuation time estimate studies normally include no special analyses of the effects of traffic accidents because accidents and breakdowns are relatively rare events. During an evacuation, accidents and breakdowns are so few (no more than in normal traffic) that there is no realistic or useful way to account for their effect in an evacuation time estimate. Planners usually minimize the potential impact of traffic accidents and breakdowns on evacuation time estimates by providing for tow bucks to remove disabled vehicles if necessary. The rapid clearance of damaged or stalled vehicles will ease any negative effect on roadway capacity.

Traffic Management

The most typical means of reducing evacuation time is the implementation of traffic management. Traffic management is only implemented at locations where it is likely to be effective in reducing evacuation time. Not all nuclear power plants require detailed traffic management strategies because traffic management does not improve evacuation time at all locations. Therefore, an evacuation time estimate study provides emergency planners the means of identifying strategies and resources needed to achieve the minimum practical evacuation time. Evacuation time estimates also provide emergency planners and decision makers with information necessary to make informed decisions.

Traffic management involves the implementation of traffic control such as the direction of traffic by traffic management personnel or discouraging certain traffic movements by use of traffic cones or barricades. Traffic management is undertaken to improved traffic flow on the roadway network.

Traffic management might involve the limited use of capacity enhancement methods, such as the provision of an additional lane at a heavily congested intersection or converting a particular road to one-way traffic. Converting all the roads leading out of the EPZ to one-way traffic is not an acceptable alternative because of the need to provide access to the emergency planning zone for emergency workers.

Traffic management is a resource intensive process and its potential to improve evacuation traffic flow is usually limited by the availability of personnel and equipment. Traffic control plans must detail the locations, strategies and resources required to carry out specific traffic management activities so that personnel carrying out the traffic management actions understand the goals.

Access control is a type of traffic management. It is necessary to discourage entry into the emergency planning zone by those who do not belong there. Access control measures serve to restrict traffic not associated with an evacuation and keeps it from affecting the flow of evacuation traffic.

Roadway Construction

The impact of roadway construction is usually not considered in developing evacuation time estimates because construction disruption due to construction is usually temporary and dynamic in nature. Roadway construction can greatly affect capacity of some segments of the roadway network at certain times. However, decision makers must consider these effects on a case by case basis. Knowledge of the sensitivity of the evacuation network to changes in demand or capacity provides decision makers the necessary information to assess the impacts of a variety of conditions, including construction activities.

Driver Behavior

It has been widely observed that during an evacuation, drivers tend not to panic (Witzig and Shillenn 1987), but act in a manner that promotes good traffic flow. They tend to obey the rules of the road and act in an orderly manner during evacuations. Furthermore, it is likely that the best driver in the family will be driving during the evacuation of a family group.

Radial Dispersion

In general, evacuees will move in a direction radially away from the power plant. Evacuation routing should not be contrary to the desired radial dispersion solely for the purpose of more effectively using available roadway capacity. However, in some cases it will be necessary, due to the available roads, for evacuees to move *towards* the power plant for some part of their trip out of the area.

Relocation Centers

A portion of the evacuation traffic will go to pre-identified relocation centers. Relocation centers are located at least 5 miles and preferably 10 miles beyond the plume exposure emergency planning zone. Good traffic circulation in the area around relocation centers should be a factor in the selection of facilities to serve as centers. To the extent practicable, selection of a particular facility to serve as a relocation center should not cause overloading of any portion of the evacuation network.

Trip Generation Time

The population within an emergency planning zone will exhibit a variety of different characteristics. For estimating purposes, it is usually divided into segments having similar travel characteristics during an evacuation. Two major groups are those using personal autos to evacuate and those that require special transportation. These groups can be divided further by location and time of day.

"Trip generation time" is the interval between the issuance (notification) of an order to evacuate and the beginning of the response, i.e., travel out of the emergency planning zone. Trip generation time includes the: activity of preparation. The trip generation time will vary depending on the location where notification is received by each evacuee.

Trip generation activities are either independent (can occur in parallel) or dependent (must occur in series). For example, a person can not prepare to leave home until they arrive home; these are dependent events. However, the spouse can be making preparations to leave while the worker is returning home; these are independent activities.

The preparation time required by an individual varies by activity. The time required for the same activity also varies by individual. It is, therefore, necessary to identify the relationships of the various events (begin notification, awareness of accident, leave work, arrive home, leave home). The distribution of times for the various activities is then determined, as individuals will each have different time requirements. One example of this process is a person at work who must return home before beginning evacuation. Table 1 shows the events associated with trip generation for an individual at work.

Table 1. Example of Events

Event Number	Event Description
1	Initiate notification
2	Awareness of accident
3	Depart work
4	Arrive home
5	Leave home

The normal sequence of evacuation events during working hours is 1,2,3,4,and 5. However, if the individual was at home (weekend or night time), the sequence of events is 1,2, and 5. The trip generation time required for individuals is simply the sum of the times required for each activity associated with the sequence of events. The time required for event sequence 1-2 is the time required for the activity "receive notification". The time required for event sequence 2-3 is the time required for the activity "prepare to leave work". The time required for event sequence 3-4 is the time required for the activity "travel home". Finally, the time required for event sequence 4-5 is the time required for the activity "prepare to leave home".

If everyone had the same time requirements for each activity, the process of estimating trip generation would be straightforward. It would only be necessary to add the times required to complete each activity. If roadway capacity is not a limiting factor, simply adding up the maximum times required for each activity would yield the time required for the last person (the one taking the longest time) to be ready to leave.

Because different individuals have different time requirements, the time required by the person taking the longest time is obviously longer than that required by many individuals. If the capacity of the roadway system is the limiting factor, assuming everyone requires the maximum trip generation time will result in overestimating the evacuation time, because some individuals would have actually left earlier. The use of distributions is desirable to avoid overestimating evacuation time for emergency planning zones where road capacity affects evacuation time.

To account for the time required by different individuals to perform an activity, a time distribution for the activity must be estimated. The probability distribution for an activity shows what fraction of the population will complete the activity in a given span of time. These probability distributions are constructed in several ways depending on the data available. Estimating the distribution from assumed average and extreme values (minimum and maximum) is a typical approach. Occasionally surveys of potential evacuees can be used to determine the appropriate distributions.

The various distributions for a given activity must be combined using compound probability. The following example illustrates the process.

The example assumes an evacuation at night from home. The events (using Table 1) are: 1) begin notification, 2) awareness of accident, and 3) leave home. Table 2 shows the warning system effectiveness in providing notification (activity 1-2). Table 3 shows the assumed time required to prepare (activity 2-5). Table 4 is the result of combining the two distributions.

Table 2. Notification Distribution (Activity 1-2)

Elapsed Time (Minutes)	Cumulative Percent Notified
5	20
10	60
15	60

Table 3. Preparation Distribution (Activity 2-5)

Elapsed Time (Minutes)	Cumulative Percent Ready to Evacuate
5	15
10	30
15	60
20	75
25	90
30	100

Table 4. Trip Generation Time

Elapsed Time (Minutes)	Cumulative Percent Ready to Evacuate
5	0
10	3
15	12
20	30
25	51
30	72
35	86
40	96
45	100

The results of combining the distributions as shown in Table 4 indicate that the maximum time required, 45 minutes, is equal to the maximum notification time (15 minutes as shown in Table 2) plus the maximum preparation time (30 minutes as shown in Table 3). The alternative analysis without distributions would ignore the roadway capacity available before 45 minutes. Without distributions, All evacuees are assumed to leave home at 45 minutes. The use of distributions is desirable in estimating evacuation times for emergency planning zones where roadway capacity causes delays to those evacuating.

Analysis Tools

The analysis simply involves estimating the number of vehicles that will evacuate during each of several time periods and comparing those numbers (the demand) with the roadway capacity. The analysis can be done manually when populations are small and roadway systems are not complex. As evacuation demand exceeds the capacity of the roadway network, the analysis becomes more tedious. The use of computer models can reduce the computational effort and allows for the consideration and refinement of more alternatives.

The use of computer models requires a competent transportation analyst. The computer model does not totally represent reality, and the process of simplifying a real roadway system into a computer representation can be poorly done. The use of computers can also give a false sense of accuracy.

The IDYNEV computer model (Urbanik et al. 1988) is a public domain program that is available through the Federal Emergency Management Agency. The IDYNEV model has been successfully used at a number nuclear power plants around the United States.

Other Considerations

Evacuation time estimate studies include a number other considerations. Issues addressed in this section include assumptions, populations that are dependent on public transport, special facilities, confirmation, state and local review, and reporting.

Assumptions

A number of significant assumptions must be made in order to estimate an evacuation time for a particular situation. It may be appropriate to conduct surveys or collect site specific data upon which to base significant assumptions. However, regardless of the basis, any assumptions used should be documented. Documenting the assumptions that went into a particular evacuation time estimate allows the decision maker to better compensate for different conditions that may exist during an actual emergency.

Public Transport Dependent Populations

Some portion of any population does not own or have access to an automobile in which to evacuate. In addition, some members of the general population have special transportation needs. Those with special needs must be provided transportation using buses, vans or ambulances.

Surveys must be conducted in the EPZ to identify those requiring special transportation and determine their needs. The buses, vans and ambulances required to transport these people must then be identified.

If enough vehicles exist to transport all those requiring special transportation in a single trip, the analysis is relatively straightforward. The only questions to be answered are 1) the time required to mobilize the vehicles, 2) the time required for the vehicles to travel to their respective assignments, and 3) the time required to load the vehicles. If the time for these special evacuation vehicles to be mobilized, driven to the loading site(s), and loaded is greater than the evacuation time for the general population, the evacuation time estimate for this group will be different from that determined for the general population.

The analysis is more complicated when multiple trips are required of the special population evacuation vehicles. The complication is estimating the outbound speed of vehicles under evacuation traffic conditions. In the one-trip scenario, the special population vehicles can not be delayed beyond the time required for the last vehicle to evacuate the emergency planning zone. In the multiple trip scenario, the travel speed that is attainable may be limited by evacuation traffic on portions of the route. The out bound travel times for buses, vans, or ambulances making multiple trips must account for delays due to evacuation traffic.

There are many alternatives for providing for the transport dependent population. The final choice will depend on local circumstances and the preferences of those providing the service. The critical issues are identifying 1) the number of persons requiring transportation, 2) the available vehicles, 3) the number of trips required, 4) the mobilization time, 5) the inbound travel time, 6) the route time, and 7) the outbound travel time (taking proper account of traffic conditions).

Special Facility Populations

Special facility populations are similar to the transport dependent. The first step is to identify the location and number of persons at special facilities. The next step is determine the number of vehicles available, the number of trips required, the mobilization time, the inbound travel time, the loading time, and the outbound travel time. If multiple trips or trips to multiple facilities are required, delays due to evacuation traffic must be considered. In some cases, certain special facilities (for example, prisons) have unique requirements and evacuation planning has to take into consideration special arrangements that may be necessary such as security for the movement of prisoners.

By definition, special facilities are unique and addressed on a case by case basis because of their individual requirements. The issue is not the identification of individual evacuation time estimates for these facilities, but the determination of transportation needs, the unique requirements at each facility, and whether special facilities, as a group, will take longer to evacuate than the general population.

Confirmation Time

Confirmation that the evacuation process is effective and the public is following the order to evacuate is necessary. The primary reason for confirmation is to assure that all the population has been notified. Additional reasons include providing assistance to those having difficulties and the need for security to assure that all persons have left.

It is not possible to confirm compliance of everyone in a timely manner in plume exposure emergency planning zones with a large population. A sampling approach may be used to determine the effectiveness of notification systems, or patrols may be established to pass through the entire emergency planning zone.

The sampling approach is to determine the sample size to generate the desired confidence that the expected percentage of the population has evacuated. Statistical analysis can determine the appropriate sample size to use. A possible sampling approach is to begin calling randomly selected households one hour before the expected completion of evacuation. If no one is home at the expected number of households, then notification is determined to be effective. Otherwise, the process is repeated after the expected time of completion of evacuation. Those at home during the telephone survey can tell if any problems exist with notification, or any other unanticipated problems with transportation.

The sampling approach could be supplemented by use of vehicles passing through the emergency planning zone along planned routes. The use of vehicles driving through the emergency planning zone could also be the primary means of confirmation.

References

Hall, Fred L. and Barrow, Deanna, *The Effect of Weather on the Relationship Between Flow and Occupancy on Freeways,* Paper Presented at the 1988 Transportation Research Board Meeting, Washington, D. C., 1988.

Jones, E. Roy and Goolsby, Merrill E., *Effect of Rain of Freeway Capacity*, Texas Transportation Institute, Research Report 24-23, College Station, August 1969.

Urbanik, T., Desrosiers, A., Lindell, M. K., and Schuller, C. R., *Analysis of Techniques for Estimating Evacuation Times for Emergency Planning Zones*, NUREG/CR-1745, U. S. Nuclear Regulatory Commission, Washington, D. C., November, 1980.

Urbanik II, T., Moeller, M. P., and Barnes, K., *Benchmark Study of the I-DYNEV Evacuation Time Estimate Computer Code*, NUREG/CR-4873, U. S. Nuclear Regulatory Commission, Washington, D. C., June 1988.

———. *The Sensitivity of Evacuation Time Estimates to Changes in Input Parameters for the I-DYNEV Computer Code*, NUREG/CR-4874, U. S. Nuclear Regulatory Commission, Washington, D. C., June 1988.

Witzig, W.F. and Shillenn, J.K., *Evaluation of Protective Action Risks*, NUREG/CR-4726, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1987.

Highway Capacity Manual, Special Report 209, Transportation Research Board, Washington, D.C., 1985.