Evacuation Planning:
A Key Part of Emergency Planning

By

Reuben Goldblatt, P.E.
Principal
KLD Associates, Inc.
47 Mall Drive
Suite 8
Commack, NY 11725
(631)543-6500
(631)543-4330 (fax)
www.kldassociates.com
email: rgoldblatt@kldassociates.com

For Presentation

83rd Annual Meeting
Transportation Research Board
January 11-15, 2004

Abstract

A key element of emergency planning is evacuation planning. Originally a requirement of the nuclear power industry, evacuation planning has been extended to other venues: This includes chemical plants (especially after the incident in Bhopal, India) and military installations (particularly where chemical or biological weapons are to be destroyed). Now, in what is widely regarded as a changed world with much greater emphasis on emergency planning, evacuation planning is more important than ever.

This paper presents an overview of the evacuation planning process and discusses a number of planning issues. A case study is presented which applies the lessons learned to one of the most important evacuation planning applications in the country: The Indian Point Emergency Planning Zone in New York.

A key element of emergency planning is evacuation planning. Originally a requirement of the nuclear power industry, evacuation planning has been extended to other venues: This includes chemical plants (especially after the incident in Bhopal, India) and military installations (particularly where chemical or biological weapons are to be destroyed). Now, in what is widely regarded as a changed world with much greater emphasis on emergency planning, evacuation planning is more important than ever.

Evacuation plans must be completely responsive to the applicable guidelines and criteria promulgated by local, state, and federal agencies. In addition, the plan must meet the approval of all federal, state, and local emergency planning personnel who have jurisdictional authority. With the release of the Year 2000 Census effort and the events of September 11th, these activities take on a renewed urgency.

Evacuation Planning – Fundamental Concepts

In talking with the general public, and indeed with some professionals, there seems to be some misunderstanding of the nature and meaning of evacuation time estimates. It therefore is useful to review some of the concepts surrounding this topic.

- Evacuation Time Estimates (ETE) serve as one criterion for developing a Protective Action Recommendation (PAR). PARs are recommendations made to decision makers in an emergency. These recommendations generally involve three choices for public action: do nothing, shelter in place, or evacuate the area.

- ETE are viewed by the public as an important indication of risk.

- There seems to be some confusion distinguishing between ETE, which is an aggregate measure, and evacuation travel times.

- Mobilization Time represents the time required by evacuees to perform all their necessary preparatory activities prior to starting the trip.

- Evacuation time (ETE) and Mobilization time are both referenced to the Advisory to Evacuate.

- Mobilization and evacuation are *processes* that take place over time and space – they are not *events* that take place at a point in time.

Figure 1 presents the relationship between the evacuation time estimate (ETE) and the average evacuation travel time. The ETE is defined as the elapsed time between the transmission of an evacuation recommendation to the public at risk, and the time that the area to be evacuated is cleared. The average travel time for an evacuee is the elapsed time from the start of the evacuation trip to the time that evacuee crosses out of the area to be evacuated.

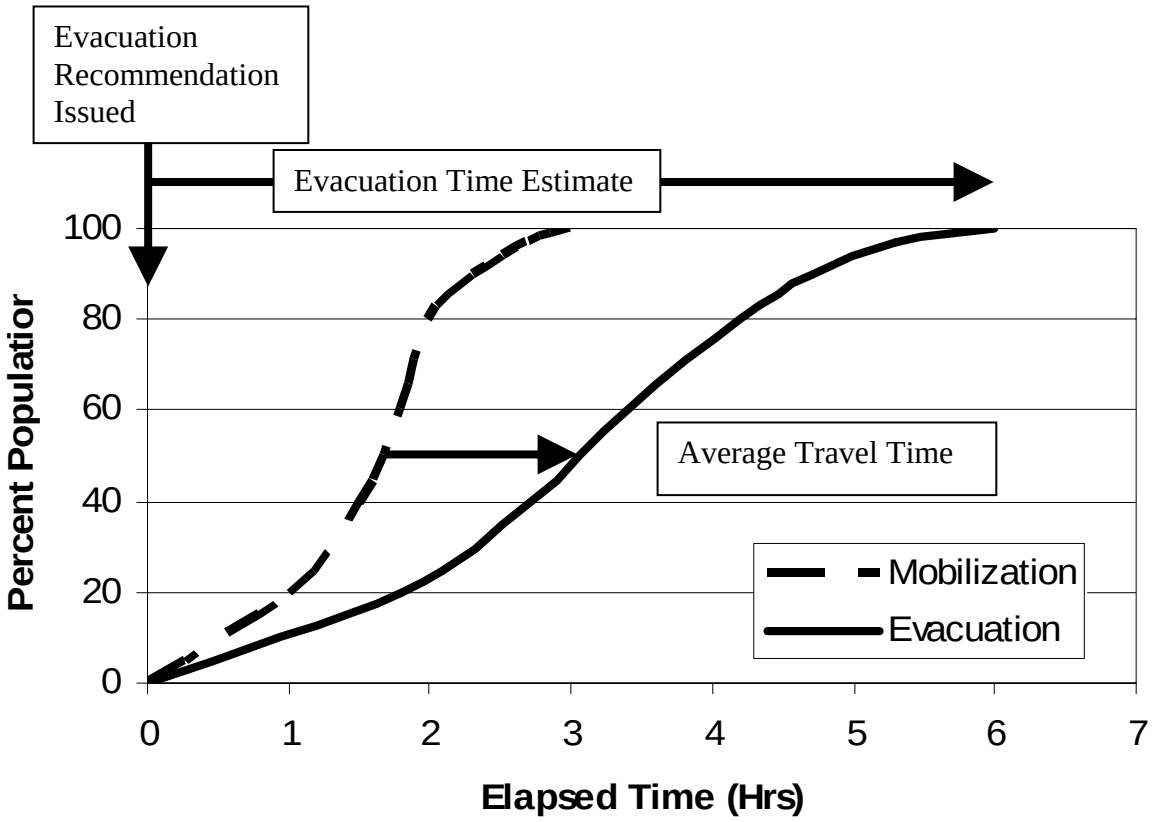

Figure 1. Relationship Between ETE and Average

The evacuation travel time depends primarily on the relationship between Traffic Demand and Highway Capacity (Supply). When Demand exceeds Capacity over some time period, travel speed declines and the traffic environment exhibits queuing (stop-and-go), which is characteristic of congested conditions. Traffic does move, but slowly.

One of the human factors responses to evacuation planning is graphically presented in Figure 2. In the case of a technological emergency or a terrorist scenario (chemical spills, radiological releases) the area to be evacuated usually takes the shape of a keyhole. A central circular area whose size is dependent on the nature of the toxic release plus an area extending outward from the central circular area in the downwind direction. The total extent of the evacuation area is dependent on the nature of the toxic release and the wind conditions (wind speed, atmospheric stability). Figure 2 presents this area as the clear-shaded area.

People who live or work in the cross-hatched region in Figure 2 may decide to voluntarily evacuate even if they are not currently at risk. However, the evacuation region could be increased to encompass portions of this area if the wind shifts and additional people are put at risk.

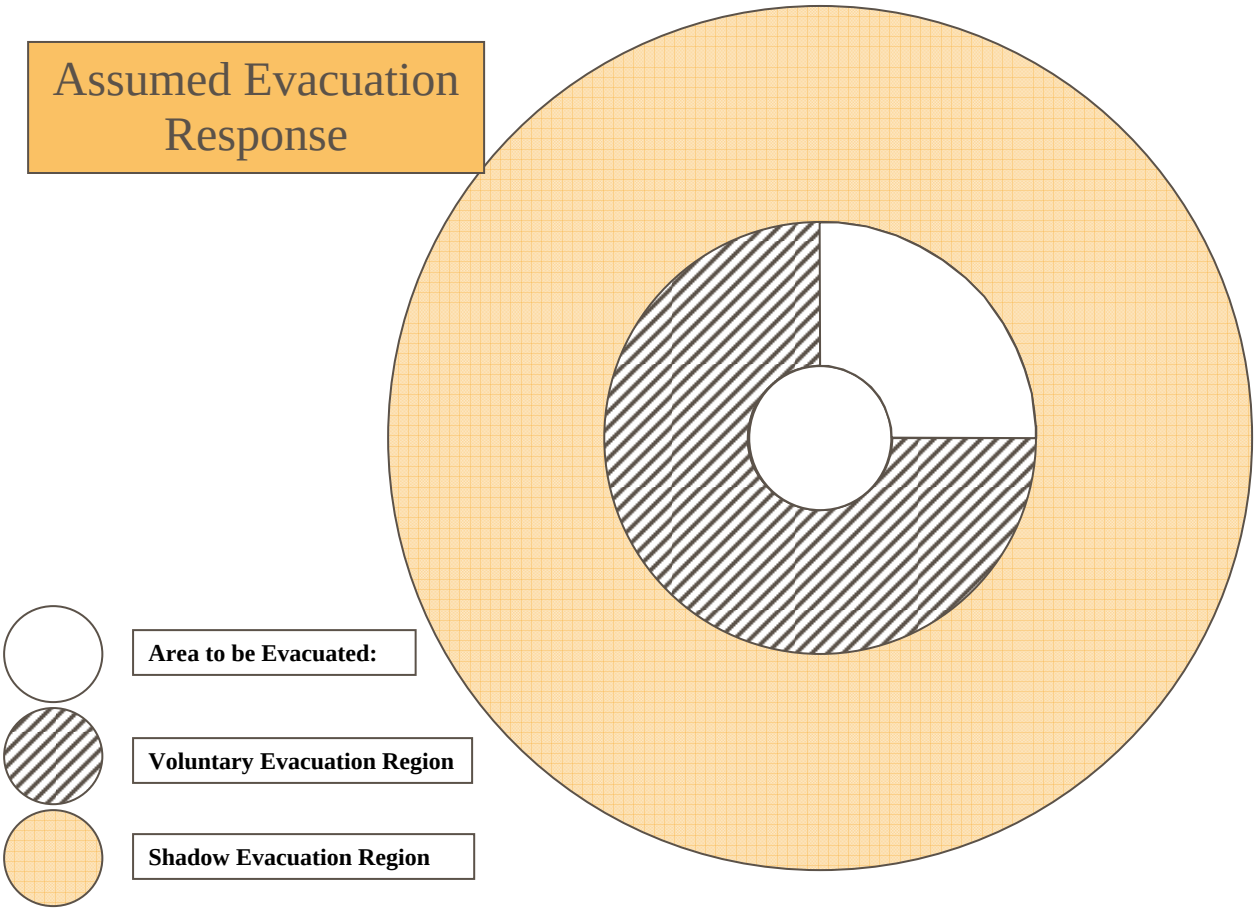

Figure 2. Public Response to Evacuation Recommendation

Finally, the shaded region in Figure 2 represents an area further removed from the area at risk, but adjacent to it. People in this area, referred to as the shadow evacuation area, might choose to relocate to areas further from the source of the hazard due to their personal perception of risk. Proper treatment of the voluntary evacuation area and the shadow evacuation area are required to introduce the effects of potential traffic congestion in these areas that would delay the departure of evacuees from the central area at risk.

Evacuation Planning Methodology

Good evacuation planning methodology involves an iterative process to identify the best evacuation routes and to estimate the time required to evacuate the area at risk. Some of the steps in this methodology are discussed here:

- Identify the region to be evacuated: keyhole or circular. Regions are defined as subsets of the entire area at risk. Usually they are comprised of groups of emergency response planning areas (ERPA). Regional configurations can be defined on the basis of wind direction and speed.

- Identify the demand (in vehicles) over the area to be evacuated and the voluntary and shadow evacuation areas. Demand population can be subdivided into permanent residents, employees who work in the area a risk, and transients who are passing through the area or staying in the area temporarily. This demand is distributed to zonal centroids which describe the changes in population density over the area.

- Sub-divide Time into "Time Periods" to represent the variation of demand over time.

- Estimate highway link capacities based on field survey observations and on scenario-based weather conditions

- Define the candidate destinations on the periphery of the region for each origin centroid. These destinations represent the points where network links cross the outer boundaries of the region.

- Apply a traffic distribution and assignment model to compute the optimal routing of evacuation trips out of the region via the specified destination nodes.

- A traffic simulation model is then applied to simulate the movement of vehicles during the course of the evacuation. The model should explicitly describe traffic conditions in the saturated flow regime to account for congestion effects.

- The ETE is the elapsed time for the evacuating traffic originating within the evacuation region, to leave that region. Note that the time it takes to travel to a destination (reception center, home of a relative, etc.) once the evacuee departs the area at risk is not a component of the ETE.

- Review simulation results to determine the need for traffic management to support the evacuation movements.

- Introduce the traffic management tactics to the simulation and repeat the ETE analysis.

Computer Modeling

Evacuation simulation can be performed with either microscopic models or with macroscopic models. Micro models move individual vehicles through a network. These vehicles have their own characteristics and their drivers respond to the presence of other vehicles, traffic control devices, and their need to follow a specific route. Macro models operate not on individual vehicles but on overall traffic flow on a given link of the network. The tradeoffs between Micro and Macro models are generally that Micro models provide a more detailed simulation at the expense of computing speed, whereas macro models are capable of simulating large areas operating under high traffic conditions very quickly. As the developers of both microscopic and macroscopic models, KLD Associates Inc. has used both classes of models for evacuation purposes.

A comparison between microscopic and macroscopic modeling was recently conducted based upon an evacuation study conducted for the Nine Mile Point Nuclear Power Station in New York State. The network consisted of 964 links. Comparison statistics are present in Table 1. Table 1 indicates that the evacuation time estimates produced by both models are similar (less than a 5% difference). However, the microscopic model took 300 times the running time to produce these results.

The table indicates that where large networks are involved and/or large numbers of evacuation scenarios must be studied the macroscopic modeling approach provided reasonable accuracy at a significantly higher level of software efficiency. This level of efficiency makes the macroscopic modeling approach a candidate for use in real-time emergency planning applications.

Table 1. Comparison of Microscopic and Macroscopic Evacuation Modeling

Measure of Effectiveness	Microscopic Model (WATSim)	Macroscopic Model (PCDYNEV)
Vehicles Evacuated	35,834	37,238
Evacuation Time Estimate	5:30	5:15
Software Running Time	2100 Seconds	7 Seconds

The PCDYNEV Evacuation Planning System is comprised of two principal models: TRAD and IDYNEV. TRAD is an Integrated Traffic Assignment and Distribution Model using user-equilibrium theory that yields link turn percentages at each node. To apply TRAD, the analyst specifies the highway network, the volume of traffic generated at all origin centroids, a set of candidate destination nodes on the periphery of the area to be evacuated for each origin and the capacity (i.e., "attraction") of each destination node. TRAD then calculates the optimal trip distribution and the optimal trip assignment (i.e., routing) of the traffic generated at each origin node to the associated set of candidate destination nodes, so as to minimize evacuee travel times.

The underlying premise of TRAD is that the selection of destinations and routes is intrinsically

coupled in an evacuation scenario. That is, people in vehicles seek to travel out of an area of potential risk as rapidly as possible by selecting the "best" route. The model is designed to identify these "best" routes in a manner that distributes vehicles from origins to destinations and routes them over the highway network, in a consistent and optimal manner.

IDYNEV is a macroscopic simulation model based upon a model named CORFLO (also known as TRAF LEVEL II), developed by KLD Associates, Inc. for FHWA. Briefly, it describes traffic flow in the form of time-varying statistical histograms on each link. The IDYNEV simulation model employs a dynamic routing feature that over-rides the TRAD-generated turn movements under certain conditions to reflect driver behavior. For example, if an evacuation route reaches a point on the network topology where two routes diverge and one of those routes is congested, then vehicles destined for the congested route will divert to the alternate route. The destination on the periphery of the area for those vehicles diverted may be changed, but the objective of leaving the area at risk in the shortest time will be satisfied.

The PCDYNEV System is completed by the use of a computer graphics display program that can be used to show animated evacuation presentations. Figure 3 presents a sample of an animation frame. Highway links are color coded by their Level of Service. Severe traffic congestion is shown as red colored links. This information can be used by the analyst to identify the need for traffic control to support the evacuation traffic flow.

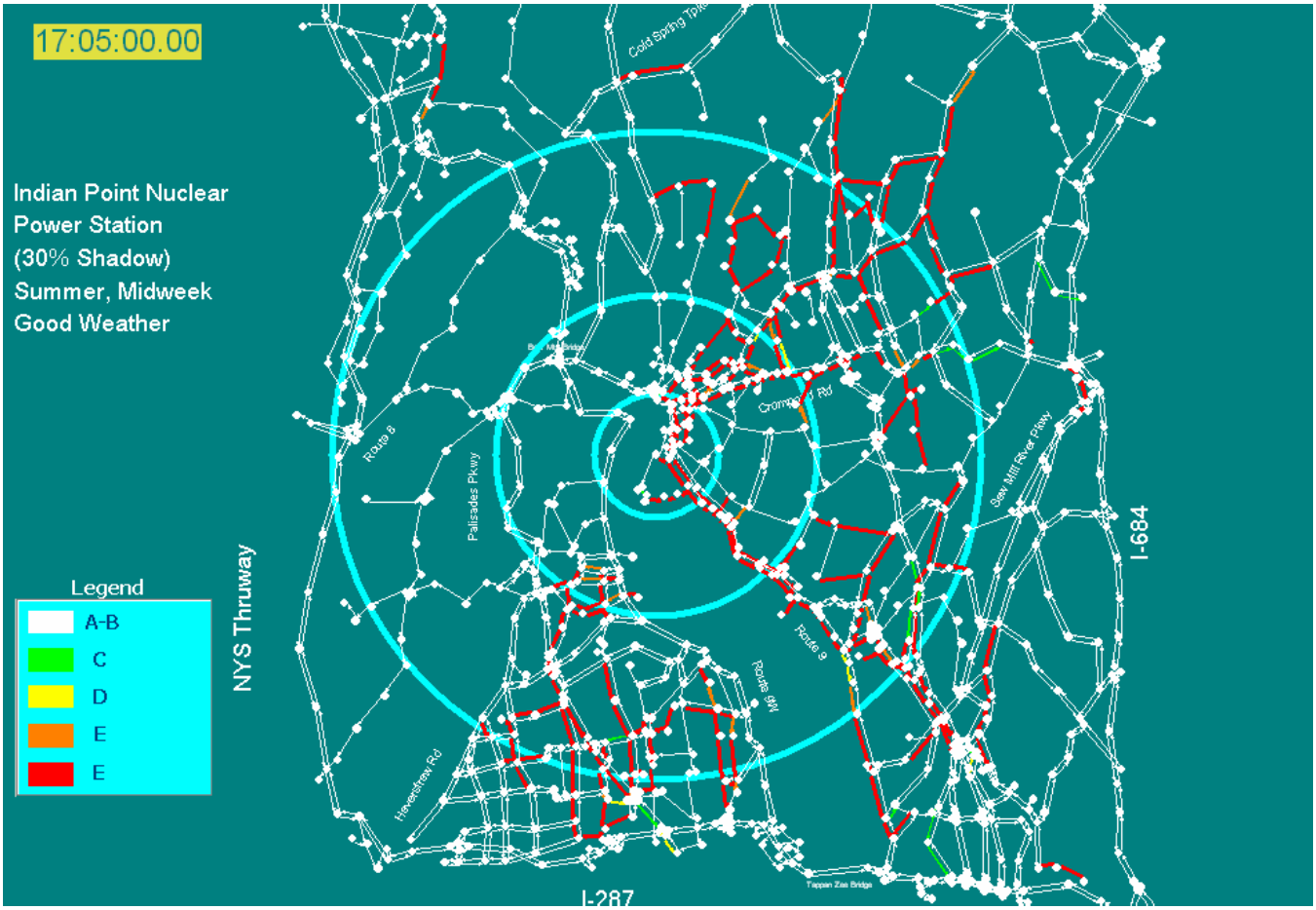

Figure 3. Sample PCDYNEV Animation Display Showing Traffic Congestion During an Evacuation

Evacuation Traffic Management Plans

The development of a traffic control and management strategy, designed to expedite the movement of evacuating traffic, is a critical part of the evacuation planning process. The resources required to implement this strategy include:

- Personnel with the capabilities of performing the planned control functions of traffic guides.
- Equipment to assist these personnel in the performance of their tasks:
  - Traffic Barriers
  - Traffic Cones
  - Signs
- A plan that defines all necessary details and is documented in a format that is readily understood.

The functions to be performed in the field are:

1. Facilitate evacuating traffic movements that serve to expedite travel out of the EPZ along routes that the analysis has found to be most effective.

2. Discourage traffic movements that permit evacuating vehicles to travel in a direction which takes them significantly closer to the power station, or which interferes with the efficient flow of other evacuees.

We employ the terms "facilitate" and "discourage" rather than "enforce" and "prohibit" to indicate the need for flexibility in performing the traffic control function. There are always legitimate reasons for a driver to prefer a direction other than that indicated. For example:

- A driver may be traveling home from work or from another location, to join other family members preliminary to evacuating.
- An evacuating driver may be taking a detour from the evacuation route in order to pick up a relative. The driver may be an emergency worker en route to perform an important activity.

The implementation of a plan must also be flexible enough for the application of sound judgment by the traffic guide. Figure 4 presents a typical traffic control point drawing. This drawing is designed to be

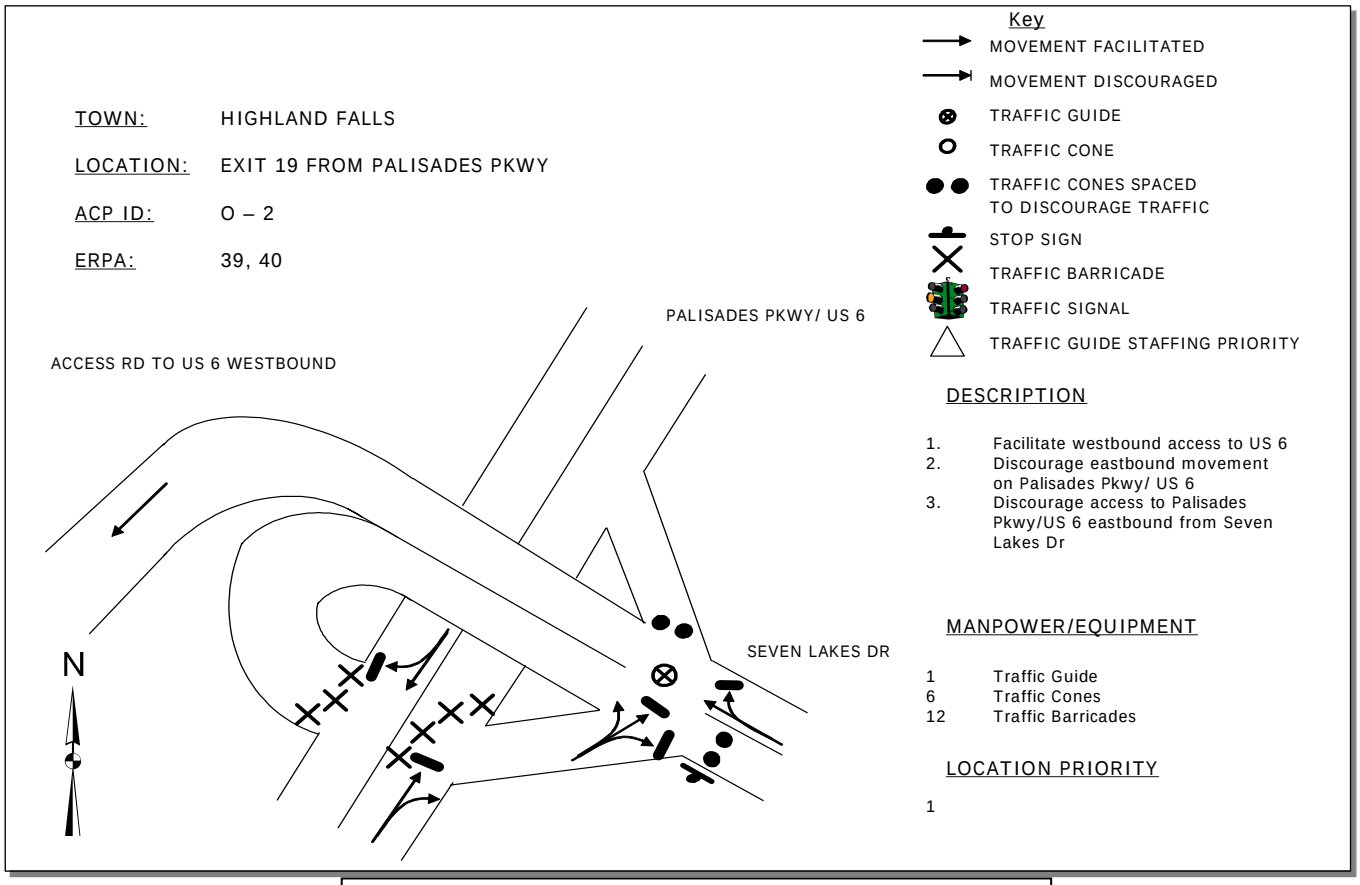

Figure 4. Traffic Control Point Diagram

distributed to field personnel to assist them in setting up the proper traffic control at a given location.

Evacuation Planning Case Study

The Indian Point Energy Center (IPEC) is located on the eastern shore of the Hudson River, in Westchester County, New York. The site is situated approximately 24 miles north of New York City. The Emergency Planning Zone contains parts of four New York State counties: Orange, Putnam, Rockland, and Westchester. Figure 5 presents a map showing the location of the site.

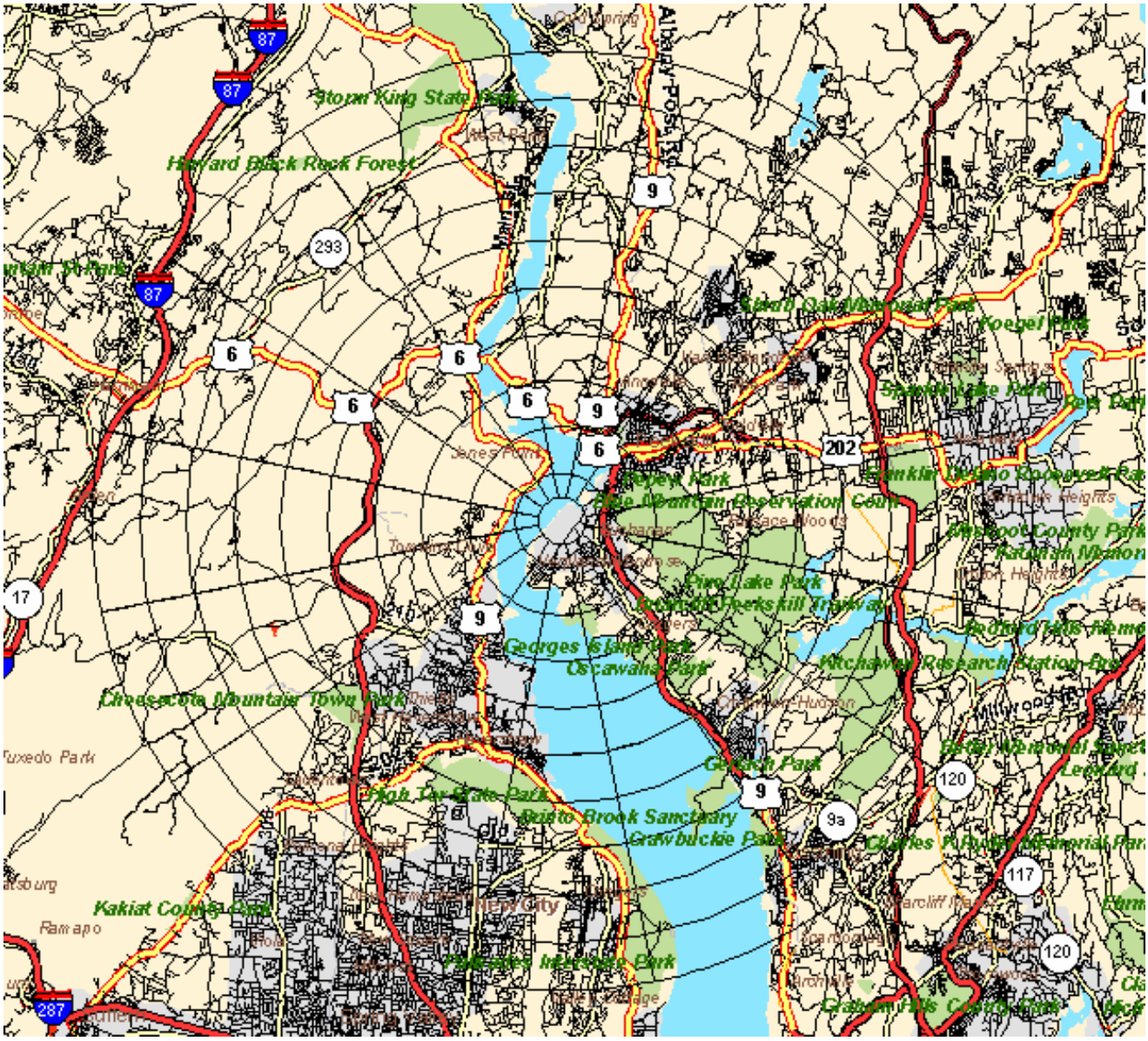

Figure 5. Indian Point General Site Area

The Indian Point Emergency Planning Zone (EPZ) is subdivided into 51 Emergency Response Planning Areas (ERPA). Figure 6 presents these areas. The ERPA were defined by a combination of geographical, topological, and political features of the area.

Table 2 presents estimates of the EPZ population in each of three population categories.

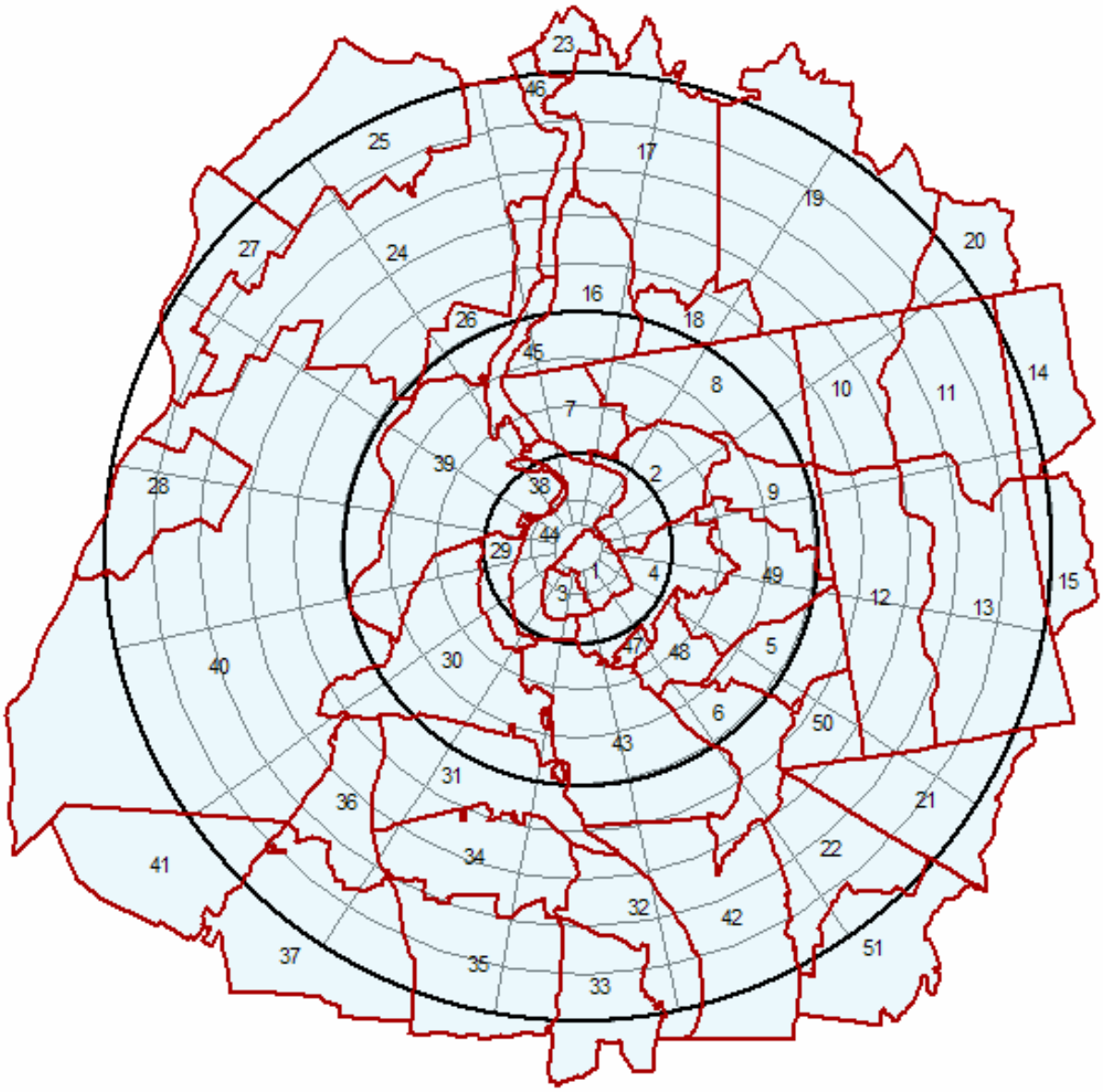

Figure 6. Indian Point Emergency Response Planning Areas (ERPA)

Table 2. Current Population Estimates by Category

	Residents		Employees		Transients	
ERPA	People	Vehicles	People	Vehicles	People	Vehicles
1	2,206	968	979	915	-	-
2	22,826	10,010	2,739	2,560	138	69
3	1,294	568	39	37	-	-
4	3,592	1,575	949	887	1,250	436
5	973	734	-	-	-	-
6	7,713	3,383	689	644	6,724	2,943
7	188	83	185	173	-	-
8	11,338	5,363	659	616	-	-
9	4,559	1,999	153	143	76	38
10	8,152	3,575	1,709	1,598	-	-
11	18,382	8,404	830	776	1,981	767
12	3,153	1,383	1,983	1,854	222	50
13	7,240	3,175	5,655	5,286	12,101	3,401
14	2,732	1,155	102	96	-	-
15	1,305	572	3,006	2,810	-	-
16	553	227	335	320	262	46
17	2,005	822	-	-	80	25
18	3,675	1,117	10	10	-	-
19	7,127	2,921	188	180	-	-
20	4,275	1,454	5,070	4,829	-	-
21	4,863	2,133	5,856	5,473	-	-
22	29,936	13,130	3,524	3,294	759	587
23	2,625	1,076	533	508	11	5
24	7,360	1,400	1,980	1,851	292	97
25	962	430	834	780	-	-
26	5,523	2,466	565	529	383	188
27	2,270	1,014	35	33	-	-
28	54	24	-	-	11,856	5,891
29	1,170	436	-	-	-	-
30	13,271	4,954	151	142	753	224
31	33,267	12,416	2,662	2,488	370	105
32	5,089	1,899	234	219	5,133	1,093
33	10,864	4,052	2,147	2,007	40	60
34	7,602	2,838	342	320	-	-
35	24,235	9,044	8,543	7,985	485	300
36	2,662	993	1,380	1,290	-	-
37	23,763	8,868	10,993	10,274	-	-
38	61	23	-	-	-	-
39	20	7	-	-	8,157	3,502
40	579	216	426	399	17,063	4,690
41	178	66	-	-	-	-
42-46	Hudson River		Hudson River		Hudson River	
47	337	148	-	-	-	-
48	3,540	1,246	231	216	-	-
49	2,866	1,257	6	6	230	12
50	479	210	116	109	771	262
51	8,412	3,690	8,219	7,682	1,254	826
Total	**305,276**	**123,524**	**74,057**	**69,339**	**70,391**	**25,617**

Table 3 presents the 14 evacuation scenarios that were studied. Each scenario represents a combination of factors which can affect either the evacuation demand or the roadway capacity. For example, a summer, weekend, midday scenario would represent a peak transient population condition, with state and local parks, campgrounds, etc operating at capacity. Winter, midweek scenarios involve schools in session and require the evacuation and/or relocation of school children as part of the general evacuation. Weather conditions affect the capacity of the roadway. Rain and/or snow conditions can reduce free-flow highway speeds by 10-15% and reduce highway capacities by a similar amount. Scenarios 1 and 2 represent the peak evacuation population scenarios. Under these conditions, a full evacuation of the entire EPZ would involve over 300,000 vehicles; 239,000 vehicles will be evacuating from the area at risk, while an additional 63,000 vehicles will be moving in the shadow evacuation region.

Table 3. Evacuation Scenarios

Scenario	Season	Day of Week	Time of Day	Weather	Special
1	Summer	Midweek	Midday	Good	None
2	Summer	Midweek	Midday	Rain	None
3	Summer	Weekend	Midday	Good	None
4	Summer	Weekend	Midday	Rain	None
5	Summer	Midweek, Weekend	Evening	Good	None
6	Winter	Midweek	Midday	Good	None
7	Winter	Midweek	Midday	Rain	None
8	Winter	Midweek	Midday	Snow	None
9	Winter	Weekend	Midday	Good	None
10	Winter	Weekend	Midday	Rain	None
11	Winter	Weekend	Midday	Snow	None
12	Winter	Midweek, Weekend	Evening	Good	None
13	Winter	Weekend	Midday	Good	West Point Football
14	Spring	Midweek	Midday	Good	West Point Graduation

Figure 7 presents the shadow evacuation region used for the Indian Point studies. The shadow region extended from the outer boundary of the EPZ to the surrounding Interstate highways.

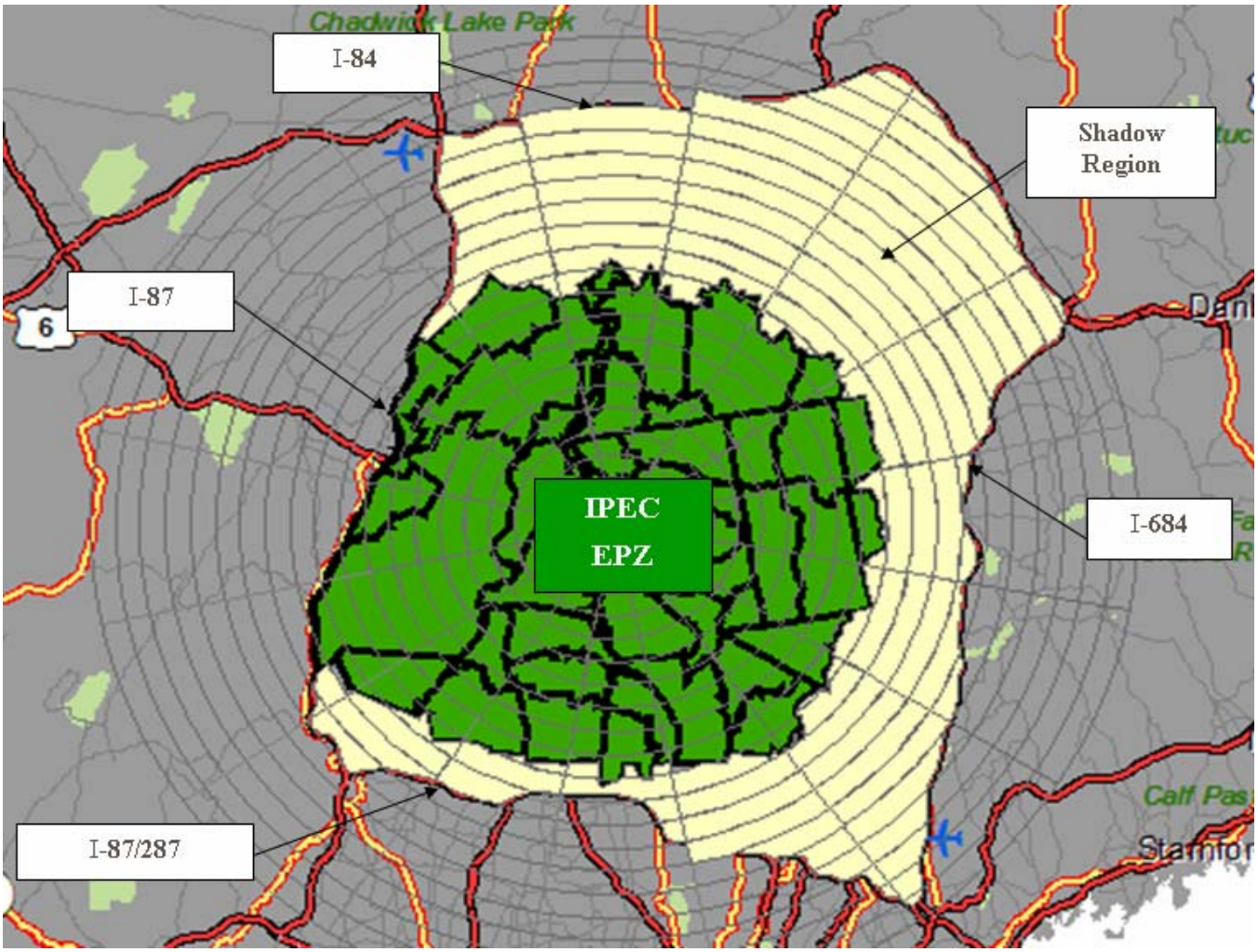

Figure 7. Indian Point Shadow Evacuation Region

The Indian Point EPZ was subdivided into 35 Evacuation Regions .Regions R1 through R3 represent ERPAs within 2 miles, 5 miles, and the full EPZ, respectively. Regions R4 through R19 represent ERPAs within 2 miles, extending to 5 miles downwind. Finally, Regions R20 through R35 represent ERPAs within 5 miles, extending to 10 miles downwind

Evacuation Time Estimate Results

Table 4 presents a sample of the ETE results for the Indian Point Case Study. Note that the evacuation time estimates for the entire EPZ (Region 3) range from just over 7 hours to about 12 hours. The ETEs for rain and snow scenarios tend to be higher than for the equivalent good weather scenarios as expected. Further, the difference in time between the public mobilization activities and

the resultant ETEs is directly attributable to the presence of significant highway congestion during the evacuation.

Table 4. Sample ETE Results

Evacuation Time Estimates - 100th Percentile

	Summer		Summer		Summer		Winter			Winter			Winter		Winter	Spring
	Midweek		Weekend		Midweek Weekend		Midweek			Weekend			Midweek Weekend		Weekend USMA Football	Midweek USMA Graduation
	Midday		Midday		Evening		Midday			Midday			Evening		Midday	Midday
Region	Good Weather	Rain	Good Weather	Rain	Good Weather	Region	Good Weather	Rain	Snow	Good Weather	Rain	Snow	Good Weather	Region	Good Weather	Good Weather
Entire 2-Mile Region, 5-Mile Region, and EPZ																
R1	4:55	5:30	4:50	5:25	4:45	R1	5:15	5:15	6:50	4:55	5:30	5:55	4:30	R1	5:30	5:15
R2	6:20	7:10	5:55	6:45	5:25	R2	6:20	7:00	8:00	5:55	6:25	7:20	5:25	R2	6:30	6:20
R3	9:25	10:30	8:50	9:30	7:15	R3	9:30	10:55	12:00	7:55	8:50	10:10	7:10	R3	8:45	9:30
2-Mile Ring and Keyhole to 5 Miles																
R4	5:45	6:20	5:10	5:35	4:50	R4	5:45	6:25	7:30	5:15	5:30	6:35	4:45	R4	5:55	5:45
R5	6:00	6:45	5:25	5:50	5:15	R5	6:10	7:00	8:00	5:25	5:45	7:10	5:15	R5	5:55	6:10
R6	6:00	6:45	5:25	5:50	5:15	R6	6:10	7:00	8:00	5:25	5:45	7:10	5:15	R6	5:55	6:10
R7	6:10	6:40	5:20	5:50	5:10	R7	6:10	6:45	8:00	5:20	5:40	7:05	5:15	R7	6:00	6:10
R8	6:10	6:35	5:20	5:50	5:10	R8	6:05	6:45	8:00	5:20	5:45	7:10	5:15	R8	6:00	6:05
R9	5:55	6:25	5:55	6:40	4:35	R9	6:00	6:30	7:35	5:10	5:30	6:45	4:35	R9	6:00	6:00
R10	5:25	5:45	5:55	6:40	4:25	R10	5:20	5:55	6:45	4:40	5:25	5:55	4:25	R10	5:30	5:20
R11	6:20	6:55	5:55	6:40	5:25	R11	6:20	6:55	7:45	5:55	6:20	7:20	5:25	R11	6:30	6:20
R12	6:20	6:55	5:55	6:40	5:25	R12	6:20	6:55	7:45	5:55	6:20	7:20	5:25	R12	6:30	6:20
R13	6:20	7:10	5:55	6:45	5:25	R13	6:20	6:55	7:40	5:55	6:25	7:15	5:25	R13	6:30	6:20
R14	6:20	7:10	5:55	6:45	5:25	R14	6:20	6:55	7:40	5:55	6:25	7:15	5:25	R14	6:30	6:20
R15	6:20	7:10	5:55	6:45	5:25	R15	6:20	6:55	7:40	5:55	6:25	7:15	5:25	R15	6:30	6:20
R16	5:25	5:40	4:50	5:10	4:25	R16	5:10	5:45	6:45	4:45	5:30	5:55	4:25	R16	5:30	5:10
R17	5:25	5:40	4:50	5:10	4:25	R17	5:10	5:45	6:45	4:45	5:30	5:55	4:25	R17	6:50	5:10
R18	5:20	5:40	4:50	5:15	4:25	R18	5:15	5:50	6:45	4:45	5:30	5:50	4:25	R18	6:50	6:00
R19	5:40	6:20	4:55	5:30	4:45	R19	5:40	6:35	7:30	5:15	5:30	6:35	4:45	R19	5:55	5:40

Figure 8 presents a graphical display of the Evacuation Time Estimate for a given scenario. Each curve represents the time to clear the indicate radius. Points are located on each curve to identify the 50th, 90th, and 95th percentiles.

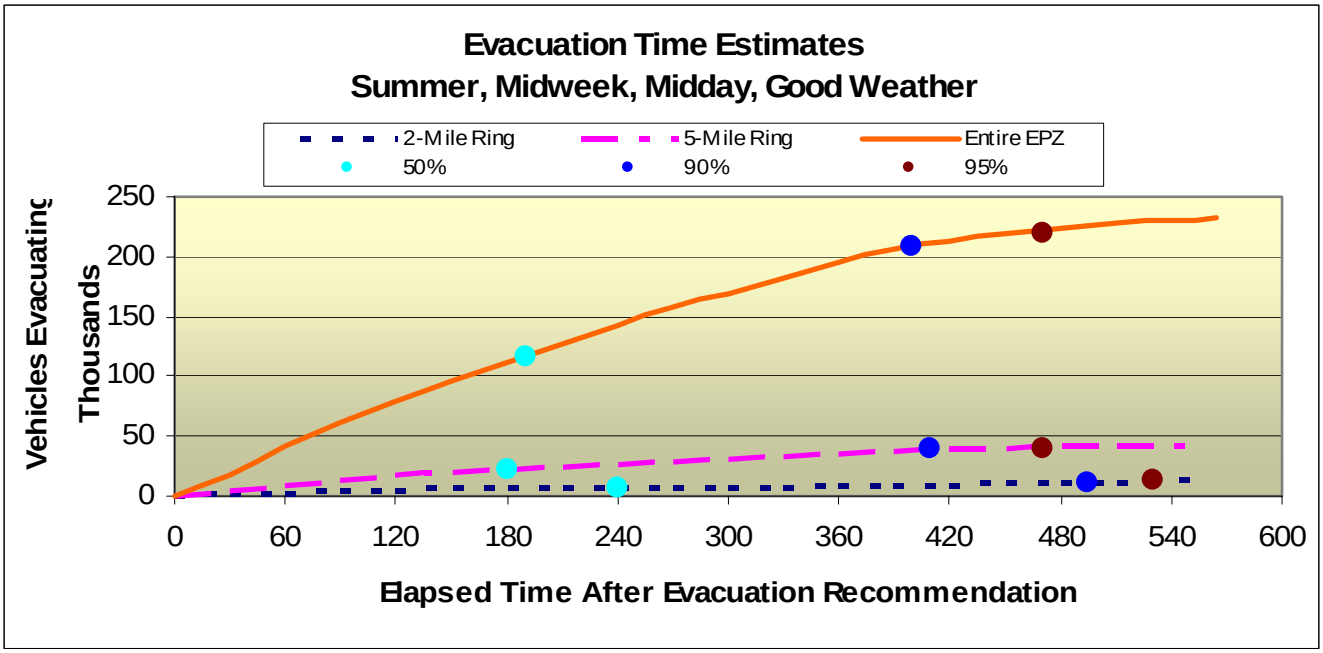

Figure 8. Evacuation Time Dynamics For A Single Scenario

Future Directions in Evacuation Planning

The evacuation planning performed for the case study can be characterized as planning for a fixed infrastructure facility. In the case of nuclear power stations, the extent of the EPZ is defined in accordance with federal guidelines. Such a planning process would suffice for any fixed facility such as chemical plants, toxic material storage sites, refineries, etc.

There is a continuing need to upgrade these procedures to make them amenable to emergencies that can occur at sites other than at fixed facilities. Transportation accidents can occur almost anywhere, likewise, terrorist attacks would require a fast response from emergency personnel. An emergency planning system would be required that could be used in real-time to plan evacuations. Given the location and the nature of the threat, the system should have all necessary information in its database to generate evacuation routing and traffic management plans. Such a system would require the evacuation models to be fast enough to operate in real time. The system should be based upon a Geographic Information System platform so that critical facilities and resources can be quickly identified in the proximity of the incident.

In short, most of the pieces of such a system have already been developed. All that is required is to design and integrate the pieces. It should also be noted that this statement is probably easier to state than it is to accomplish.

Acknowledgements

The author wishes to acknowledge the guidance and information received from various sources during the course of the Indian Point work effort. The New York State Emergency Management Office, emergency planning personnel in Westchester, Rockland, Orange, Putnam Counties, and at Entergy Nuclear Northeast all contributed greatly to the project.