# Evacuation Time Evaluation for the San Onofre Nuclear Generating Station

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## Introduction

In June 2005 Wilbur Smith Associates (WSA) was hired by the Southern California Edison Company (SCE) to update the evacuation time evaluation (ETE) for a nuclear power plant located in Southern California. This paper presents a summary of the project process, the results, and lessons-learned from the evaluation.

## Background

The San Onofre Nuclear Generating Station (SONGS) is located in San Diego County, California, approximately four miles southeast of San Clemente and 15 miles north of Oceanside. The station is situated between Interstate 5 and the Pacific Ocean. The Southern California Edison Company, operator of SONGS, began generating electricity from Unit 1 in January 1968, from Unit 2 in August 1982, and from Unit 3 in April 1983. Unit 1 ceased generating electricity in 1992.

## Regulatory Requirements

The recommendations of Nuclear Regulatory Commission documents *NUREG-0654, Rev. 1* and *NUREG/CR-6863* suggest that the evacuation time estimates should be updated as local conditions change.

The Nuclear Regulatory Commission has requested that licensees of nuclear power plants provide information regarding time estimates for evacuation of the resident and transient population within a radius of about 10 miles from the nuclear reactor sites. This area is called the Emergency Planning Zone (EPZ). The evacuation time estimates are for use by those emergency response personnel charged with recommending and deciding on protective actions during an emergency.

The Nuclear Regulatory Commission stipulates that the EPZ must include land areas within 10 miles of the SONGS site[1]. **Figure 1** shows the 10-mile radius EPZ boundary which encompasses all of the cities of San Clemente, San Juan Capistrano, Dana Point, and a large portion of the United States Marine Corps Base, Camp Pendleton. San Juan Capistrano, and Dana Point have been included in the EPZ evacuation time estimates although the 10-mile radius actually bisects these communities. This expanded planning area, or geopolitical EPZ, is here after referred to as simply the EPZ or study area.

The previous evacuation time estimates for the SONGS area were prepared in 2000, with results documented in a 2001 study report.[2] The study included evacuation time estimates for projected 2006 area population.

[1] NUREG/CR-6863 p.4

[2] Analysis of Time Required to Evacuate Transient and Permanent Population from Various Areas within the Emergency Planning Zone, San Onofre Nuclear Generating Station, Update for 2000-2006, prepared for Southern California Edison Company by Wilbur Smith Associates, July 2001.

Moderate population growth has occurred in the area since the 2001 evacuation time analysis. Current developer activities and plans indicate that slightly more than expected new development has occurred since the 2006 projections were prepared in 2000.

**Figure 1**
**Emergency Planning Zone (EPZ)**


Source: Wilbur Smith Associates, November 2006.

## Project Overview

The project was initiated by the Southern California Edison Company. All Analyses were completed by Wilbur Smith Associates staff from the Los Angeles, San Francisco, and Salt Lake City offices. The project was completed over a period of 18 months. Contacts were made with local and regional planning agencies, County and State transportation departments, and local and county officials responsible for emergency response planning.

The principal emergency response plans reviewed for the study include:

- County of Orange Nuclear Power Plant Emergency Plan for the San Onofre Nuclear Generating Station, January 2005;
- City of San Juan Capistrano Emergency Operations Plan, February 2004; San Onofre Nuclear Generating Station Emergency Response Plan, June 2004.
- City of Dana Point Emergency Plan, January 2004;
- City of San Clemente Multi-hazard Emergency Response Plan, December 2003;
- Marine Corps Camp Pendleton Force Protection Plan, Annex C (Operations), July 2004;
- Department of California Highway Patrol, Border Division Nuclear Response Plan for the San

Onofre Nuclear Generating Station, March 2005;
- Capistrano Unified School District Emergency Guide, San Onofre Nuclear Power Plant, October 2005;

## Approach

The Southern California Edison Company requested that the evacuation time estimates reflect resident and transient populations anticipated for the area in mid-2010. For the purposes of this study, the Year 2011 was identified for future estimates. This would provide emergency response personnel with evacuation time estimates that would continue to be useful as the anticipated new development occurs within the area. The evacuation time study includes:

1. The identification of resident and transient population within the area in 2006, based upon available information, and the estimated numbers and distribution of population by 2011.
2. Identification of existing institutions which require special evacuation assistance, as well as those known new institutions planned for construction.
3. An evaluation of the evacuation routes relative to their traffic-carrying capacity during an evacuation.
4. Estimation of evacuation time requirements for the resident and transient population, and special institutions, under normal and adverse weather conditions.
5. The assessment of evacuation time requirements if major damage occurs to the primary evacuation routes as a result of an earthquake (or similar disruptive event) occurring prior to, or during, the evacuation.
6. Review and inclusion of new NUREG elements where appropriate.

Data collection included the following efforts:

1. Establishment of a study area;
2. Review of Emergency Response Plans for the various jurisdictions and agencies within the EPZ;
3. Inventory of existing highway facilities, including roadway facility type, number of lanes, operating speeds, and traffic controls;
4. Review of available demographic data, employment data, recreational facility usage and future plans and forecasts; and
5. Assembly of information for schools and special institutions within the area.

All spatially referenced data was compiled and referenced to a Geographic Information System (GIS) database. Included in this GIS database are all the features obtained or created by the project team.

## ETE Development

An Emergency Planning Zone (EPZ) structure was developed based on prevailing wind direction at the SONGS facility and grouped large areas of population and employment for evacuation time estimates. These areas are identified as Protective Action Zones (PAZs).

The estimates for population, employment, and vehicles within each PAZ were developed using the data described in the remaining sections of this paper. An estimate of population and employment by PAZ is provided in **Table 1**.

**Table 1**
**Year 2011 EPZ Population Summary**

| PAZ | RESIDENTS (ALL SCENARIOS) | NON-RESIDENTS | | | | | | GRAND TOTALS | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | SUMMER WEEKEND | | SUMMER WEEKDAY | | NIGHT | | SUMMER WEEKEND | SUMMER WEEKDAY | NIGHT |
| | | WORKER | BEACH/ VISITOR | WORKER | BEACH/ VISITOR | WORKER | BEACH/ VISITOR | | | |
| 1 | 1,349 | 62 | 14,760 | 2,225 | 7,380 | 8 | 1,476 | 16,171 | 10,954 | 2,833 |
| 2* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 10,982 | 0 | 0 | 0 | 0 | 0 | 0 | 10,982 | 10,982 | 10,982 |
| 4 | 81,795 | 5,636 | 16,468 | 13,851 | 9,166 | 949 | 1,711 | 103,899 | 104,812 | 84,455 |
| 5 | 90,821 | 8,334 | 19,560 | 19,713 | 9,956 | 987 | 1,206 | 118,715 | 120,491 | 93,014 |
| TOTAL: | 184,947 | 14,032 | 50,788 | 35,789 | 26,503 | 1,944 | 4,393 | 249,767 | 247,239 | 191,284 |

Source: Wilbur Smith Associates, November 2006

Note:

1. PAZ 2 is the Pacific Ocean. It is not possible to estimate the number of ocean going vessels that may occupy this PAZ under Year 2011 conditions; however, it is assumed that in an emergency situation the appropriate evacuation notice would be provided to any vessels within the EPZ and evacuation times would be within the total estimates ETE as summarized in the subsequent sections.

**Table 2** shows the resultant summary of vehicles by PAZ and evacuation scenario:

**Table 2**
**Year 2011 Vehicles Evacuated by Scenario**

| PAZ | RESIDENTS VEHICLES (ALL SCENARIOS) | NON-RESIDENTS VEHICLES | | | | | | GRAND TOTAL VEHICLES | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | SUMMER WEEKEND | | SUMMER WEEKDAY | | NIGHT | | SUMMER WEEKEND | SUMMER WEEKDAY | NIGHT |
| | | WORKER | BEACH/ VISITOR | WORKER | BEACH/ VISITOR | WORKER | BEACH/ VISITOR | | | |
| 1 | 337 | 52 | 5,216 | 2,184 | 2,608 | 8 | 522 | 5,605 | 5,129 | 865 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2,746 | 0 | 0 | 0 | 0 | 0 | 0 | 2,747 | 2,746 | 2,746 |
| 4 | 45,065 | 4,696 | 5,819 | 11,542 | 3,239 | 791 | 604 | 55,580 | 59,846 | 46,461 |
| 5 | 48,771 | 6,945 | 6,911 | 16,427 | 3,518 | 822 | 425 | 62,627 | 68,717 | 50,019 |
| Total | 96,919 | 11,693 | 17,946 | 30,153 | 9,365 | 1,621 | 1,552 | 126,558 | 136,438 | 100,091 |

Source: Wilbur Smith Associates, November 2006

Evacuation estimates were prepared for the following combinations of PAZs:

- PAZ 1 and 2
- PAZ 1 and 3
- PAZ 1 and 4
- PAZ 1, 3, and 4
- PAZ 1, 4, and 5

These groupings reflect communities and areas affected based on their distance from SONGS and wind direction.

Each of the five combinations of PAZ evacuations shown above were tested for the following scenarios:

- Daytime summer weekday
- Daytime summer weekend
- Night
- Adverse weather conditions
- Earthquake conditions

In addition to the scenarios described above, sensitivity tests were run for the following conditions under the daytime summer weekday condition:

- Contra-flow on I-5 - (Evacuation utilizing both sides of the freeway to allow increased vehicle capacity in a single direction of travel)
- Incident on I-5 – (A vehicle breakdown, accident, or similar event that would impact the capacity of the freeway)
- Delayed mobilization – (Population within the EPZ mobilizes for evacuation over a longer period than typical; resulting in a longer duration between the evacuation warning and all residents leaving their homes)
- 20% shadow demand – (20% of the population immediately surrounding the EPZ evacuating without specific evacuation notice)
- 80% population under earthquake conditions – (Only 80% of the population within the EPZ evacuates under an earthquake condition; the remaining 20% of the population remains in-place)
- Aggressive access control on I-5 – (Access to I-5 is limited through traffic control)

## Simulation

The previous ETE was completed using a static travel demand forecasting model. The key assumptions in the previous evacuation modeling were:

1. All evacuation routes were predetermined.
2. Specific subsectors of the evacuation area would utilize designated routes.
3. All evacuating vehicles would utilize specified routes regardless of congestion levels.
4. If capacity was unavailable on designated routes, evacuating vehicles would queue and experience delays until the congestion had dissipated.

For the purposes of this updated ETE, a dynamic simulation model was sought to more accurately reflect "real world" evacuation conditions. It was the goal of the project to identify and utilize a simulation tool that would model vehicles changing travel routes over an unspecified time-frame as congestion levels changed.

This study does not rely on specific evacuation route maps that unnecessarily imply the public should take routes which may not be the most ideal for the duration of the evacuation. Instead it relies on individual decisions of route selection that comply with traffic control points, access management plans, and actions coordinated through a supervisor.

The evacuation time assessment was conducted using DYNASMART-P. DYNASMART-P is a state-of-the-art dynamic route assignment model sponsored by the Federal Highway Administration and developed at the University of Maryland. This software package provides a blend of four step regional models and corridor level micro-simulation models.

Individual driver behavior is considered in selecting available routes, and the model attempts to route them in the most efficient manner possible. This model represents intersections on the arterial system, and ramp merges on freeways as significant constraining points. Its dynamic assignment capability allows each vehicle to determine its best path out of the area.

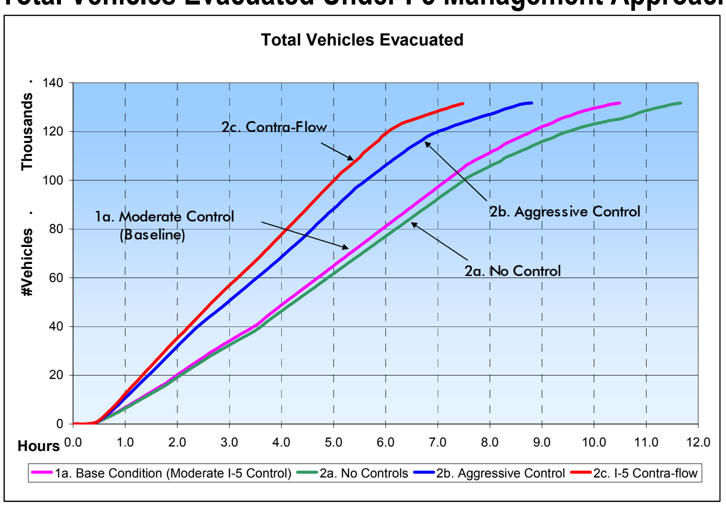
On the freeway system, it represents the stop-and-go conditions when there is overwhelming demand. Conversely, it shows that both speeds and throughput are increased when an aggressive access management plan is in place. DYNASMART-P tracks the performance of individual links, as well as reports minute by minute the number of vehicles that have successfully crossed the EPZ boundary line.

## Summary of ETE results

**Figure 2** shows how many vehicles moved beyond the EPZ boundary at each hour for several I-5 control scenarios. The point at the upper-right of each curve represents the total ETE for the respective scenario.

Compared to the no controls alternative, the existing I-5 management plan is effective at improving the ETE. The procedural action of ensuring that I-5 operates at maximum throughput improves the estimates dramatically. The addition of two contra-flow lanes is also significant but has implementation and operational issues.

**Figure 2**
**Total Vehicles Evacuated Under I-5 Management Approaches**

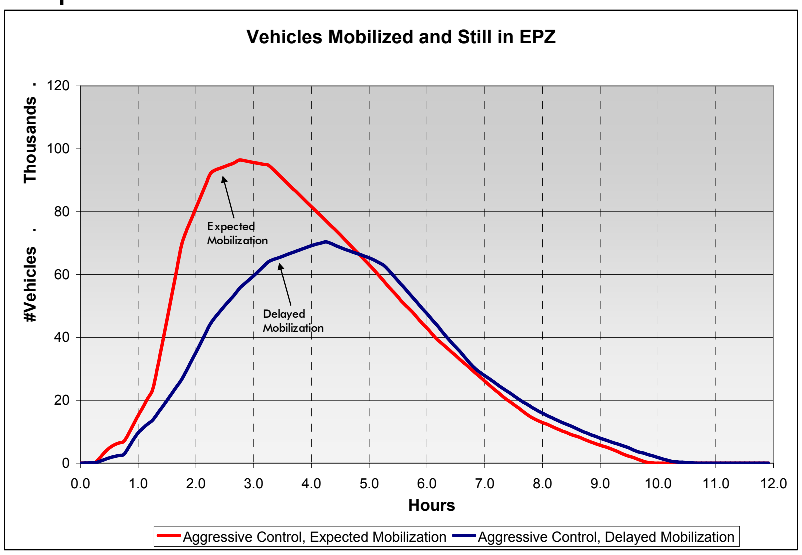



Source: Wilbur Smith Associates, 2006

**Figure 3** shows how many vehicles were mobilized, but were still in the EPZ over time. The highest curve has a lot more people stuck in traffic, while the bottom curve lets them stay at home a little longer. All vehicles from the bottom curve are fully mobilized in the fifth hour, at which point they enter congestion the same as if they had been sitting in their vehicles the whole time. The slight differences after hour five are not meaningful and can be considered noise.

Potential negative outcomes of extreme congestion may be worth considering when determining a mobilization plan. Vehicles running out of fuel, aggressive driving, and shoulder commandeering could add significant time to the evacuation and are typical of extreme congestion. Staged mobilization can reduce the potential for these negatives. While it makes no difference in the total ETE, it would make a difference to each individual.

**Figure 3**
**Comparison of Mobilization Rates**




Source: Wilbur Smith Associates, 2006

**Figure 4** shows an analysis of I-5 with various levels of access management. The second highest line (yellow) shows that aggressive I-5 access control would likely move nearly 2,200 vehicles per hour per lane (vphpl) until nearly the seventh hour, where demand starts to dissipate.

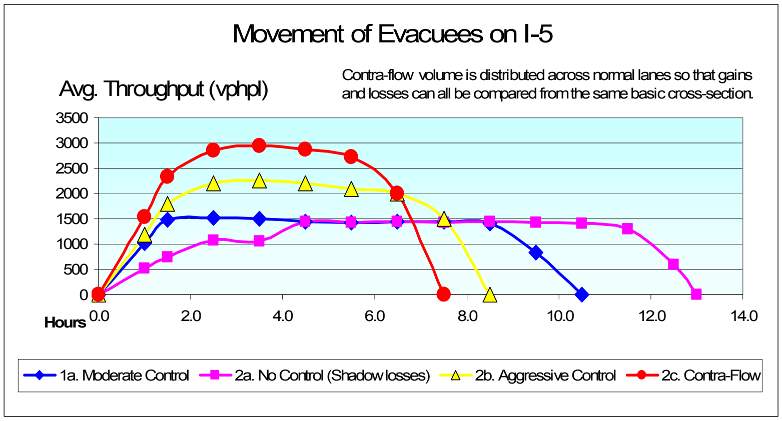
The base case line (blue) will move evacuees at about 1,500 vphpl (about 30% loss) until nearly the ninth hour, at which point demand falls off.

The no-control line (purple) shows what occurs when shadow demand can access I-5 beyond the EPZ. For the first several hours I-5 carries less than 1,500 vphpl. In reality I-5 will still move 1,500 vphpl, but many of them are not evacuees. This figure shows only evacuees. No-control would stretch the evacuation out to nearly 13 hours.

In the contra-flow scenario, the lanes do not actually carry 3,000 vphpl each. This is theoretically impossible. The total volume from contra lanes is added to the original number of lanes to make it comparable with the other scenarios.

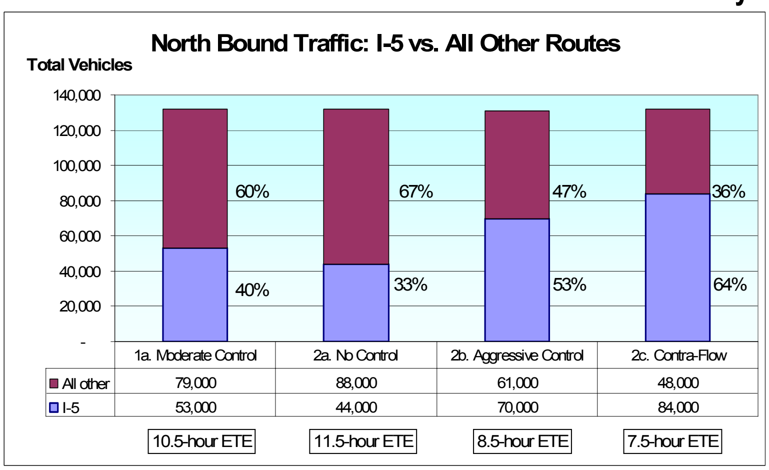
**Figure 5** is a depiction of how much of the evacuation is estimated to occur on I-5 as opposed to all other roadways for the different management scenarios. In each case there are 132,000 vehicles. In the base case 40% of the traffic is moved on I-5, while in the contra-flow case up to 64% of the traffic would use I-5.

**Figure 4**
**Average Throughput of an I-5 Lane During Evacuation Scenarios**




Source: Wilbur Smith Associates, 2006

**Figure 5**
**Relative Share of Evacuation Traffic on I-5 and Non-Freeway Routes**




Source: Wilbur Smith Associates, 2006.

**Tables 3 and 4** summarize the evacuation time results by PAZ. Data in **Table 3** provides a summary of all simulations, while **Table 4** provides a summary of the sensitivity tests performed against the daytime summer weekday evacuation condition.

**Table 3** indicates that the combination of PAZs 1, 4 and 5 take the longest time to evacuate. These regions include southern Orange County, San Clemente, Dana Point, San Juan Capistrano, and the SONGS facility. It requires 9.5 hours to evacuate these areas on a weekday. This is more than three times the evacuation time for PAZs 1 and 3, the facility and Camp Pendleton. The fact that PAZ 4 and PAZ 5 are more populated than the other PAZs is a significant contributing factor to this trend.

PAZs 1 and 4, and PAZs 1, 3 and 4 take the same amount of time to evacuate both on a weekday and during night; each taking more than seven and six hours respectively. PAZs 1 and 2, and PAZs 1 and 3, take the same amount of time to evacuate under different scenarios.

**Table 3**
**Summary of Total ETE for All Scenarios Tested**
**(Total Hours to Evacuate EPZ)**

| PAZ COMBINATION | WEEKDAY | WEEKEND | NIGHT | ADVERSE WEATHER | WEEKDAY EARTHQUAKE |
|---|---|---|---|---|---|
| PAZ 1 & PAZ 2 | 3.0 | 3.3 | 1.5 | 4.0 | 11.0 |
| PAZ 1 & PAZ 3 | 3.1 | 3.3 | 1.5 | 4.0 | 11.0 |
| PAZ 1 & PAZ 4 | 7.3 | 6.8 | 6.3 | 8.3 | 14.3 |
| PAZ 1 & PAZ 3 & PAZ 4 | 7.3 | 7.0 | 6.3 | 9.0 | 16.3 |
| PAZ 1 & PAZ 4 & PAZ 5 | 9.5 | 9.2 | 8.2 | 10.3 | 18.0 |

Source: Wilbur Smith Associates, 2006

**Table 4**
**Summary of Total ETE Sensitivity Test on Daytime Summer Weekday Conditions**
**(Total Hours to Evacuate EPZ)**

| PAZ COMBINATION | CONTRA-FLOW ON I-5 | INCIDENT ON I-5 | DELAYED MOBILIZATION | 20% SHADOW DEMAND | 80% POPULATION UNDER EARTHQUAKE CONDITIONS | AGGRESSIVE ACCESS CONTROL ON I-5 |
|---|---|---|---|---|---|---|
| PAZ 1 & PAZ 2 | 2.3 | 5.1 | 3.1 | 3.3 | 5.0 | 3.0 |
| PAZ 1 & PAZ 3 | 3.0 | 5.1 | 3.1 | 3.3 | 5.1 | 3.0 |
| PAZ 1 & PAZ 4 | 6.4 | 8.0 | 7.4 | 7.3 | 10.2 | 6.5 |
| PAZ 1 & PAZ 3 & PAZ 4 | 6.5 | 8.2 | 7.5 | 9.0 | 10.2 | 6.5 |
| PAZ 1 & PAZ 4 & PAZ 5 | 7.5 | 11.0 | 8.5 | 11.2 | 12.3 | 8.2 |

Source: Wilbur Smith Associates, 2006

**Table 4** describes the Sensitivity Tests on a summer weekday for the different combination of PAZs. In summary:

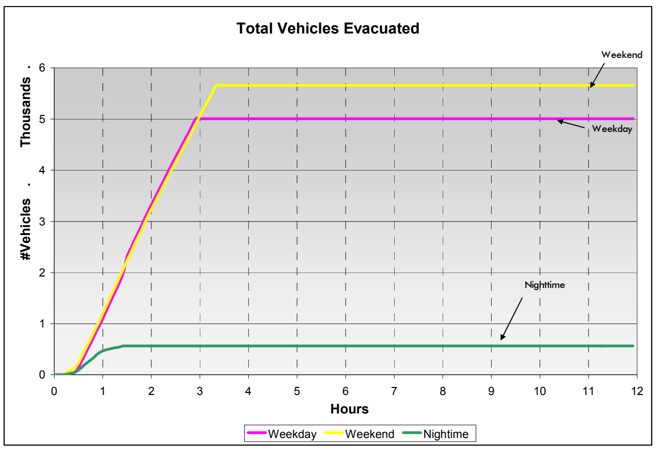
- Contra-flow operations on I-5 would reduce the time required to evacuate all combinations of PAZ evacuations, with the greatest reduction occurring for the combination of PAZ 1, 4, and 5 of approximately two hours.
- An incident on I-5 could increase the evacuation times by nearly two hours.
- Delayed mobilization has a negligible effect for the majority of PAZ evacuation combinations; however, for the combination of PAZ 1, 4, and 5 the total evacuation time actually reduces by approximately one hour. This is assumed to be a result of the dense populations within these PAZs and the benefits of delayed mobilization as compared to available capacity on the EPZ roadway network: The roadway network does not reach capacity as quickly and therefore can move more vehicles faster out of the EPZ when the mobilization is delayed.
- When shadow demand is assumed to be at 20%, the effects are proportional to the volume evacuating the EPZ. Therefore, the effect of increased shadow demand is minimal for the PAZ evacuation combinations of lower populations.

Under the combination of PAZ 1, 4, and 5, the increased shadow demand would potentially increase evacuation times by almost two hours.

- If only 80% of the population evacuates under earthquake conditions, the total evacuation time for each PAZ combination reduces substantially. The greatest reduction occurs for the PAZ combinations with the smallest populations (PAZ 1 and 2).
- Aggressive access control on I-5 will have the greatest reduction in evacuation times for those PAZ combinations with the highest total volume of evacuating population.

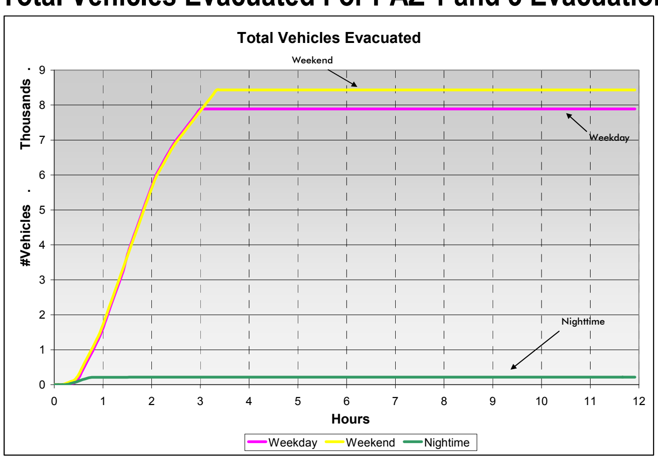
**Figures 6 though 10** present a visual summary of ETE simulation results.

**Figure 6**
**Total Vehicles Evacuated For PAZ 1 and 2 Evacuation**



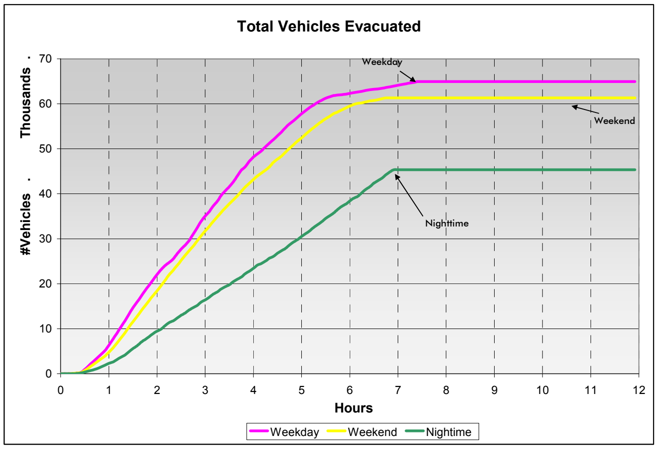

Source: Wilbur Smith Associates, 2006

**Figure 7**
**Total Vehicles Evacuated For PAZ 1 and 3 Evacuation**



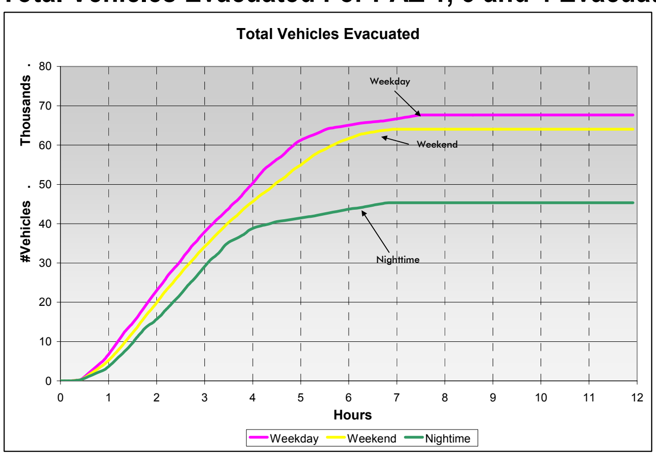

Source: Wilbur Smith Associates, 2006

## Figure 8
## Total Vehicles Evacuated For PAZ 1 and 4 Evacuation



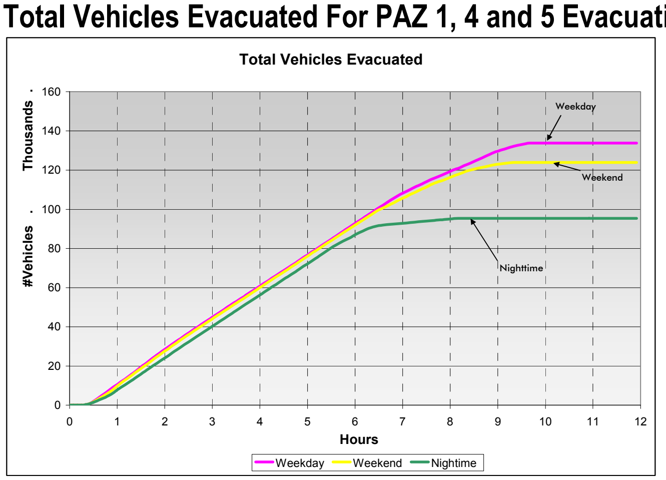

Source: Wilbur Smith Associates, 2006

## Figure 9
## Total Vehicles Evacuated For PAZ 1, 3 and 4 Evacuation




Source: Wilbur Smith Associates, 2006

## Figure 10
## Total Vehicles Evacuated For PAZ 1, 4 and 5 Evacuation




Source: Wilbur Smith Associates, 2006

## Conclusion

The goal of the project was achieved through the application of the DYNASMART software package. This tool allowed WSA to model the effects of varied congestion levels over a large transportation network during the entire evacuation period. By utilizing this tool, WSA was able to make better assessments of evacuation times required for multiple scenarios. In addition, the cumulative effects of various scenarios could be better estimated.

Lessons learned:

- The effects of mobilization time do not have a substantial effect on total evacuation times; evacuation time is a function of available roadway capacity.
- The effects of access control are substantial, again indicating the role of roadway capacity and the population distribution over available capacity.
- The effects of dynamic simulation and the results compared to the previous study show a more realistic use of available evacuation routes.