A Framework for Developing and Integrating Effective Routing Strategies Within the Emergency Management Decision-Support System

MTI Report 11-12

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REPORT 11-12

A FRAMEWORK FOR DEVELOPING AND INTEGRATING EFFECTIVE ROUTING STRATEGIES WITHIN THE EMERGENCY MANAGEMENT DECISION-SUPPORT SYSTEM

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May 2012

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16. Abstract

This report describes the modeling, calibration, and validation of a VISSIM traffic-flow simulation of the San José, California, downtown network and examines various evacuation scenarios and first-responder routings to assess strategies that would be effective in the event of a no-notice disaster.

The modeled network required a large amount of data on network geometry, signal timings, signal coordination schemes, and turning-movement volumes. Turning-movement counts at intersections were used to validate the network with the empirical formula-based measure known as the GEH statistic. Once the base network was tested and validated, various scenarios were modeled to estimate evacuation and emergency vehicle arrival times. Based on these scenarios, a variety of emergency plans for San José's downtown traffic circulation were tested and validated. The model could be used to evaluate scenarios in other communities by entering their community-specific data.

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EXECUTIVE SUMMARY

Spontaneous evacuations of New York City and Washington, DC, following the 9/11 terrorist attacks in 2001 demonstrated the lack of preparation in U.S. cities for managing the sudden influx of traffic into road transportation networks caused by a no-notice disaster. While anticipated events such as hurricanes have long been the basis for evacuation planning, there is now increasing interest in evacuation planning based on hypothetical no-notice events. Advances in computing technologies have made it possible to simulate urban transportation networks in great detail. These traffic simulation models can be used to devise strategies for evacuation and emergency response in the event of a disaster.

This report describes the modeling, calibration, and validation of a VISSIM traffic simulation model of downtown San José, California (VISSIM is an acronym for the German words “Verkehr in Städten –Simulation” which means traffic in cities simulation model). The model is then used to test various scenarios to assess the effectiveness of evacuation strategies for use in the event of a human caused or other no-notice disaster.

The modeled network required a large amount of data on network geometry, signal timings, signal coordination schemes, and turning-movement volumes. Turning-movement counts at intersections were used to assess the differences between observed and simulated counts. For freeways, the simulation model was validated using actual travel time information. Once the base network was validated, various scenarios were tested to estimate vehicle-based evacuation time and travel time of emergency-response vehicles.

It was found that in the event of coordinated terrorist attacks simultaneously occurring at four locations in the downtown San José area, evacuee traffic would cause severe bottlenecks. To alleviate the downtown congestion and speed traffic onto the freeway, contraflow lanes could be used on Montgomery Street (which becomes Bird Avenue). However, evacuations could be complicated by the difficulty of establishing contraflow lanes following a no-notice disaster, traffic accidents potentially resulting from the congestion, and failure to comply with new traffic-control devices required to implement contraflow.

The simulations indicated that the optimal approach for achieving a rapid evacuation of the downtown would be to reduce the number of vehicles on the road through public transit ridership, leaving area roads less congested for emergency-response vehicles. In a scenario in which 30% of the evacuees used transit at Diridon Station Transit Center, travel times for the remaining evacuees as well as the first responders were minimized. Other scenarios provided response strategies that could be used if the transit station were affected by the attacks or road surfaces were impacted by damage or accidents.

I. INTRODUCTION

This report describes the use of traffic simulation for developing an evacuation plan for a downtown region and creating emergency vehicle routing for use in case of a no-notice disaster. Traffic simulation can be used to augment or verify computer aided dispatch (CAD) system route selections and routing based on global positioning system (GPS) guidance. The report also describes a variety of decisions that had to be made in this research, including the choice of simulation software and the modeling procedure.

Problem Statement

In times of crisis, failure to provide an effective emergency evacuation system for a metropolitan area can result in a second catastrophe, stranded residents. Low-lying hurricane-prone communities have developed evacuation plans that can be activated when the National Weather Service gives warning of an impending storm. But although such plans can be well publicized and practiced, their implementation may not be successful because of circumstances requiring sudden changes in instructions to residents and rerouting of traffic. In 1999, residents of North and South Carolina evacuated in advance of Hurricane Floyd, only to be trapped on the freeway as the storm's direction changed. The emergency management community recognized the need for more effective emergency evacuation strategies.

In 2005, 1.2 million people were successfully evacuated from the New Orleans metropolitan area in advance of Hurricane Katrina with the use of a car-based contraflow network plan, but 70,000 people stayed behind by choice or necessity and were stranded in the unexpectedly flooded city. Before the storm, many Amtrak trains left New Orleans empty because evacuation plans did not incorporate heavy rail. Mass-transit buses carried people without cars to outlying shelters, but bus drivers were unwilling to return for more passengers as the storm worsened. School buses, which were not included in evacuation planning, became a lost opportunity (Cooper and Block, 2006).

During Hurricane Rita, the evacuation plan failed because excessive reliance on automobiles resulted in traffic congestion and fuel shortages (Litman, 2005). Texas was long considered to have the best evacuation plans in the nation, but after seeing people stranded on their roofs in New Orleans, the residents of the metropolitan area surrounding Houston took to their cars, even though they were not in the evacuation areas mapped out in the plan. The unplanned-for evacuees used up the available gasoline and filled the shelters before the planned evacuations occurred (Dale, Mayer, and Moss, 2008).

The aftermath of these two devastating hurricanes highlights the need for emergency-evacuation planning efforts that integrate relevant transportation-planning agencies and use available resources more efficiently. Texas's post-Rita evacuation plan integrated better public education, tow truck operators, gasoline delivery mechanisms, and shelter planning ("Task Force on Hurricane Evacuation Issues," 2006).

Not all disasters requiring evacuation come with warning. Creative pre-planning is needed for evacuation in the event of a no-notice disaster. For example, hazardous materials accidents on rail lines and freeways may require the immediate evacuation of nearby populations. Terrorist attacks have caused similar evacuation requirements. The September 11, 2001, attacks destroyed portions of New York City's subway system and PATH stations that were part of the World Trade Center complex, caused the closure of the tunnels to New Jersey, and required the use of ferries to augment available evacuation capabilities. The attacks at the Pentagon forced the closure of the adjacent freeway in Virginia, complicating the evacuation of Washington, DC, as the 14th Street Bridge was closed. The uncoordinated release of federal employees led to gridlock on Washington's streets, as there was no time to establish contraflow or other traffic controls (Jenkins and Edwards-Winslow, 2003).

Mass-transit centers have been the targets of several terrorist attacks in large urban areas over the past decade. Large-scale coordinated attacks on mass-transit systems in Madrid in 2004, London in 2005, and Moscow in 2010 showed both the vulnerability of the mass-transit centers in these urban areas and their importance. The attacks demanded rapid response by fire/rescue and emergency-medical-services personnel. While crowds were running away from the scene of the disaster, the first responders had to get access to the victims and then to the hospitals. A response plan for such events cannot be created in detail in advance, but modeling may enable estimates to be made of the best routes and the most efficient traffic-management strategies for generalized emergency planning.

Evacuation planning requires the integrated knowledge of traffic planners, emergency managers, and first-responder agencies. Together they may pre-plan corridors for evacuation of congested downtown areas, high-population areas, and high-occupancy spaces such as convention centers and sports venues. Sophisticated computer software has enabled the modeling of emergency evacuation plans for major disasters (Chiu and Zheng, 2007). An efficient emergency response decision-support system can not only save lives, it can coordinate multiple independent agencies. A streamlined, coordinated decision process that utilizes real network routing information can greatly improve disaster traffic management and minimize fatalities. This study provides a simulation-model-based framework for assessing a variety of routing mechanisms to improve evacuations.

Evacuation planning is one of the most difficult elements of emergency response to design and implement. Effective integration of routing strategies with a community's existing emergency-response resources requires coordination between traffic operations and emergency management plans of multiple agencies and often multiple levels of government. For example, streets located within a city may be maintained by the county transportation department, in which case repair schedules and lane closures may not be well coordinated. The interstate-system freeways run through cities but are maintained by state departments of transportation and are patrolled by states' highway patrol. While a local mass-transit operator, which may itself be a special district, is often listed as a resource within the logistics section of the emergency operations plan (EOP), it is seldom part of the emergency planning effort. Bringing the crucial emergency-response entities—emergency services, transportation, and transit—together to develop key data for use in all aspects of evacuation planning would result in more practical, realistic, and effective multiagency, multimodal traffic management and evacuation plans.

Modeling and simulation of traffic flow can generate information sufficient to allow for reproducing the flow of whole networks in real time (Shreckenberg, Neubert, and Wahle, 2001). Transportation engineers can use traffic simulations to optimize traffic management and evacuation systems and run feasibility tests to determine their practicality (Molaghasemi and Abdel-Aty, 2003). Simulation models can also answer “what if” questions to aid system designers in assessing the impact on existing systems of various alternatives that cannot be field-tested. For example, traffic management schemes like contraflow on city streets or the use of public transit can be tested to estimate their impacts on the speed and efficiency of post-disaster traffic management. In addition, interactions of various traffic sectors can be studied to improve first-responder access without the risks, costs, and complexity of multiple evacuation drills.

A timely and effective response to a disaster can save lives but requires coordination among multiple first responders, including ambulance crews, fire departments, and law enforcement personnel.

The study reported here was undertaken to:

1. Develop a microscopic simulation model to evaluate the pre- and post-disaster performance of a downtown street network.

2. Find traffic bottlenecks that would impede evacuating private vehicle traffic and emergency vehicle entry.

3. Develop a simulation-based framework for evaluating routing strategies for dispatching emergency-response vehicles into the disaster area and evacuating the general public given existing transportation network conditions.

4. Demonstrate rerouting strategies for vehicles in the event of network link closures.

The street network modeled in the study is in downtown San José, California. Diridon Station Transit Center in San José is very close to the HP Pavilion, which is home to the San José Sharks, rock concerts, and major public and corporate events. With this location as the focal point of the study, disaster scenarios were created to demonstrate potential sources of routing demands. The information garnered from the microscopic traffic simulation is used to develop an integration of routing strategies within the existing emergency-response framework.

The San José Downtown Area

The study area consists of approximately three square miles around downtown San José. The disaster scenario, which is described in more detail in the next section, includes the HP Pavilion and Diridon Station Transit Center. Interstate 280 (I-280) serves as an important thoroughfare in the freeway network, carrying more than 15,000 vehicles during the evening peak hour. Highway 87 is another important route into the downtown area, carrying more than 6,000 vehicles during the evening peak hour.

Diridon Station Transit Center is the central transit hub and passenger rail depot linking Silicon Valley to the rest of California. In addition, it is expected to become a future stop on the BART extension to Silicon Valley in 2018 and the California high-speed rail system. The study area is outlined in Figure 1.

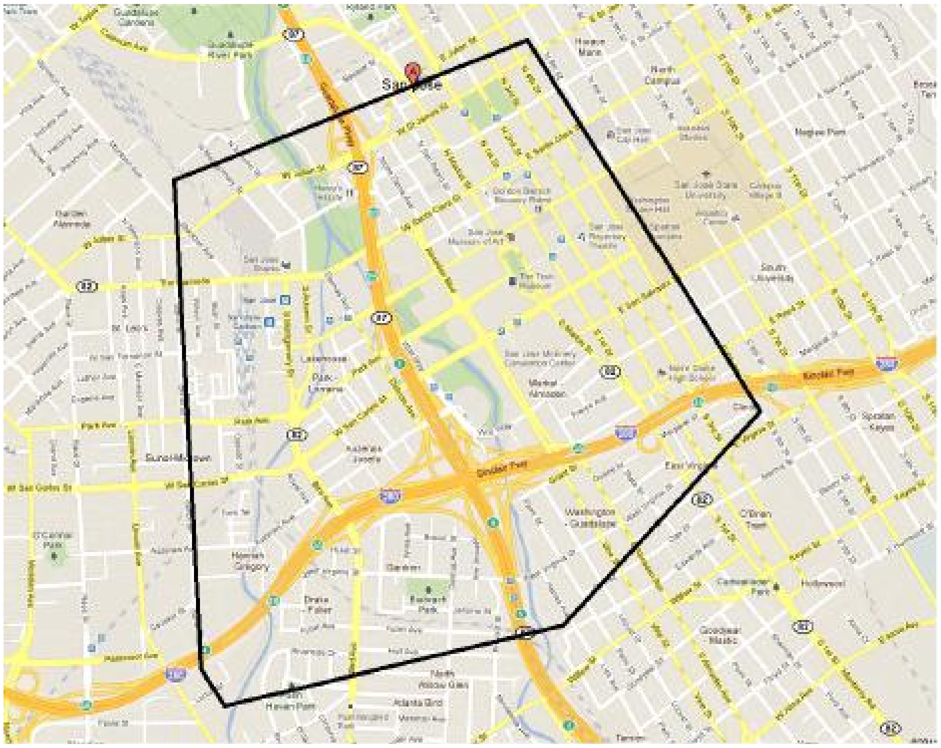


Figure 1. Study Area Map

DISASTER SCENARIO

The base case disaster scenario is a series of coordinated bombings in downtown San José on a Friday afternoon. The bombings all occur in high-occupancy buildings, including HP Pavilion, the federal Internal Revenue System (IRS) building, the State of California office building, and the San José Convention Center, during the afternoon peak traffic hour at 4:00 pm. The locations are shown in Figure 2. HP Pavilion is hosting a business seminar, “How to Make $10K a Month from Home,” a sold-out event, with 19,100 attendees on site. All 1,800 on-site parking slots were sold as part of VIP tickets, and adjacent city and privately owned parking lots are full. Adjacent lots are located on Santa Clara Street at Delmas, Santa Clara Street at Cahill, and Autumn Street north of Julian. The lot on Santa Clara Street has exit potential onto Santa Clara both eastbound and westbound, while the Santa Clara Street at Cahill lot exits onto Autumn and then Santa Clara in either direction, or Montgomery southbound, with the first cross street being Park Avenue.

The first bombing was a truck bomb in the HP Pavilion parking lot adjacent to the loading dock on Montgomery Street. A smaller device was detonated on the floor of the arena in the middle of the seating area. At the State of California building (located at 100 Paseo de San Antonio), another truck bomb detonated while it was parked on the Third Street side of the building in a no-parking zone along the west side of the street. Next, at the IRS building (located on S. Market Street), a truck laden with explosives, parked on the west side of Market Street in a loading zone, detonated. The final bombing occurred at the Convention Center (located on Almaden Boulevard), where another truck bomb exploded while it was parked on the exhibit-area loading ramp adjacent to the exhibit-hall door.

Various response strategies were tested to determine which one yielded the most efficient way to evacuate people and allow the emergency-response vehicles to travel from the disaster areas to hospitals. The response scenarios have a majority of network features in common, including signal timing and traffic volumes. All of the alternative response scenarios, as well as the base case scenario, include a 5-minute simulation warm-up, followed by a 60-minute simulation time, and a 5-minute “clearing period” for the remaining cars to reach their destinations. In addition, only emergency vehicles (such as ambulances and fire vehicles) traveling on I-280 northbound (NB) or southbound (SB) can exit into the downtown area. These vehicles were defined as a separate vehicle class in the model. On I-280 NB, the closed off-ramps were from 4th Street to Bird Avenue, while on I-280 SB, the exits closed were from Bird Avenue to E. Virginia Street. Highway 87 NB and SB were completely closed to all vehicular traffic except for emergency vehicles to prevent further gridlock on city streets, as well as to potentially provide emergency vehicles a quicker, more efficient route to access the bombing locations. In addition, to accommodate the large number of vehicles expected to exit the parking lot across from the San José Convention Center, a new intersection was added at Woz Way and Almaden Boulevard. Another intersection was coded into the network at San Pedro and Santa Clara Streets for the expected mass exodus of cars from locations around the bombed IRS building.

Emergency vehicles from the three fire stations most likely to be assigned to immediate rescue needed the fastest, most direct route into the disaster areas, while ambulances would need the fastest routes from the bombing locations to the hospitals. For this study, three hospitals and three fire stations were identified as responders within the critical first hour. No hospitals are located within the study area, so Google Maps was used to find the travel time to the point where the path to the hospital began in the coded network. The Google Maps travel time was added to the simulation time to estimate the total travel time from the disaster area to the hospital. The hospitals and fire stations are shown in Figures 19 and 20 in Chapter IV.

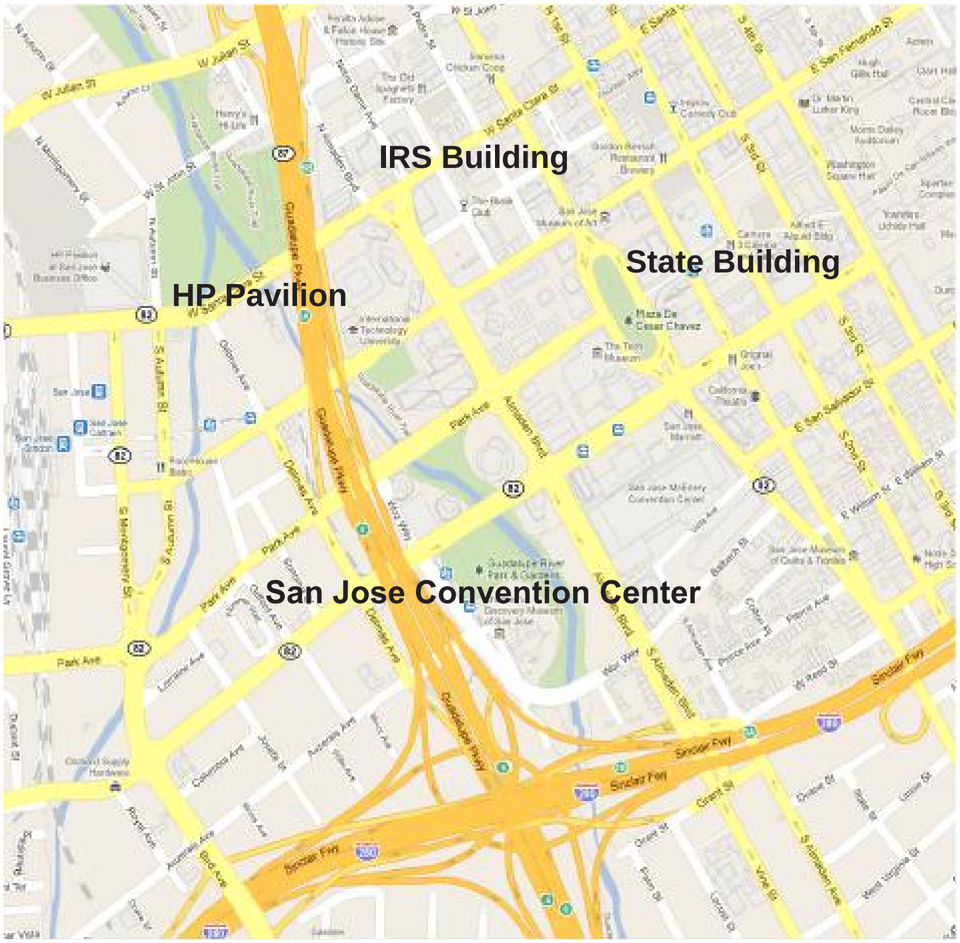


Figure 2. Bombing Locations

Report Organization

Chapter II presents a literature review of computer modeling for traffic management, which provides information about state-of-the-art traffic simulations that have been conducted for various purposes, including emergency evacuation and routing-strategy evaluation. It also discusses the basis for ultimately choosing VISSIM to develop the microsimulation model.

Chapter III presents a detailed discussion of the model development and coding. Data collection and network coding in preparation for calibration and validation are shown, and the process of calibration and validation is explained.

Chapter IV describes four disaster-response scenarios and presents summaries of simulation results from those scenarios.

Chapter V presents the conclusions of the study and offers suggestions for future research.

II. TRAFFIC SIMULATION: DISCUSSION AND LITERATURE REVIEW

This chapter provides details of traffic-simulation applications and the potential advantages and disadvantages of microsimulation. It also reviews prior studies related to simulation-model application for emergency-response scenarios.

TRAFFIC SIMULATION

Traffic simulation has been defined as a "numeric technique for conducting experiments on a digital computer, which may include stochastic characteristics, be microscopic or macroscopic in nature, and involve mathematical models that describe the behavior of the transportation system over extended periods of real time" (Molaghasemi and Abdel-Aty, 2003). Technological advances have made traffic simulation models a feasible option for addressing traffic management problems. Traffic simulation packages offer a wide range of practical traffic analysis tools, ranging from evaluation of alternative roadway treatments, evacuation studies, and safety analyses through the simulation of traffic accidents. Modern simulation models are based on random vehicular movements, which makes them suitable for modeling human driving behavior and enables animated vehicles to be viewed on a two- or three-dimensional graphic representation of a network.

Traffic simulation can be used to treat algorithms used in mathematical and logical modeling that are infeasible or complicated, to represent systems in detail. Also, congestion effects on roadways can be monitored through vehicle animation, which presents the system characteristics in minute detail.

SIMULATION-MODEL CHOICES

Traffic simulation models can be broadly classified as microscopic (high-fidelity), mesoscopic (mixed-fidelity), or macroscopic (low-fidelity). Numerous microscopic traffic simulation models are currently being used to study transportation network operations. These models typically offer the greatest flexibility and result in more-accurate estimations of measures of performance than other models. The real world is represented more practically in microscopic simulation models, because they can simulate vehicle-to-vehicle interaction and provide continuous profiles of vehicle locations and speed (Molaghasemi and Abdel-Aty, 2003). Given parameters such as travel demand, they can evaluate the dynamic evolution of congested traffic and performance measures of alternative traffic management strategies in response to traffic congestion. However, the size of the network simulated must be smaller than that possible with macroscopic planning models, because of the comparatively high number of required inputs, calibration and validation efforts, and computing power needed for microscopic models (Rousseau et al., 2007).

Macroscopic models are appropriate for regional or large-scale studies. They are typically used by transportation planners and demand modelers. Planners use a systematic process to translate land use, household and employment characteristics, and transportation supply into predictions of current and future travel patterns and demand through mathematical formulation and simplification. Cars are aggregated, and measurements of flow, density, and average speed are then measured. These models are less accurate than their microscopic-simulation counterparts, but they are faster and require fewer variables for network coding. Networks developed by macroscopic modeling provide a static view of transportation systems that is appropriate for long-term planning (Molaghasemi and Abdel-Aty, 2003).

Mesoscopic models have both microscopic and macroscopic characteristics. They simulate groups of vehicles or platoons and use aggregated microscopic-model results. Mesoscopic models can be classified as either stochastic or deterministic. Stochastic models include probability distributions, which offer the option to model uncertainty or randomness. Deterministic models perform the same way for a given set of initial conditions, i.e., they do not include any randomness.

Depending on the scope of investigation, different levels of detail are necessary for modeling infrastructure and vehicles. The model that is ultimately chosen for a particular project should provide the appropriate functionality, i.e., arterial, freeway, or integrated (Rousseau et al., 2007). For simulations of large road networks, macroscopic flow models are the common choice, while microscopic models are more often used for studying traffic flow in smaller areas but in greater detail (Fellendorf and Vortisch, 2001). The appropriate model choice is essential to the success of a simulation experiment. The choice is essentially a tradeoff between the accuracy and precision of the model and the development costs, data needs, and time required to execute the simulation (Rousseau et al., 2007).

SIMULATION STEPS

Experience and awareness of how a simulation model operates are necessary to achieve good results. The technique suggested by Lieberman and Rathi (1999) consists of the following steps:

1. Recognize and establish the scope of the problem.

2. Describe the goal of the study.

3. Find alternative methods to resolve the problem.

4. Explore the available simulation models.

5. Fine-tune the model.

6. Execute the model.

7. Check the integrity of the model.

8. Analyze the model output.

Before starting any study, it is necessary to recognize and establish the scope of the problem. In a transportation study, this includes specifying the traffic environment (characterized by level of service and highway geometrics, for example), the boundary of the study area, and the control environment.

After describing the goal of the study (e.g., predicting travel demand, picking the least intrusive alignment for a new highway), one must pick the variables that measure effectiveness (travel time, travel volume) and choose how specific the study needs to be, the time line, the budget, and the predicted precision and constancy.

After the goals of the study are established, the next step is to determine the way to obtain the sought-after results. A comprehensive literature review needs to be performed to compare how similar studies were conducted and to learn what problems were encountered and how they were overcome. Mathematical and simulation modeling methods should be surveyed and their advantages and disadvantages compared according to fundamental theories, simplicity, price, computing specifications, assistance available, quality of animation, and the transparency of their documentation. After comparing different types of simulations, the need for a simulation should be checked—in some cases, a mathematical model can solve the problem, and a time-intensive simulation is not needed. When simulation modeling is deemed necessary, the most desirable model that meets the needs of the problem must be selected.

The next action is to collect the data required for the simulation model (including the signal timing plan, overhead photographs, vehicle composition, roadway schematics, and various traffic data such as the average annual daily traffic). A small section of the study area should then be tested to calibrate the model. Calibration entails tuning the factors of the simulations (such as perception time, headway allocations, and traffic-control-device locations) with various scenarios. The simulation model should be evaluated against real data and possibly with the widely accepted Highway Capacity Manual.

Using simulation models can be thought of as performing an extensive statistical experiment. Initially, a model needs to be implemented to start up its database. That is required to make the data correctly characterize the starting state of the traffic setting. Analyzing the results is the most crucial step. With the complexity of all the progression occurring in the real-world traffic setting, the researcher needs to:

- Make certain that all parts of the model proficiently represent the vital processes.
- Confirm that the input data that were required for the calibration are free from typographical or other errors.
- Verify that the output from the simulation trials is acceptable.
- Ensure that the statistical analysis lacks any flaws.
- Scan for any “bugs” in the model and the demeanor of the algorithms utilized.

Detailed inspection of animation is vital, because it shows the data and observations from the body of the traffic setting. Animation is the dominant tool for interpreting the simulation output. It shows the source and consequence relationship and checks for unusual results.

The technique described above was used to develop the simulation model for the downtown San José area.

ADVANTAGES AND DISADVANTAGES OF TRAFFIC SIMULATION

The continuing increase in computer processing power and improvements in the graphical user interface (GUI) for simulation packages have enabled the development of very practical traffic analysis tools. They allow traffic engineers and planners to artificially analyze alternative roadway treatments, test new roadway designs, perform safety analyses through incident recreation, and view dynamic emergency evacuation procedures.

Sisiopiku et al. (2004) provided a brief summary of many traffic simulation models that are being successfully used to evaluate both microscopic and macroscopic network operations. CORSIM is a microscopic simulation model developed for the Federal Highway Administration (FHWA), used mainly in modeling urban traffic conditions. VISSIM is a microscopic simulation model created by PTV Vision for modeling complex dynamic systems, such as the interaction among pedestrians, public transit, and vehicles. Integrated Traffic Simulator (INTRAS) is a microscopic simulation model that has been used for incident analyses and to simulate traffic on freeways, ramps, and adjoining streets.

While current simulation models can easily incorporate relevant data, there are still many variables that cannot be modeled (Algers et al., 1996). For example, simulation models are unable to mimic congestion. The majority use simplistic car following and lane-shifting algorithms to simulate vehicle motion, which may not realistically replicate driver behavior. Also, with climate change receiving increasingly greater attention, there has been an emphasis on including emission generation in simulation models. But automobile emissions are difficult to model realistically, and obtaining current emissions data to validate findings may be difficult.

Benefits and shortcomings of simulation modeling are summarized in Table 1, from the Highway Capacity Manual, which contains concepts, guidelines, and procedures for computing the capacity and quality of service of various roadway facilities.

Table 1. Benefits and Shortcomings of Simulation Modeling

Simulation Modeling Benefits	Simulation Modeling Shortcomings
Can adjust demand over space and time	Output may not be able to be duplicated for each model trial
Can model peculiar arrival and service trends that do not match more conventional mathematics	A less demanding method of solving the problem may exist, e.g., a mathematical model
Can move unserved queued traffic from one time to another	Extensive input parameters and data are required, which may be challenging to find or unattainable
Can experiment with untested scenarios that do not presently occur in real life	Many steps need to be completed to check a model's credibility; if those steps are ignored, the model might not be accurate
Can examine the system in condensed, stretched, or actual time	Users of the simulation model may not understand the model's assumptions or limitations
Can perform possibly dangerous experiments without danger to the researchers	Creating a simulation model requires an understanding of statistics, traffic-flow theory, and computer programming
Distributions can be tested off-line without using an online trial-and-error approach	Researchers using the model may not know what the model embodies
Can be the last-resort method of analysis	Simulation models are not user friendly; they often lack guides and may need special computers
Can deal with interrelated queuing processes	
Can give time and space sequences with statistical information, including means and variances	
Can analyze how variation can affect the operation of a system	
Can replicate base conditions for equitable comparisons of improvement alternatives	

Source: Transportation Research Board, 2000, Chapter 31.

USING SIMULATION TO CREATE EMERGENCY PREPAREDNESS PLANS

Evacuation Modeling for Natural Disasters

Traffic simulation has been used to analyze emergency evacuation conditions for vulnerable coastal areas in the southeastern United States. When Hurricane Floyd struck in 1999, evacuations of North and South Carolina resulted in highly congested arterial highways, and as a result, several states created lane reversal plans (contraflow lanes) for interstate and/or divided highways along evacuation routes. To test the plans' effectiveness, a major research study funded by the North Carolina Department of Transportation used simulation modeling to determine performance measures. It was ultimately determined that the lane reversals provided considerable capacity increases for traffic attempting to exit via I-40 in North Carolina (Tagliaferri, 2005). The contraflow transition is shown in Figure 3.

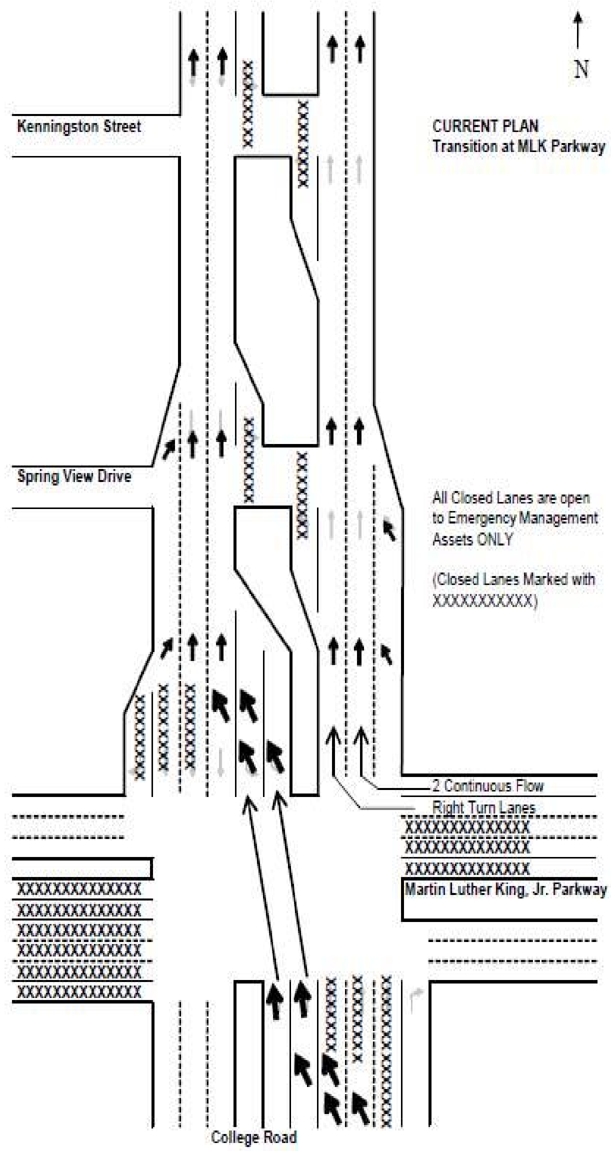


Figure 3. Schematic of Contraflow Transition for I-40 in North Carolina

Source: Tagliaferri, 2005.

Theodoulou (2003) used CORSIM 5.0 simulation model results to evaluate the effectiveness of a contraflow segment on westbound I-10 out of New Orleans and found that the use of contraflow lanes could increase the traffic flow significantly; alternative plans that were developed also resulted in effective roadway usage.

Evacuation Modeling for Human Caused Disasters

More relevant to this research is evacuation preparedness for urban areas that can be affected by human caused disasters. Two studies have applied microscopic traffic simulation to assess effective, post-disaster routing of emergency vehicles for human caused disasters. Elmitiny, Ramasamy, and Radwan (2007) simulated strategies for evacuating a transit station to help LYNX bus service in the Orlando, FL, metropolitan region evaluate its evacuation plans. Mollaghasemi and Abdel-Aty (2003) analyzed the highway network around Orlando International Airport to identify the most effective routing strategies for emergency vehicles.

Evaluation of Routing Strategies

Haghani, Hu, and Tian (2003) created an integer programming model to conduct a simulation experiment in routing emergency medical service using a dynamic shortest-path algorithm. Through a series of mathematical tests to verify the model's validity and sensitivity to changes in various parameters, it was ultimately determined that the model provided advantages in real-time emergency vehicle dispatching. Through a dynamic network, individual nodes were treated as moving vehicles, which provided a twofold benefit: the emergency-response capability was improved, and dynamic travel time helped to optimize emergency response time for severe incidents (see Figure 4).

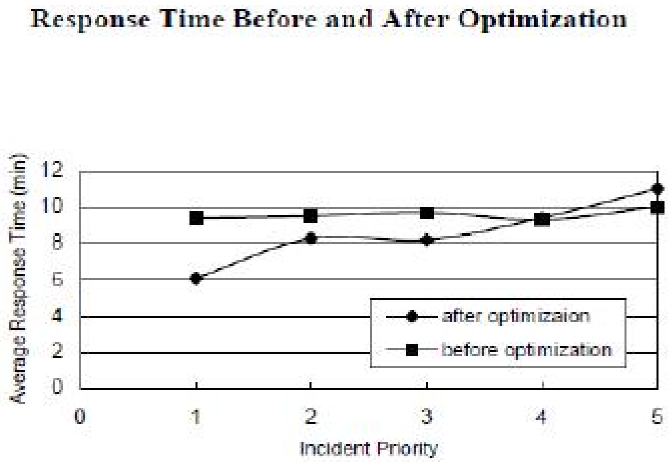


Figure 4. Response Time Before and After Optimization
Source: Haghani, Hu, and Tian, 2003.

Pal, Graettinger, and Triche (2002) used ArcView Geographic Information Systems (GIS) and Oak Ridge Evacuation Model System (OREMS) 2.5 to develop evacuation models for two counties along the Alabama Gulf Coast, which is particularly vulnerable to hurricanes. Arcview GIS was used to organize input data from roadway links to population data in preparation for entry into OREMS. Using a system of nodes and links, the resulting simulation showed that complete evacuation of Baldwin and Mobile Counties would take approximately 21 hours and 8 hours, respectively. This information, along with a progressive evaluation of the percentage of the population evacuated, is displayed in Figure 5.

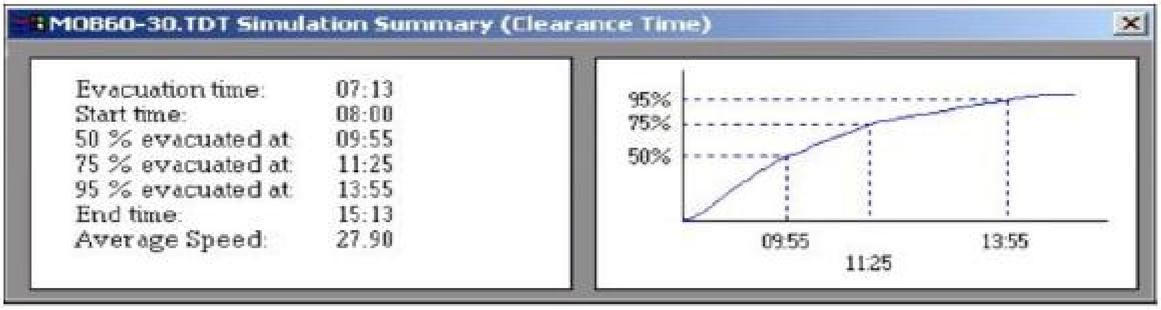


Figure 5. Simulation Model Output for Mobile County

Source: Pal, Graettinger, and Triche, 2002.

Chiu and Zheng (2006) developed a general mathematical evacuation model using linear programming that provided a comprehensive treatment of the simultaneous, multidimensional decisions on multipriority group mobilization during emergency evacuation. The proposed network transformation from a node-to-node basis to a cell-transmission technique permitted complex multidimensional mobilization to be determined in the most efficient way. Chiu and Zheng also acknowledged the model's limitations and noted that future research would be needed to improve its capability.

CONCLUSIONS

While previous studies are thorough and helpful in their own way, they lack the effective integration of routing strategies (for emergency vehicles and/or evacuees) within a community's overall emergency-response framework. The regional traffic model developed by Sisiopiku et al. (2004) is also limited in its ability to simulate real-time emergencies and does not model vehicular behavior at the microscopic level. The present study attempts to provide a clear framework for integrating the routing strategies within the overall response plan for a community.

On the basis of information gained in the detailed review of the literature, the VISSIM microscopic modeling tool was selected because of its strengths as a stochastic microscopic, time-step, behavior-based program developed to model urban traffic and transit operations. VISSIM can analyze traffic as well as transit operations under constraints such as lane configuration, traffic composition, and traffic signals, thus making it a useful tool for evaluating alternatives.

This study also captures the real dynamics of emergency routing decisions that could be easily applied to other locations. While precise routing strategies may not be directly transferrable to other transit centers, the approach presented here can be used to identify optimal routing strategies for emergency situations elsewhere in the United States.

III. NETWORK MODELING

The network modeled was that on the afternoon peak hour on a weekday, the worst-case scenario (for traffic) following multiple terrorist bombings throughout the downtown area that would induce a wide-scale response and add to the already congested freeway and highway networks. This chapter describes the details of data collection, network modeling, and validation.

DATA COLLECTION

To provide a basis for calibration of the simulation model, data for downtown surface streets were obtained from the San José Transportation Department (SJDOT), and freeway counter data for I-280 and counts for Highway 87 were obtained from the Caltrans Performance Measurement System (PeMS). A regional Cube Voyager model from SJDOT provided approximate, directional traffic volumes throughout the entire network. After the traffic data were obtained and a calibration base was established, a traffic model had to be created that would accurately simulate driving conditions encountered in the base case, including the links or roads necessary to travel on, traffic signals, stop signs, yield control, reduced-speed areas, and desired-speed decisions.

The driving behavior parameters that VISSIM offers were then implemented to calibrate the simulation to match reality as closely as possible. The final network is summarized in Table 2.

Table 2. Final Network Summary

Number of links	974
Signalized Intersections	45
Vehicle Inputs	70

MODEL BUILDING

To recreate the network's geometry, a network coded with Cube Voyager was imported. Cube Voyager is used to model a wide variety of regional-level planning policies and improvements. Although it is a macroscopic model that is appropriate primarily for forecasting personal trips, its use was initially thought to be a viable option. PTV Vision has developed a macroscopic planning model called VISUM, so the Cube Voyager model was imported into VISUM to be lightly edited and then exported into VISSIM.

Unfortunately, this process was unsuccessful because of the nature of the Cube Voyager model. For example, it included an extra high occupancy vehicle (HOV) lane that was separate from the rest of the freeway lanes and could connect only at certain points. The most critical problem, however, was the program-to-program data transfer. Attempts to change the network geometry in VISSIM, such as lane additions or link movement, produced node errors and created an irreparable network. Many other problems were also encountered, and it was decided that the macro-level model lacked the appropriate level of detail to be applied for this study.

The approach adopted then was to code the network geometry through multiple aerial images. An image of the proposed network area was captured from Google Maps. The network was then properly scaled and links (roads) were added to create the vehicle thoroughfares. Initially, the area to be modeled consisted of 20 square miles, including all the freeways and arterials in the network. The initial boundary is shown in Figure 6. The image on the left of the figure is from Google Maps, and the image on the right is from Google Earth.

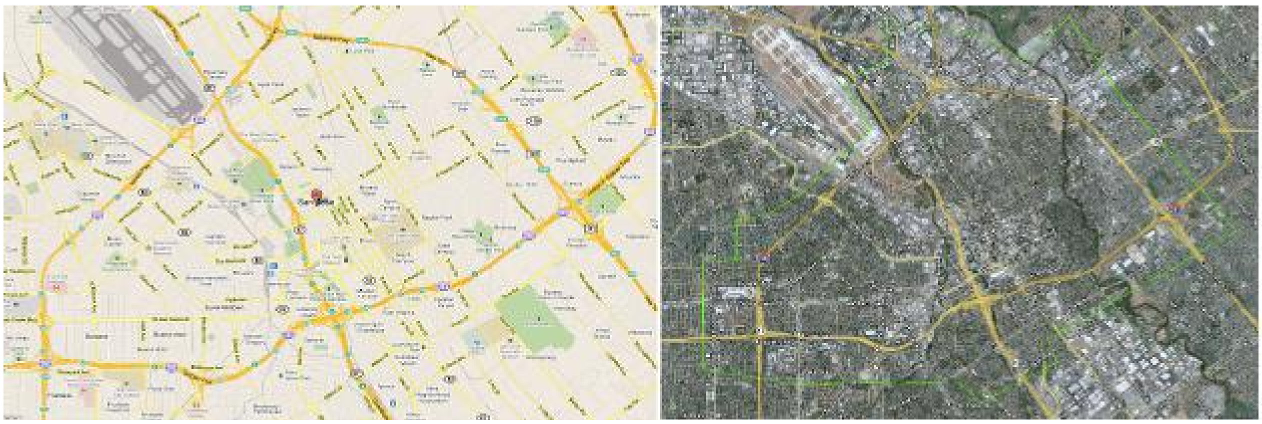


Figure 6. Initial Area of the Evacuation Study

The entire network within the study area was coded in VISSIM with the help of multiple images. However, while calibrating a network with so many intersections and streets, the traffic-assignment algorithm was not able to converge. Multiple attempts were made to overcome this, by relaxing constraints on convergence and increasing the lengths of some of the links to provide enough pockets to store queued vehicles. In addition, a dynamic traffic-assignment feature known as “route guidance,” which assumes that some cars have GPS and will continually gather data on the fastest routes available, was used. To get the dynamic assignment to converge, merging needed to be made smoother, for example, by eliminating locations where two connectors came from a multiple-lane link to a link that had fewer lanes. This problem caused cars to make unnecessary lane changes because there were two possible routes.

Moreover, this large network was not precise enough to provide the modeling detail needed. Therefore, the scope of the network was reduced. The reduced network is shown in Figure 7. It captures all the major exit and entry points into the downtown area and still can be precisely modeled with all the requisite details in a microsimulation environment.

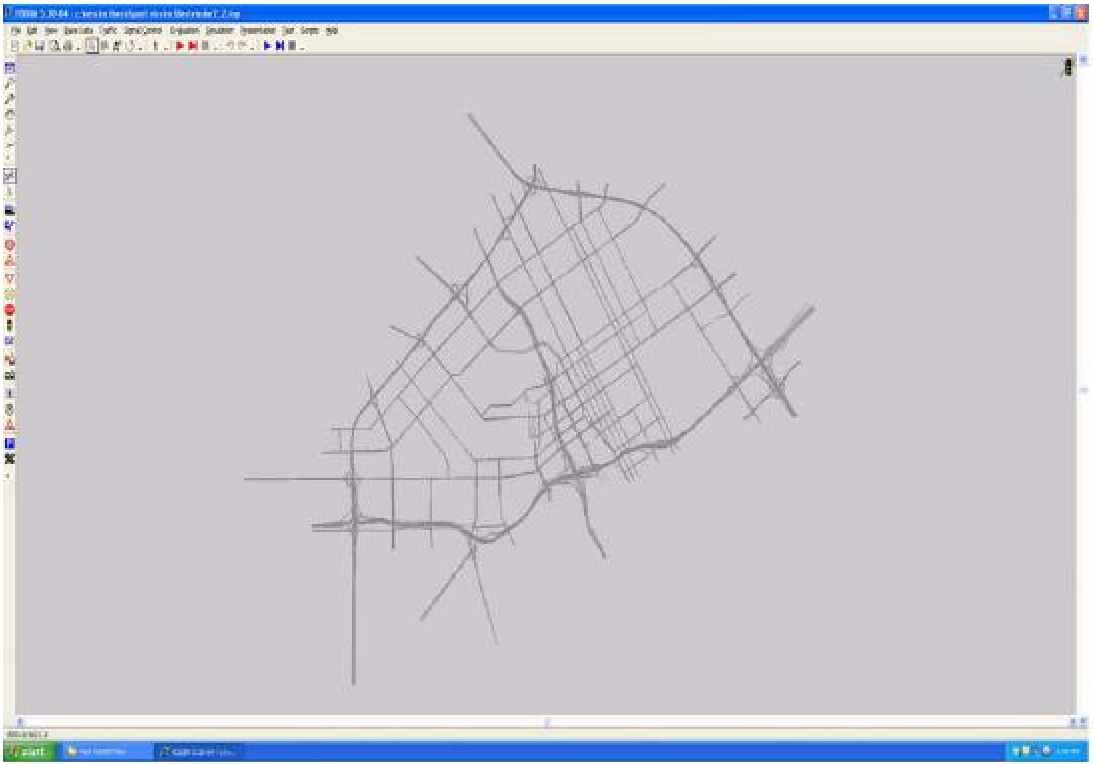


Figure 7. Reduced Evacuation Study Area

This network chosen for simulation was based on proximity and relevance to the terrorist bombings that would occur in the disaster scenario. Since the larger network of San José had previously been created with traffic signals and desired-speed decisions to regulate the roadway speeds, the remaining work consisted of simply removing the extraneous freeways and surface streets. The final study area is shown in Figure 8.

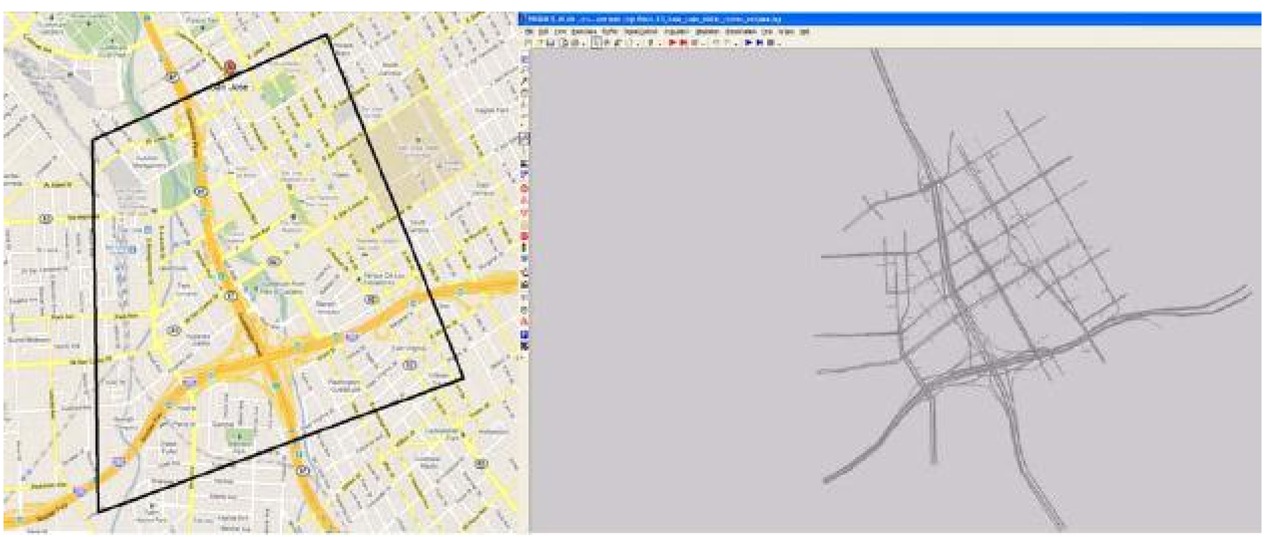


Figure 8. Final Evacuation Study Area

In addition to changes such as deletion of irrelevant network elements, functional changes were made that initially produced unrealistic driver behavior and traffic congestion during test runs. A number of elements had to be carefully changed to ensure that the simulation replicated reality as well as possible. The detailed, thorough process of modifying the network is summarized in Table 3.

Table 3. Network Modification Procedure

1. Insertion of vehicle inputs
2. Create routing decisions from each vehicle input to respective destinations
3. Check speeds throughout network on desired speed decisions
4. Input stop signs for controlled intersections for modeling of right turn on red on signalized intersections
5. Check conflict areas to ensure proper yield rules at conflict points (such as permitted left turns)
6. Check proper positioning of signal heads (an improper location in VISSIM may lead to vehicles not stopping at red signals)
7. Input vehicle detectors at intersections working in correspondence with signal heads

SIGNAL TIMING DATA

The signal timing and volumes were set up to match the base case scenario. The signals during the peak hour were modeled as Ring Barrier Controller in VISSIM, since it captures the general signal timing pattern created for the intersections throughout the network.

In order for the network to recognize the signal heads, each was assigned a signal controller number. Every time a new signal was input into the network, a new signal file was created through the “edit controllers” option. The Ring Barrier Controller software is one of the actuated-signal timing options within VISSIM. The controller dialog consisted of the standard options to create a customized signal timing plan, including minimum green time, as well as yellow and red timings. In addition, the Ring Barrier Controller offered the option of mostly signalizing intersections with four approaches, the occasional protected left turn, vehicle extensions, and vehicle detection. Figure 9 shows the standard signal timing that accommodated the eight movements (four through and four protected left turns) at the intersections.

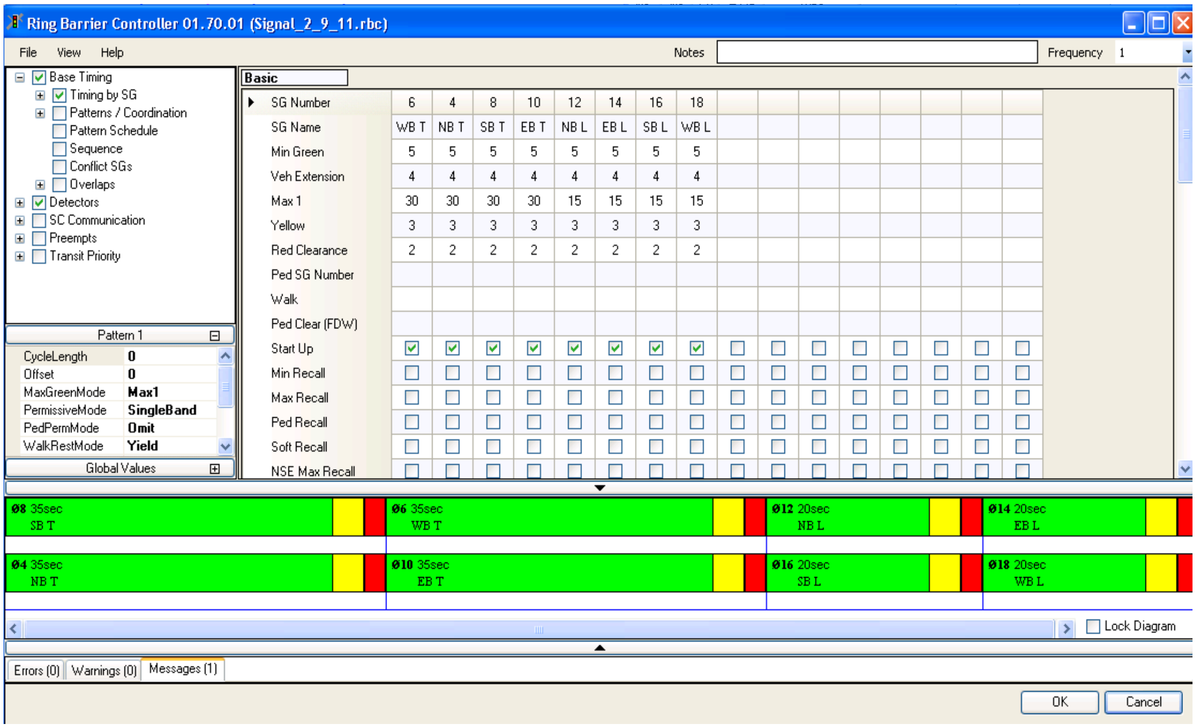


Figure 9. Ring Barrier Controller Timing Template

For intersections that allowed only permitted left turns, the left-turn-only phases of 12, 14, 16, and 18 were not input, and vehicles were instructed to yield to oncoming traffic through conflict areas. Another unique feature of Ring Barrier Controllers is the ability to synchronize vehicle detectors with the signal controllers. This allowed a much more efficient flow of traffic that enabled a phase to be skipped, if necessary, to call on a signal controller that had cars waiting at the intersection. It also mimics the functionality of the actual signals in most urban areas.

Just as the network modification procedures followed standard steps, the signal timing was input and tested in simulation to ensure that the network traffic ran properly. The steps taken are displayed in Table 4.

Table 4. Signal Timing Procedure

1. Input the signal group number, name, minimum green, maximum green, yellow, red, and vehicle extension timings
2. Check the existing network geometry in Google Streetview to determine whether protected left phases are necessary
3. Set the phasing order and ensure vehicle detectors are selected according to the signal group numbers
4. Install actual signal heads and detectors within the network
5. Install stop signs on right-turning connectors to allow right turn on red
6. Complete simulation test run to ensure proper phasing and vehicle detection

After signal-head creation and signal timings were completed for the base case scenario, it was necessary to input and balance the vehicle volumes.

VOLUME DATA FOR SURFACE STREETS

The available surface-street volume data were compiled into one spreadsheet. The best available data, including intersection counts throughout downtown San José from 2006 to 2009, were obtained from SJDOT. However, this information was insufficient for determining all the volumes at every intersection. The next option was to refer to the Cube Voyager data, also from SJDOT, which included directional traffic volumes throughout the network. Prior to coding the counts in VISSIM, all the SJDOT traffic-count data were entered into a single Excel spreadsheet. An intersection was shown as four different approaches (see Figure 10).

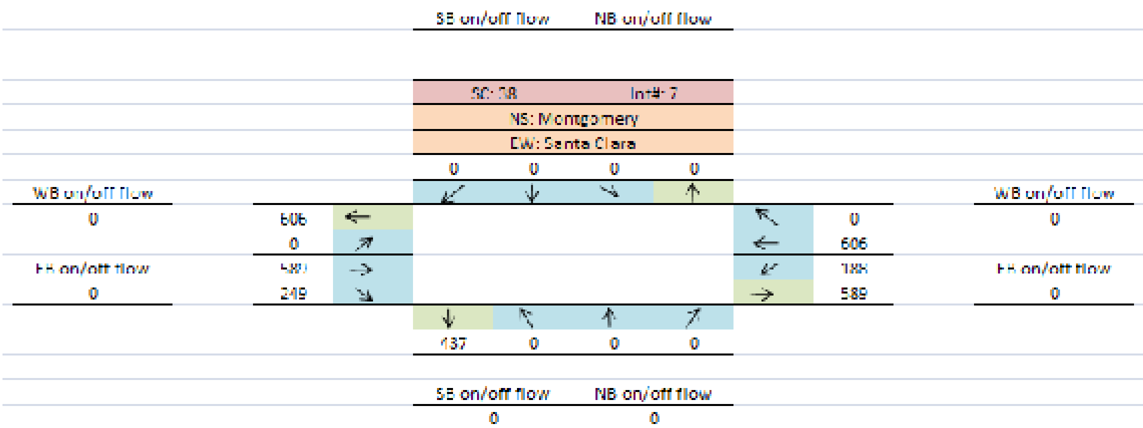


Figure 10. Traffic Volume Excel Spreadsheet

The purpose of the directional “on/off flow” cells in Figure 10 was to calculate the volume difference between the upstream intersection departure and the downstream intersection approach. While the spreadsheet shows a completely balanced intersection, prior to the volume balancing, if the on/off flow cells presented a negative integer, a volume had to exit the road before the next intersection. However, if the cell value was positive, the number of vehicles indicated in the cell would enter the road prior to the adjacent intersection.

The procedure of using the best available volumes in the Excel file, then using Cube Voyager data to fill in the missing intersections, is summarized in Table 5.

Table 5. Volume Input and Balancing Procedure

1. Enter volumes from the 2006–2009 Excel files into the turning-movement cells at each intersection
2. Working away from the known intersections, integrate the Cube Voyager data into adjacent intersections; to get the volumes to match, use midblock driveways as either feeders or exits from the network
3. Using an iterative (west to east, north to south) approach, balance the network so that the “on/off flow” cells are as close to zero as possible
4. Perform as many iterations as required to prevent volume balances being upset, as they would be if any approach fed into the balanced segment from an adjacent intersection

The next step was to create the midblock driveways in the network, using the procedure shown in Table 6.

Table 6. Midblock Driveway Coding Procedure

1. Select a roadway in VISSIM and place a single link at each location, depending on whether the link serves as a feeder into the network or an exit from the network; if the spreadsheet shows a volume departing from the road, create an exit as if vehicles had to enter the road, and code an entrance
2. Check that driveway locations include links, connectors, and conflict areas to resolve right-of-way issues
3. Code midblock exits as far upstream as possible to discourage unrealistic weaving and to allow adequate lane change distances for vehicles; create midblock entrances as far upstream as possible, again to allow ample lane change distances
4. Place the driveways were placed on their respective roads, refer to the traffic volume compilation and place the corresponding volumes into the network

Figure 11 shows the layout of a typical entrance and exit. For most driveways, if traffic flows in, there are no vehicles departing from the driveway and vice versa. Occasionally, the placement of a midblock driveway was not realistic (e.g., the Bird Street interchange and the Julian Street interchange) and driveways were not coded.

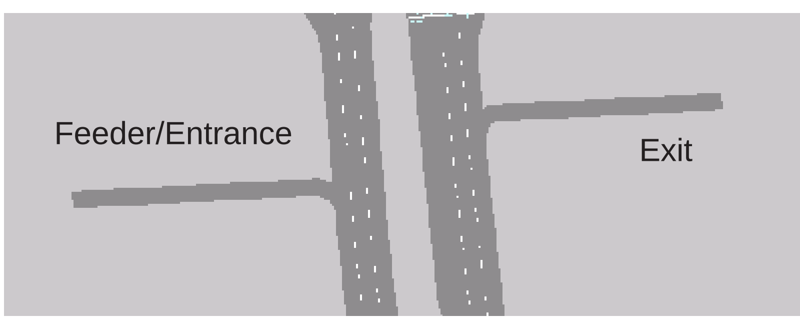


Figure 11. Midblock Driveway Entrance and Exit

Certain midblock feeders and exits warranted signals because of the large entering/exiting volumes and their placement. Figure 12 depicts the placement of one such midblock feeder with signals. This was an example of a feeder in which both an entrance and an exit were warranted due to the large number of vehicles entering and exiting. Also, a signal actually exists at that location.

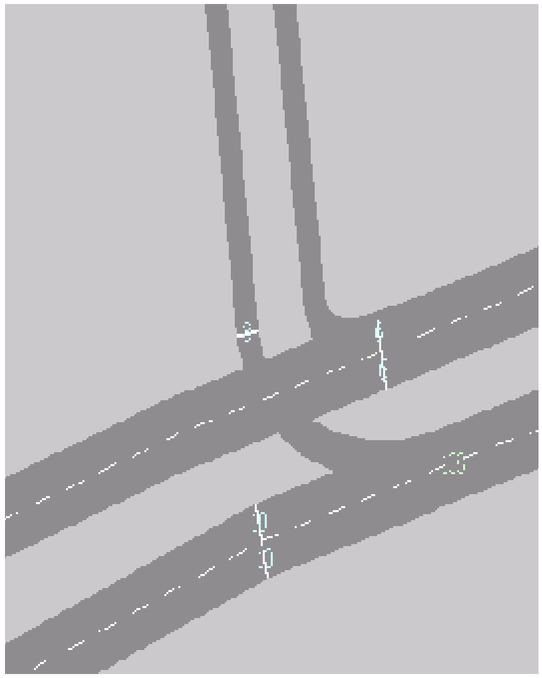


Figure 12. Signalized Midblock Driveway

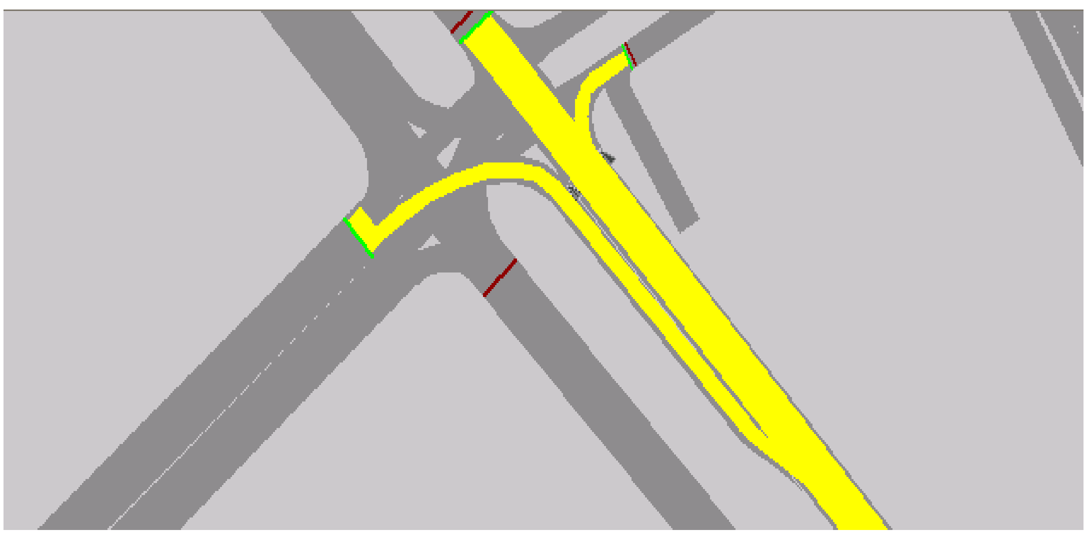


Figure 13. Illustrative Routing Decision

Following the driveway coding, the traffic volumes and turning movements from the compiled spreadsheet were entered into the vehicle routing decisions. Figure 13 shows a routing decision that branches through several intersections after a routing combination. There were also locations throughout the network where closely placed intersections exhibited large through and turning volumes. As a result, some cars could not change lanes fast enough to access the connector they should have traveled on. The solution to this problem was to create one routing decision that would span several intersections to allow vehicles ample time to make necessary lane changes. Figure 14 depicts the intersection routing combinations needed to allow for vehicles to properly access their destinations.

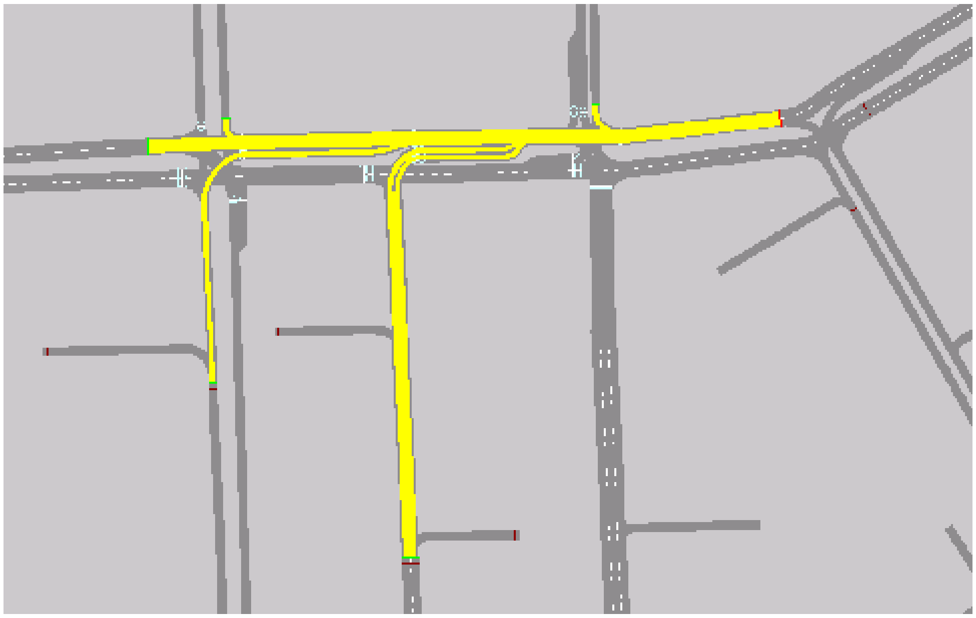


Figure 14. Intersection Routing Combination

VOLUME DATA FOR FREEWAY AND HIGHWAY SEGMENTS

Caltrans has placed data counters on both I-280 and Highway 87. Volumes for both locations were obtained from PeMS data. However, data for the freeway/highway segments included only one set of counters each on I-280 SB and NB at I-280 and the Highway 87 interchange within the simulated area. In addition, there was only one counter along Highway 87 NB and none on Highway 87 SB. The data for Highway 87 NB, which were last collected in 2006, displayed approximately 9,000 fewer vehicles than a more current dataset (2009 Annual Average Daily Traffic "Peak Hour").

The most current data available were used for all freeway and highway segments. The turning-movement spreadsheet occasionally contained volumes coming onto the surface streets from an off-ramp or vehicles departing onto the freeway/highway. These data were used first, and Cube Voyager data were used to fill in the locations for which no traffic-count data were available.

An AutoCAD file depicting the highways and freeways, along with the respective on-ramp and off-ramp volumes, was created for visualization purposes (see Figure 15).

Figure 15. On-Ramp/Off-Ramp Volumes on a Google Maps Image

VISSIM NETWORK CALIBRATION

After routing decisions were entered, calibration and validation were performed. Calibration in the completed VISSIM network for the base case scenario involved refining and adjusting the network to simulate realistic driving conditions. Calibrating a microscopic simulation model can include adjusting components, such as turning-movement volumes, car following model parameters, and traffic speeds. A well-calibrated model is essential for this research to predict future vehicle behavior and model alternative disaster scenarios. The model's volumes were compared to those in the SJDOT or Caltrans data. If the data did not match the models' volumes, behavior parameters in the VISSIM network were modified and the entire process was repeated. The calibration process is described in additional detail below.

Driving Behavior Parameters

The final network consists of both freeway and local streets involving different car following model parameters and driving behavior. Surface streets that use the "Urban (motorized)" driving behavior were not altered. Figure 16 shows a screenshot of the default values used in the simulation.

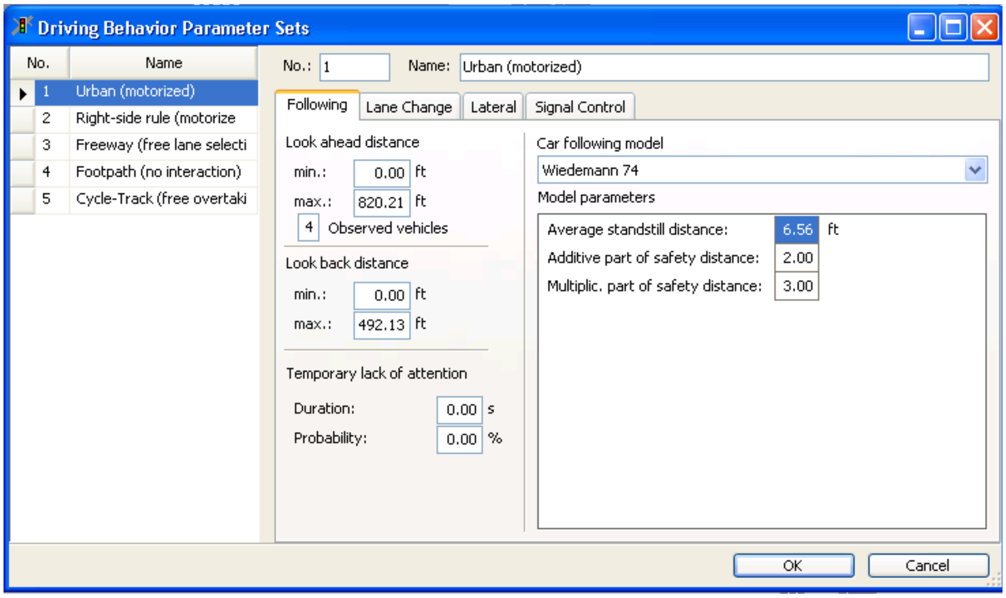


Figure 16. Driving Behavior Parameter for Local Roads

For freeway driving behavior, several of the car following parameters needed to be altered to adjust the network behavior to resemble reality. During the simulation of the base case scenario (i.e., a typical Friday afternoon), unrealistic congestion (i.e., not observed by the researchers in their trips to the region) built up at the on-ramps and off-ramps of I-280 NB and SB, as well as Highway 87 NB and SB. The congestion was created by many free-flowing vehicles traveling on the rightmost lanes, which prevented other vehicles on adjacent on-ramps from entering into the freeway. Also, free-flowing vehicles that were in an exit-only lane on the freeway would change lanes too late and create congestion. The congestion was corrected under the “Lateral” tab for freeway (free lane selection). The desired position at free flow on the freeways had previously been set to the middle of the lane, but this was changed to the left lanes on the freeway, and vehicles no longer queued at the on-ramps and off-ramps.

Table 7 presents the default values, a short description of the parameters, and the values used if the parameter was altered.

Table 7. Calibration of Freeway Car Following Parameters

Parameters	Parameter Description	Default Value	Parameter Values
CC0	(Standstill distance) or distance between stopped cars	4.92	1.51 ft
CC1	(Headway time) or time driver wants to maintain while following another car Example: The higher the value the more cautious the driver	0.90	1.00 s
CC2	(Following variation) or maximum distance a driver can go beyond safety distance before moving closer to front car Example: The higher the value, the more aggressive the driver	13.12	13.12 ft
CC3	(Threshold for entering "Following") defines when a driver needs to accelerate before reaching safety distance	-8.00	-8.00
CC4 and CC5	("Following" thresholds) control speed differences during "Following" state CC4 is used for negative and CC5 for positive speed differences Example: Smaller values result in a more sensitive reaction of drivers to accelerations or decelerations of the preceding car, i.e., the vehicles are more tightly coupled	(-0.35, 0.35)	(-0.35, 0.35)
CC6	(Speed dependency of oscillation) describes effect of distance on speed oscillation in the following process If parameter is zero, the speed oscillation will be independent of distance to preceding car Example: Larger values cause greater speed oscillation with increasing distance	11.44	11.44
CC7	(Oscillation acceleration) defines acceleration during oscillation process	0.82 ft/s^2	0.82 ft/s^2
CC8	(Standstill acceleration) defines desired acceleration from standstill situation	11.48 ft/s^2	11.48 ft/s^2
CC9	(Acceleration at 50 mph) defines desired acceleration at 50 mph	4.92 ft/s^2	4.92 ft/s^2

Vehicle-Record Data

Once behavior parameters were altered to represent reality satisfactorily, data were needed to advance to base-network validation. Data counters were placed to collect the number of vehicles passing a particular intersection point. In addition, travel time counters were placed for the entire length of the freeway and highway segments on the network. These data-collection methods were believed to be best suited to measure the network's similarity to data collected on individual vehicles throughout San José. The number of vehicles passing through an intersection was tallied every time a vehicle passed a data counter, and at the end of the simulation period of 4,500 seconds, the data were written to a file. For the travel time counters, data were collected every 1,500 seconds and the average was taken.

VISSIM NETWORK VALIDATION

Although the calibration process facilitated the creation of a VISSIM simulation that was visually similar to reality, the network had to be tested to see how it would respond to changes in the seed numbers. This process is important because validation of the network would justify its use in different disaster scenarios and would permit realistic comparison of the scenarios' performance.

Seed Numbers

The network's performance was tested with ten different seed numbers. When a random seed is chosen for a microscopic simulation, a random-number generator assigns values for certain parameters based on stochastic (probabilistic) distributions built into VISSIM. The random-number generator produces different numbers (based on the underlying distribution) for parameters such as lane changing, driver behavior, route choice, and car following. Running the simulation with the same seed number produces identical results on different runs. When seed numbers are altered, the simulation output displays different values based on different numbers assigned to driving behavior parameters.

GEH Statistics Validation for Turning-Movement Counts

After each simulation run based on one of the random seed numbers, turning movements at the three intersection locations were collected for analysis. The intersections were Santa Clara Street and Market Street, Park Avenue and Almaden Boulevard, and San Carlos Street and Almaden Boulevard. To define a baseline accuracy to test the simulation's validity, SJDOT field counts were compared to the simulation turning volumes using GEH statistics.

GEH statistics are commonly used in transportation analysis and simulation to compare sets of traffic volumes. The empirical formula is similar to that of a Chi-squared test:

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}} \qquad \textbf{(1)}$$

where M = traffic count from the simulation model, and C = traffic count observed in the real world.

The GEH statistics formula is not considered a true statistical test, but because it does not follow a linear pattern due to the potentially large variations in traffic volumes, it avoids common pitfalls of using simple percentage comparisons (Kilbert, 2011).

The simulation of downtown San José was assumed to be reasonably accurate when GEH statistics for all 36 turning movements were less than 5. The averaged statistics for the initial run shown in Table 8 are an average of the ten different-seed-number runs. None of the recorded volumes displayed a GEH statistic over 5, indicating that the simulation was validated for surface streets. Tables of the complete statistics from each simulation run and random seed are given in Appendix A.

Table 8. GEH Statistics for the Initial Model Run

Roadway/Intersection	Movement Direction	Simulation[a]	Actual[a]	GEH Statistic
Almaden and San Carlos	NbR	132	158	2.17
	NbT	285	348	3.56
	NbL	69	88	2.10
	EbR	217	209	0.54
	EbT	826	759	2.37
	EbL	198	184	1.01
	SbR	103	100	0.29
	SbT	1009	1017	0.25
	SbL	113	104	0.89
	WbL	120	106	1.33
	WbT	588	514	3.16
	WbR	94	83	1.22
Almaden and Park	NbR	34	36	0.37
	NbT	223	237	0.93
	NbL	35	37	0.36
	EbR	116	117	0.13
	EbT	83	86	0.37
	EbL	97	105	0.79
	SbR	87	86	0.10
	SbT	955	965	0.33
	SbL	43	48	0.70
	WbL	178	163	1.17
	WbT	112	104	0.79
	WbR	68	60	0.98
Market and Santa Clara	NbR	47	41	0.93
	NbT	276	231	2.85
	NbL	79	69	1.14
	EbR	119	114	0.49
	EbT	613	581	1.29
	EbL	92	87	0.51
	SbR	125	80	4.48
	SbT	886	760	4.40
	SbL	79	118	3.93
	WbL	107	90	1.68
	WbT	448	395	2.56
	WbR	91	80	1.20

[a]The number of vehicles that passed through the data-collection point during the simulation.

Travel Time Validation

Validating the network travel time required a method other than GEH statistics. Travel times were recorded separately for each highway and freeway segment in the network by driving the highways for the same distance as was coded. The actual travel times were then compared with the simulation times. The freeways in the network for which driving times were recorded were I-280 NB and SB, and the highways were Highway 87 NB and SB.

According to calibration targets developed by the Wisconsin Department of Transportation for its Milwaukee freeway-system model, model travel times must be within 15% of the observed travel times for more than 85% of the cases. The average statistics for the initial run of the San José model are shown in Table 9. None of the recorded volumes had a percentage error even close to 15%. Tables for the complete statistics detailing each simulation run and random seed number are presented in Appendix B.

Table 9. Initial Run Travel Time Statistics

Roadway	Actual Travel Time (min)	Percent Error	Simulation Average Travel Time (min)
I-280 NB	3.43	–3.3	3.3
I-280 SB	4.15	–3.2	4.0
Hwy 87 NB	3.15	–2.5	3.1
Hwy 87 SB	3.15	7.1	3.4

ESTIMATING THE NUMBER OF RUNS

Estimating the adequate number of simulation runs for the acceptable margin of error is an iterative process. The results from the ten runs used in the validation process were first used to obtain estimates of standard error and averages of the parameters of interest. These averages and standard deviations were then used with a specified margin of error to determine the appropriate number of runs for the disaster scenarios. If fewer than ten runs were needed, the ten runs would be used; if more than ten were needed, the simulation would be run that many times to repeat the estimation. The following equation was used to estimate the number of runs:

$$n_r \geq \frac{s^2 z^2_{\frac{\alpha}{2}}}{\varepsilon^2}$$

where s^2 = performance-metric variance based on ten trial runs

$z^2_{\frac{\alpha}{2}}$ = threshold value for a 100 percent (1–α) confidence interval

n_r = required number of times to run the simulation

ε = maximum error of the estimate

Freeway travel times were chosen as the performance measure to determine the number of simulation runs required. A 95% confidence level (α = 0.05) was chosen, which corresponds to a z-value of 1.96. The maximum error of the estimate (ε) was assumed to be 5% of the mean for each performance metric. The number of runs required from each calculation was rounded up to the nearest whole number. The minimum number of runs specified from each performance metric on each roadway is shown in Table 10.

Table 10. Number of Simulation Runs Required

Roadway	I-280 NB	I-280 SB	Hwy 87 NB	Hwy 87 SB
Average (min)	3.3	4.0	3.1	3.4
Standard deviation(s)	0.1	0.1	0.1	0.0
Variance (s^2)	0.0	0.0	0.0	0.0
$z^2_{\alpha/2}$ for 95% confidence level	1.96	1.96	1.96	1.96
$z^2_{\alpha/2}$ for 95% confidence level	3.84	3.84	3.84	3.84
ε	0.2	0.2	0.2	0.2
Number of runs required (n)	3	1	1	1

Although fewer than five runs were required for all of the metrics, ten simulations were run for the disaster scenarios. It can be concluded that ten simulation runs should be more than sufficient to establish a travel time estimate for the disaster scenarios with a 95% level of confidence.

IV. ALTERNATIVE DISASTER SCENARIOS

The validated base case network was used to estimate network performance and related variations resulting from the mass exodus of vehicles from the downtown area.

DISASTER SCENARIO ASSUMPTIONS

One important assumption for all the disaster scenarios was that all the parking lots are filled to capacity because of the special events being organized (making them essentially worst-case scenarios). It was also assumed in all the scenarios that HP Pavilion traffic leaving from the directly adjacent parking lot divide evenly (1/4 of 1,460)—meaning 365 vehicles each were input onto Julian Street, Cahill Street, Alamden Boulevard, and N. Autumn Street—and all leave at approximately the same time. Three-quarters of the cars in the San José Convention Center parking lot across from the center would exit onto Almaden Boulevard from Woz Way. The remainder would exit onto Woz Way toward the Highway 87 NB off-ramp. In the base case disaster scenario, people evacuate as they might according to these assumptions. This scenario is compared with three alternative scenarios. In each case, the travel times (for evacuees as well as for emergency-response personnel) are compared to the base case scenario. These scenarios were chosen to demonstrate how various scenarios can be tested using simulation. Of course, emergency planners may deem other scenarios more likely or realistic than these.

The San José Fire Department uses the Opticon system (for traffic-light preemption by first responders) during normal traffic operations. However, traffic-light preemption may not be effective in disasters such as those considered here, as motorists are likely to block intersections when lights change, making it impossible for emergency vehicles to pass through. Therefore, the Opticon function was not factored into the travel time estimates.

CONTINGENCY SCENARIOS

Scenario 1

The first contingency scenario was created to test the effect of an incident such as an accident or construction work resulting in road closure. At the peak hour, one lane on Bird Avenue was closed as cars were trying to leave HP Pavilion and the other affected areas. The closure was positioned southbound along Bird Avenue between San Carlos Street and the I-280 NB on-ramp. Figure 17 depicts the location of the closure.

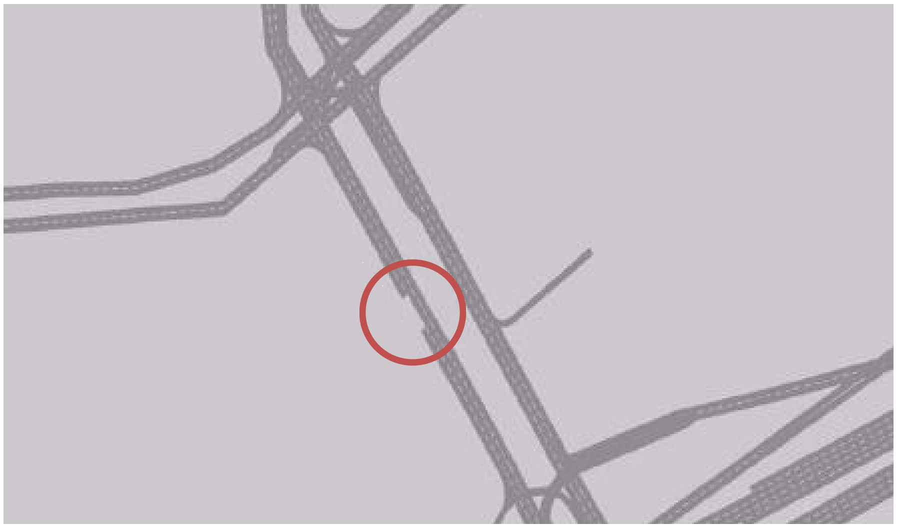


Figure 17. Scenario 1: Right Lane Closure on Bird Avenue

Scenario 2

The second scenario was to created to test the effects, if any, of contraflow lanes exiting toward the freeway on S. Montgomery Street, beginning at the Montgomery and Park intersection, and heading south toward I-280 and past the on- and off-ramps. All the traffic was expected to depart from HP Pavilion toward the freeway, and the contraflow lanes provided another path to exit the area. The lane configurations from Montgomery Street to Bird Avenue are shown in Figure 18.

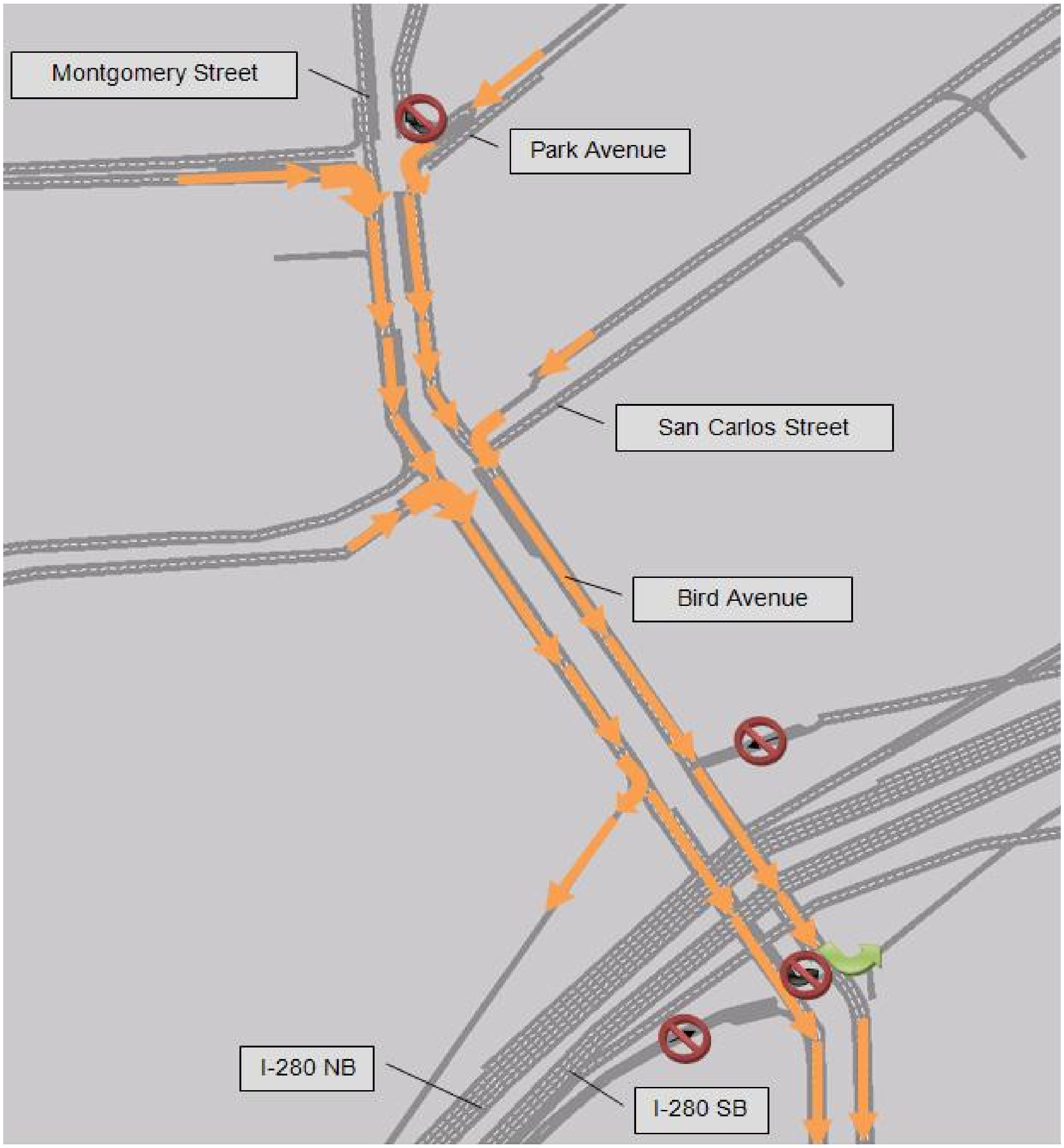


Figure 18. Scenario 2: Contraflow Lanes

This was the most complex scenario to model because it involved traffic rerouting on at least four different streets and one freeway on-ramp. The expected congestion on Montgomery Street/Bird Avenue could potentially be alleviated by creating a path for left-turning vehicles from both San Carlos Street and Park Avenue to exit toward I-280. For vehicles heading east on both Park Avenue and San Carlos Street, there are two right-turn lanes onto Montgomery Street/Bird Avenue. In addition, left-turn and through movements from this intersection approach are prohibited.

Vehicles traveling west on San Carlos Street and Park Avenue have one left-turn lane each when turning onto Montgomery Street/Bird Avenue. Through movements are prohibited, and from Park Avenue, only emergency vehicles are allowed to make a right turn going north toward HP Pavilion. From San Carlos Street, right-turn movements are entirely prohibited because there is no emergency vehicle-only lane.

Also, as depicted in Figure 18, the Bird Avenue exits for both I-280 NB and SB are open to emergency assets only. In addition, vehicles wanting access to the I-280 SB on-ramp to Bird Avenue must be on the contraflow lanes, not the original lanes, because there will be no left turns from the original lanes onto the on-ramp. The green arrow in the figure indicates the permitted left-turn movement from the contraflow lanes onto the freeway.

Scenario 3

In the third scenario, it is assumed that more people take public transit from the Diridon Station Transit Center to exit the disaster area, which could result in less congestion and a faster exit from the disaster area for everyone. Volume from the 24 exiting parking lots of the disaster areas was reduced by 30% as a result of the evacuees using public transit (In VISSIM, any vehicle generating point within the simulation is called a “parking lot.”). This scenario was created to demonstrate how effective public transit can be for emergency evacuation in a downtown area. The proportion of drivers choosing transit can be modified to test different scenarios.

EMERGENCY VEHICLE ROUTING

The model was used to aid in determining the optimal routing strategy for dispatching a fleet of emergency-response vehicles from fire stations to the disaster sites. The three fire stations in San José that would certainly respond in a disaster scenario are Stations 1, 7, and 30. Their locations are shown in Figure 19.

The shortest and fastest routes for response vehicles traveling from the disaster site to hospitals were also analyzed. The primary hospitals to receive the injured from the disaster were (1) O’ Connor Hospital, (2) Valley Medical Center, and (3) the Regional Medical Center, shown in Figure 20.

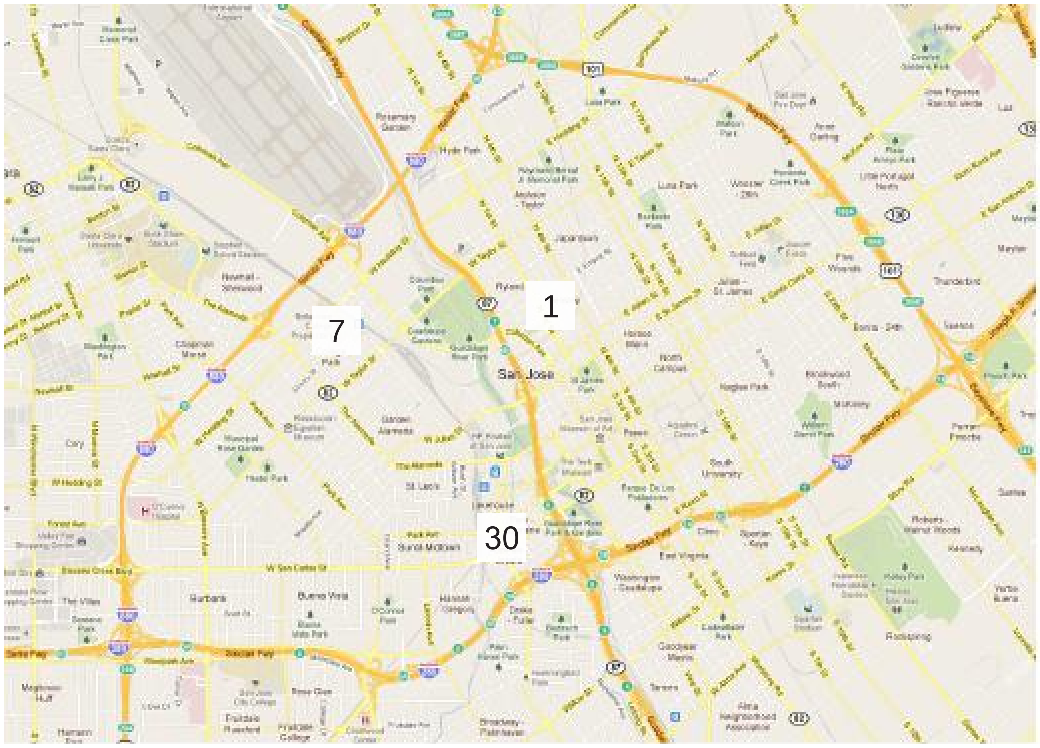


Figure 19. Primary Fire Station Responders

Figure 20. Primary Hospitals to Which the Injured Would Be Taken

For each scenario, including the base case, the fastest route was determined using the traffic simulation and Google Maps travel times. For example, from HP Pavilion to O' Connor Hospital in the base case scenario, the fastest total time from beginning to end was achieved by traveling via Montgomery, R onto Julian -> R onto Highway 87 SB on-ramp -> R onto I-280 NB -> R onto I-880 NB -> exit R onto Stevens Creek Boulevard -> L onto Bellerose -> L onto Forest. Since O' Connor Hospital was outside the simulated network, a Google Maps time was substituted for the time until a coded network road began in the simulation. The total travel time was 11.3 minutes, of which 5 minutes was Google Maps travel time and 6.3 minutes was simulation time.

Two of the fire stations are within the network. To record the travel time for the emergency vehicles to the disaster areas, two new vehicle compositions were created. For network locations where emergency vehicles and other vehicles could emerge together, a vehicle composition called Car + Emergency was created that would generate 3% of the total flow as emergency vehicles. In locations where only fire station vehicles would emerge, a separate vehicle composition called Fire stations was created, consisting of heavy gross vehicles (HGVs), i.e., fire trucks and engines. In addition, new routing decisions for the vehicles had to be created and directed to the disaster sites. The averaged fastest travel times, as well as the most efficient routes for both hospitals and fire stations, are listed in Tables 11 through 14 for each scenario tested.

Table 11. Most Efficient Routes and Fastest Times from Disaster Areas to O' Connor Hospital and Santa Clara Valley Medical Center

Hospital	Origin	Base case Routes	Total Time (minutes)			
			Base Case	Scenario 1[a]	Scenario 2[a]	Scenario 3[a]
O' Connor Hospital	HP Pavilion	From Montgomery, R onto Julian -> R onto Hwy 87 SB onramp -> R onto I- 280 NB -> R onto I- 880 NB -> exit R onto Stevens Creek Blvd. -> L onto Bellerose -> L onto Forest Ave.	11.3	11.8	11.7	11.5
	San José Convention Center	From Almaden exit from San Jose Convention Center -> L onto Almaden -> R onto I-280 NB onramp -> exit R onto I-880 NB onramp at interchange -> exit R onto Steven's Creek Blvd -> L onto Bellerose -> R onto Forest Ave.	8.1	8	8	7.9
		From Market St. exit from San Jose Convention Center -> R onto Market -> R -> on W Reed -> Straight onto I-280 NB onramp -> exit R onto I-880 NB onramp at interchange -> exit R onto Steven's Creek Blvd -> L onto Bellerose -> R onto Forest Ave.	8.3	8.9	8.8	8.8
	IRS Building	Continue SE on Market toward Park -> R on Park -> L on Almaden -> R onto I-280 NB onramp -> exit R at I-880 NB exit -> exit R at Stevens Creek Blvd. exit -> L on Bellerose -> L on Forest Ave.	13.1	18.9	12.6	12.6
	100 Paseo de San Antonio	From 3rd continue towards San Fernando -> R on San Fernando -> R on 4th -> Continue onto 4th St. onramp for I-280 NB -> exit right at the I-880 NB interchange -> exit right onto Stevens Creek -> L onto Bellerose -> L onto Forest Ave.	10.9	11	10.8	10.9
Santa Clara Valley Medical Center	HP Pavilion	Continue on Montgomery toward Julian -> R on Julian -> R onto Hwy 87 SB -> R onto I-280 NB -> exit R at Parkmoor -> L onto Bascom -> R onto Renova	11.3	11.8	11.7	11.5
	San José Convention Center	From Market exit from San Jose Convention Center -> -> R onto Market -> R on W Reed -> Straight onto I-280 NB onramp -> exit R at Parkmoor -> L onto Bascom -> R onto Renova	8.1	8	8	7.9
		From Almaden exit from San Jose Convention Center -> L onto Almaden -> R onto I-280 NB onramp -> exit R at Parkmoor -> L onto Bascom -> R onto Renova	8.9	8.9	8.8	8.8
	IRS Building	Continue SE on Market toward Park -> R on Park -> L on Almaden -> R onto I-280 NB onramp -> exit R at Parkmoor -> L at Bascom -> R on Renova	12.1	17.9	11.5	11.6
	100 Paseo de San Antonio	Continue on 3rd towards San Fernando -> R onto San Fernando -> R on 4th -> R onto I-280 NB 4th St. onramp -> exit R at Parkmoor -> L on Bascom -> R on Renova	9.9	10	9.8	9.9

Table 12. Most Efficient Routes and Fastest Times from Disaster Areas to Regional Medical Center

Hospital	Origin	Base Case Routes	Total Time (minutes)			
			Base Case	Scenario 1[a]	Scenario 2[a]	Scenario 3[a]
Regional Medical Center of San Jose	HP Pavilion	Continue NW on Montgomery toward Julian -> R on Hwy 87 SB onramp -> R on I-280 SB exit -> L at I-280 NB and SB split -> I-280 SB becomes I-680 NB -> exit R at McKee Rd -> L at split for West McKee Rd -> L onto Jackson	14.3	14.5	14.5	13.3
	San José Convention Center	From Market St. exit -> R onto Market -> R onto I-280 SB onramp -> I-280 SB becomes I-680 NB -> exit McKee Rd -> L onto Jackson	13.5	13.1	11.7	10.9
		From Almaden exit -> R on Almaden -> R on San Carlos -> R on Market -> R onto I-280 SB onramp -> exit R onto Hwy 101 NB -> L at split for Hwy 101 NB -> exit R at McKee Rd -> R onto Jackson	10.1	10.1	10	9.9
	IRS Building	Continue SE on Market towards I-280 -> R onto I-280 SB ramp -> Continue onto I-680 N -> exit R at McKee Rd -> L at split for McKee Rd W -> L onto Jackson	15.2	14.9	13.6	13.4
	100 Paseo de San Antonio	Continue on 3rd towards San Fernando -> R on San Fernando -> R on 4th -> L on San Salvador -> R on 7th -> L at Virginina St onramp to I-280 SB -> I-280 SB becomes I-680 N-> exit R at McKee Rd -> L at split for McKee Rd W -> L onto Jackson	15.3	15.3	15.4	15.3

Table 13. Most Efficient and Fastest Times to Disaster Areas from Fire Station 1 and Fire Station 7

Fire Station	Destination	Base Case Routes	Total Time: Base Case (min)	Scenario 1 Routes	Total Time: Scenario 1 (min)	Scenario 2 Routes	Total Time: Scenario 2 (min)	Scenario 3 Routes	Total Time: Scenario 3 (min)
Fire station 1 (225 North Market St.)	HP Pavilion	Beginning from Julian L onto Almaden	9.7	Beginning from Julian L onto Almaden	9.6	Beginning from Julian L onto Almaden	9.7	Beginning from Julian L onto Almaden	9.5
	San José Convention Center	Down Market St -> R onto Santa Clara -> L onto San Carlos St.	8.2	Down Market St -> R onto Santa Clara -> L onto San Carlos St.	8.5	Down Market St -> R onto Santa Clara -> L onto San Carlos St.	7.6	Down Market St -> R onto Santa Clara -> L onto San Carlos St.	8.2
	IRS Building	Beginning on Market St. head south	3.4	Beginning on Market St. head south	3.9	Beginning on Market St. head south	3.6	Beginning on Market St. head south	3.5
	100 Paseo de San Antonio	Beginning on Market St. head south -> L onto San Carlos -> L onto 3rd	2.5	Beginning on Market St. head south -> L onto San Carlos -> L onto 3rd	2.5	Beginning on Market St. head south -> L onto San Carlos -> L onto 3rd	2.3	Beginning on Market St. head south -> L onto San Carlos -> L onto 3rd	2.3
Fire station 7 (800 Emory St.)	HP Pavilion	From Emory St. -> R on Laurel -> L on Taylor -> R on Stockton -> L onto Julian -> R on Mongomery	3.5	From Emory St. -> R on Laurel -> L on Taylor -> R on Stockton -> L onto Julian -> R on Mongomery	3.5	From Emory St. -> R on Laurel -> L on Taylor -> R on Stockton -> L onto Julian -> R on Mongomery ->	3.5	From Emory St. -> R onto Laurel -> L onto W. Taylor St. -> Merge onto Hwy 87 SB -> Exit Julian St -> R onto Montgomery	3.5
	San José Convention Center	From Emory St. -> R onto Laurel -> L onto W. Taylor St. -> Merge onto Hwy 87 SB -> exit Park Ave. -> L onto San Carlos	6.3	From Emory St. -> R onto Laurel -> L onto W. Taylor St. -> Merge onto Hwy 87 SB -> exit Park Ave. -> L onto San Carlos	7.8	From Emory St. -> R onto Laurel -> L onto W. Taylor St. -> Merge onto Hwy 87 SB -> exit Park Ave. -> L onto San Carlos	7.2	From Emory St. -> R onto Laurel -> L onto W. Taylor St. -> Merge onto Hwy 87 SB -> exit Park Ave. -> L onto San Carlos	7.4
	IRS Building	From Emory St. -> R onto Laurel -> L onto W. Taylor St. ->R onto Coleman -> Coleman becomes Market	8	From Emory St. -> R onto Laurel -> L onto W. Taylor St. ->R onto Coleman -> Coleman becomes Market	8.4	From Emory St. -> R onto Laurel -> L onto W. Taylor St. ->R onto Coleman -> Coleman becomes Market	8.3	From Emory St. -> R onto Laurel -> L onto W. Taylor St. ->R onto Coleman -> Coleman becomes Market	8.4
	100 Paseo de San Antonio	From Emory St. -> R onto Laurel -> L onto W. Taylor St. ->R onto Coleman -> Coleman becomes Market -> L onto San Carlos -> L onto 3rd	9	From Emory St. -> R onto Laurel -> L onto W. Taylor St-> R onto 4th -> R onto San Carlos -> Right on 3rd	10.3	From Emory St. -> R onto Laurel -> L onto W. Taylor St-> R onto 4th -> R onto San Carlos -> Right on 3rd	10.2	From Emory St. -> R onto Laurel -> L onto W. Taylor St. ->R onto Coleman -> Coleman becomes Market -> L onto San Carlos -> L onto 3rd	10.3

Table 14. Most Efficient Routes and Fastest Times to Disaster Areas from Fire Station 30

Fire Station	Destination	Base Case Routes	Total Time: Base Case (min)	Scenario 1 Routes	Total Time: Scenario 1 (min)	Scenario 2 Routes	Total Time: Scenario 2 (min)	Scenario 3 Routes	Total Time: Scenario 3 (min)
Fire station 30 (454 Auzerais Avenue)	HP Pavilion	L on San Carlos -> R on Montgomery -> L on St. John	2.9	R on Montgomery (from Auzerais) -> L on St. John	2.9	L on San Carlos -> R on Montgomery -> L on St. John	4	L on San Carlos -> R on Montgomery -> L on St. John	2.5
	San José Convention Center	R on Gilford -> R on San Carlos	1.9	R on Gilford -> R on San Carlos	1.8	R on Gilford -> R on San Carlos	1.2	R on Gilford -> R on San Carlos	1.4
	IRS Building	R on Gilford -> R on San Carlos -> L on Almaden -> R on Santa Clara -> L on Market	7.1	R on Gilford -> R on San Carlos -> L on Almaden -> R on Santa Clara -> L on Market	6.1	R on Gilford -> R on San Carlos -> L on Almaden -> R on Santa Clara -> L on Market	5.6	R on Gilford -> R on San Carlos -> L on Almaden -> R on Santa Clara -> L on Market	3
	100 Paseo de San Antonio	R on Gilford -> R on San Carlos -> L on 3rd St.	7	R on Gilford -> R on San Carlos -> L on 3rd St.	2.9	R on Gilford -> R on San Carlos -> L on 3rd St.	2.3	R on Gilford -> R on San Carlos -> L on 3rd St.	2

EMERGENCY VEHICLE TRAVEL TIMES

Travel Times to O' Connor Hospital

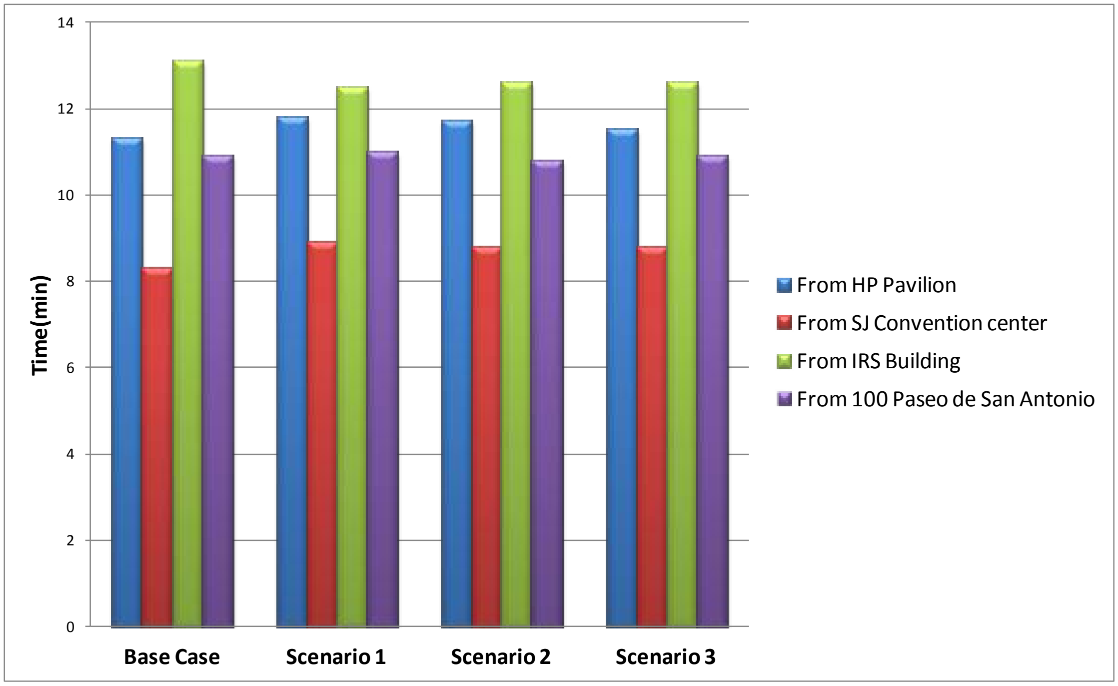


Figure 21. Travel Times to O' Connor Hospital from Disaster Sites

Figure 21 shows that travel time for ambulances from the disaster sites to O'Connor Hospital were relatively consistent for all four scenarios. For example, an ambulance traveling from HP Pavilion to O' Connor Hospital would have the same travel time in all the scenarios. Likewise, the travel times for ambulances traveling from the San José Convention Center would differ by no more than 30 seconds. One of the reasons for the consistent travel times is that ambulances going to O' Connor Hospital were traveling on the most optimized routes, which are the same for each scenario.

Travel Times to Santa Clara Valley Medical Center

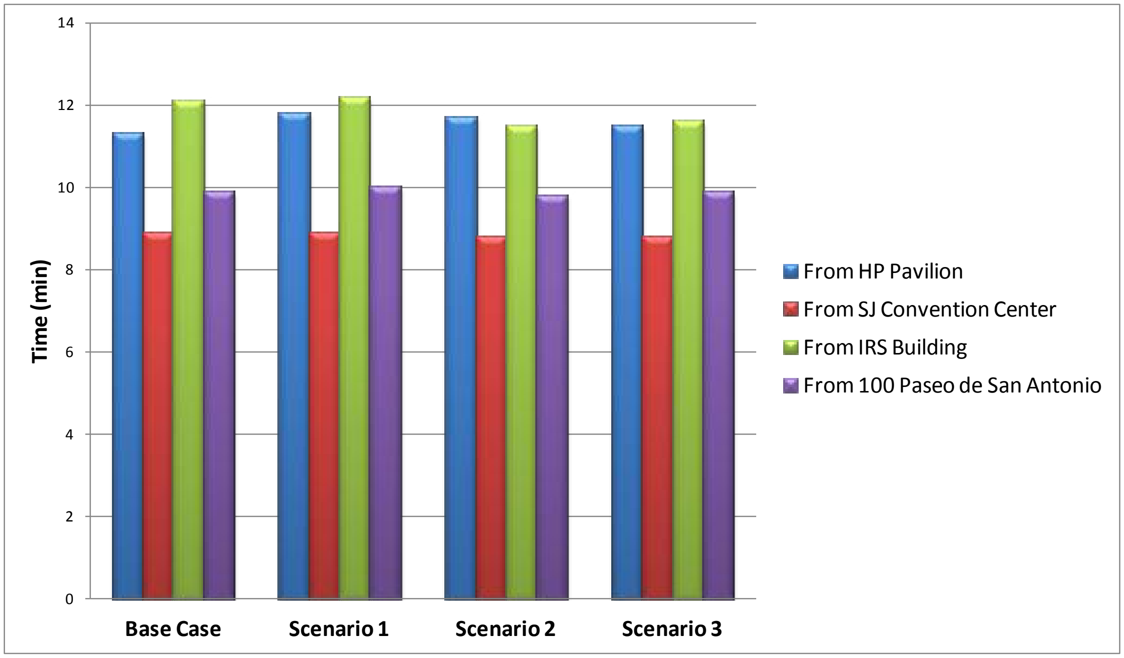


Figure 22. Travel Times to Santa Clara Valley Medical Center from Disaster Sites

As shown in Figure 22, the results for ambulances dispatched to Santa Clara Valley Medical Center from HP Pavilion were very similar in consistency to those for O' Connor Hospital, although the travel times from the disaster sites varied. Overall, the emergency vehicle travel times from the San José Convention Center were the shortest. The travel time for trips to Santa Clara Valley Medical Center are mostly unaffected by the existing traffic or the additional congestion created by the mass exodus of vehicles from parking lots. Most of the ambulance route from the San José Convention Center is on I-280 NB, which would be impacted less than local and collector roads near the disaster area.

Travel times for ambulances from the HP Pavilion did not differ significantly among the scenarios, primarily because of ambulances having sole access to Highway 87. This suggests that authorities may be able to get help to HP Pavilion victims quite easily under the circumstances simulated. Without any congestion, the ambulances could quickly gain access to the necessary route from HP Pavilion; other route options involved less distance, but travel would be on local roads.

Travel times from the IRS building would be greatest for the base case, Scenario 1, and Scenario 2 because of the congestion severity encountered along Santa Clara Street. The simulation showed that vehicles would travel quickly along Highway 87 but would encounter severe congestion approaching the hospital via the Santa Clara Street off-ramp. Other route options explored resulted in even more travel time. There were no significant differences in travel time for ambulances traveling from 100 Paseo de San Antonio.

Travel Times to the Regional Medical Center

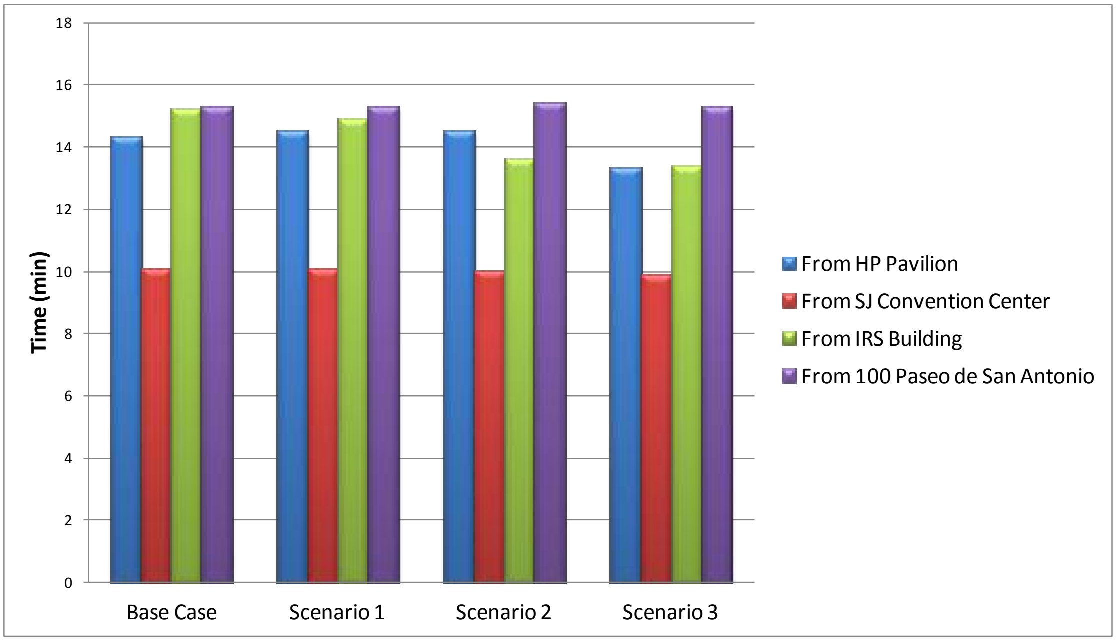


Figure 23. Travel Times to the Regional Medical Center from Disaster Sites

As shown in Figure 23, the travel times to the Regional Medical Center were very consistent for ambulances traveling from HP Pavilion, again because emergency vehicles have exclusive access to Highway 87, thereby avoiding congestion on the local roads. The same consistency was found for ambulances traveling from the San José Convention Center. Travel times from 100 Paseo de San Antonio were the longest in all the scenarios due to the congestion on 4th Street caused by vehicles attempting to access I-280 NB. The travel times were relatively consistent among the scenarios.

Travel Times from Fire Station 1

This section examines the travel times from fire stations so that the best dispatch location for each affected area can be identified.

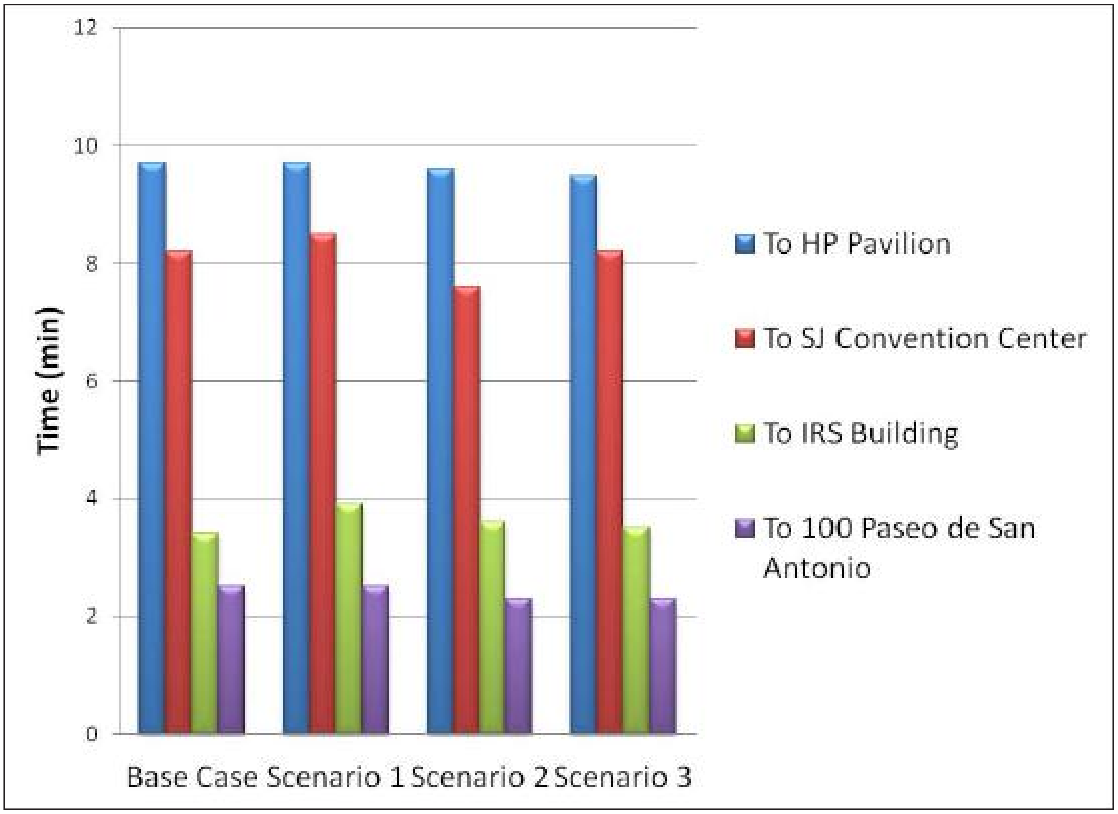


Figure 24. Travel Times from Fire Station 1 to Disaster Sites

As shown in Figure 24, an emergency vehicle trip from Fire Station 1 to HP Pavilion took the most time. Although the vehicles had to travel only 0.7 miles, they encountered a great deal of congestion on Julian Street as a result of vehicles exiting the parking lots in addition to the regular traffic flow. Travel times for emergency vehicles going to the San José Convention Center were generally consistent at approximately 8 minutes. Also, vehicles traveling to the IRS building, which was right down the street, did not encounter any congestion. It is clear that Fire Station 1 should be used to dispatch vehicles to the IRS building and to 100 Paseo de San Antonio.

Travel Times from Fire Station 7

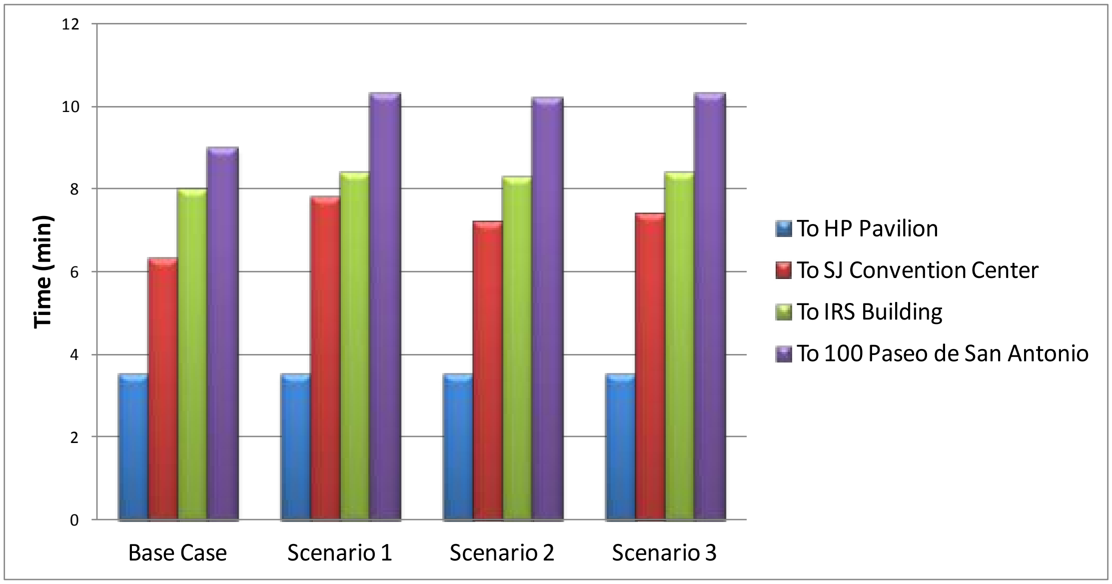


Figure 25. Travel Time from Fire Station 7 to Disaster Sites

As shown in Figure 25, there was very little difference between travel times from Fire Station 7 to the four disaster sites. For example, the travel times from Fire Station 7 to HP Pavilion were identical across all four scenarios, as was the case for most of the destinations.

Travel Times from Fire Station 30

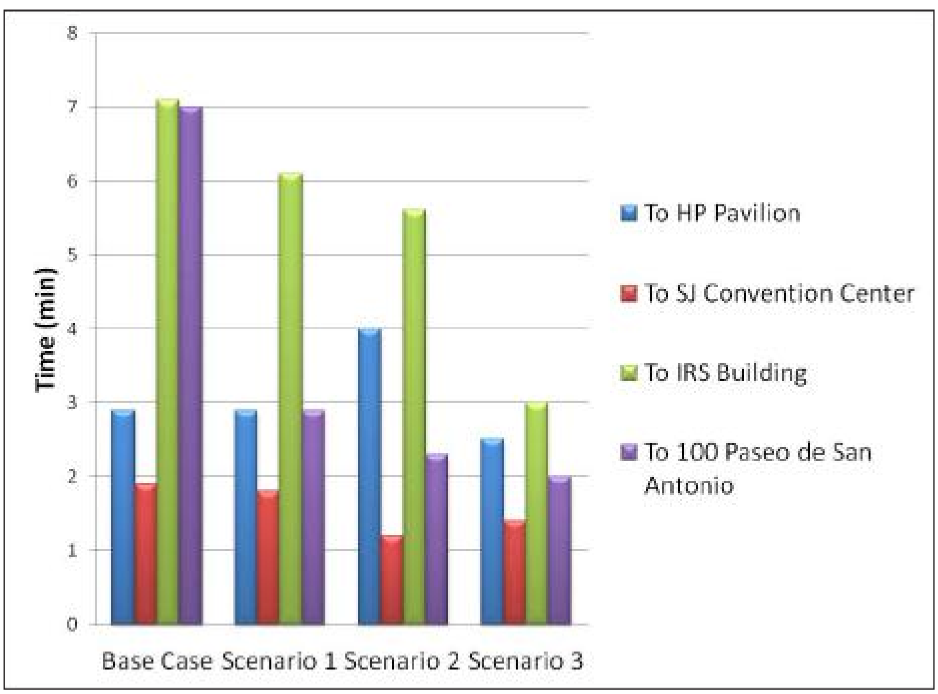


Figure 26. Travel Time from Fire Station 30 to Disaster Areas

Figure 26 shows that emergency vehicles traveling from Fire Station 30 to HP Pavilion would encounter very similar travel times at around 3 minutes, except in Scenario 2. The simulation travel time was about half the predicted Google Maps travel time of 5 minutes. However, in Scenario 2, the contraflow lanes providing traffic routing away from HP Pavilion seemed to have an adverse effect on travel time. The travel times for emergency vehicles traveling to the San José Convention Center were around 1 to 2 minutes. The trips to the IRS building most clearly highlighted the effects of the vehicle reduction resulting from greater use of public transit in Scenario 3. Whereas travel times in the three preceding scenarios were over 5 minutes, the Scenario 3 travel times were around 1.5 to 3 minutes.

EMERGENCY RESPONDER TRAVEL TIMES TO AND FROM DISASTER SITES

Travel Times from Disaster Areas to Hospitals

The hospital at which patients could most quickly arrive was analyzed for each disaster area. Figure 27 shows the travel times from HP Pavilion to the primary hospitals in the disaster scenarios.

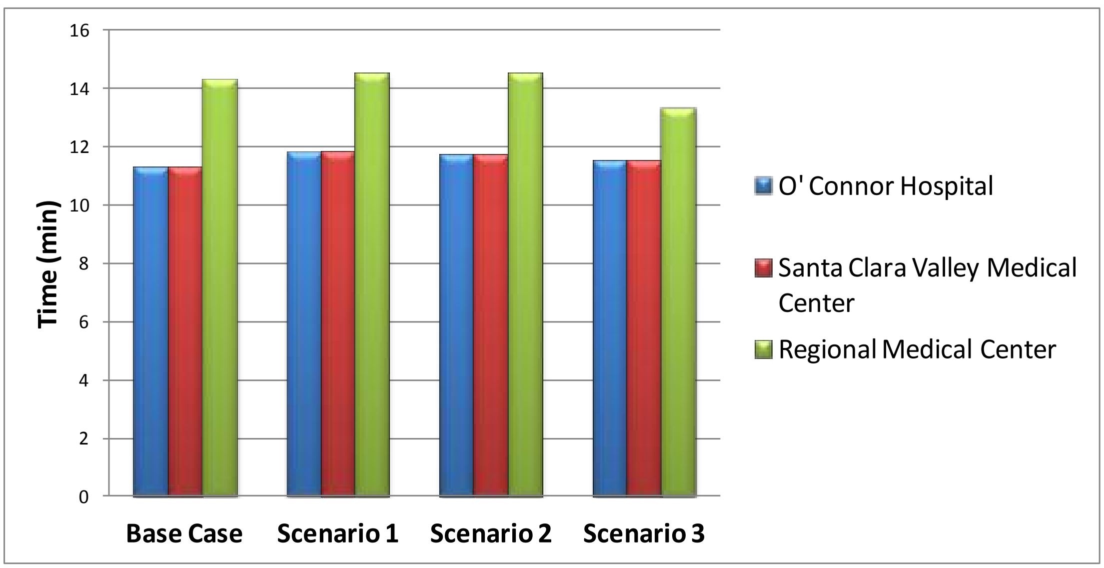


Figure 27. Travel Times from HP Pavilion to Primary Hospitals

Ambulances could take patients affected by the disaster to either O'Connor Hospital or Santa Clara Valley Medical Center. The travel times from HP Pavilion were all very close to 11 minutes, indicating that the ambulance routes were relatively unaffected by the differences in the scenarios.

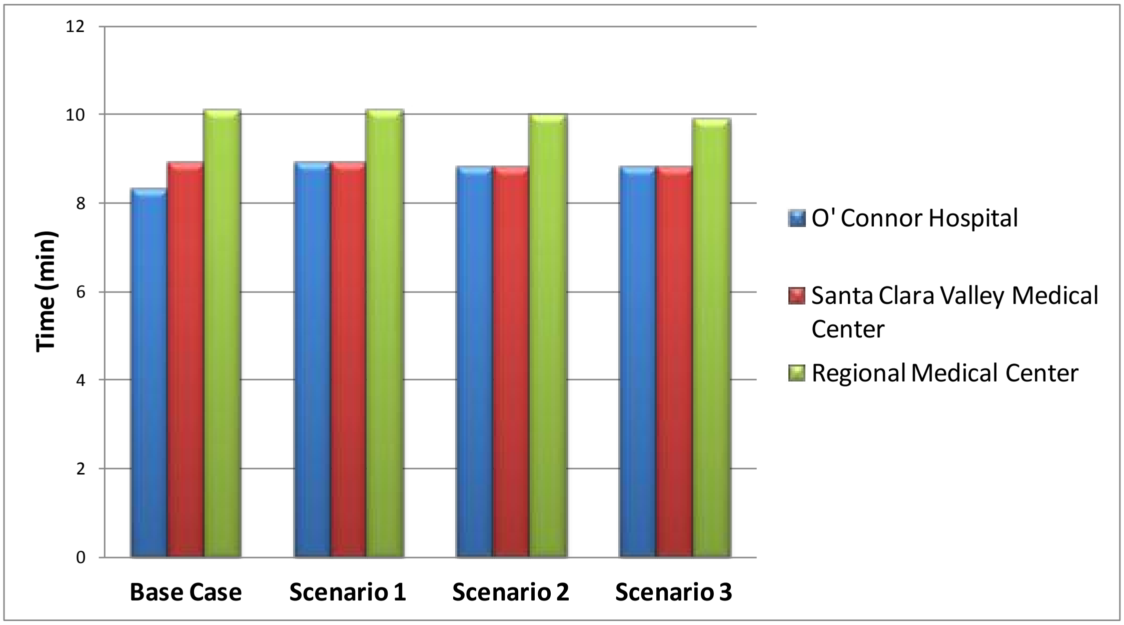


Figure 28. Travel Times from the San José Convention Center to Primary Hospitals

Persons injured at the San José Convention Center should be dispatched to either O' Connor Hospital or Santa Clara Valley Medical Center in Scenarios 1, 2, and 3 because the travel time is less than that to the Regional Medical Center. For the base case scenario, however, O' Connor Hospital would be preferred as the travel time to it is 1 minute less than the time to the next closest hospital, Santa Clara Valley Medical Center (see Figure 28).

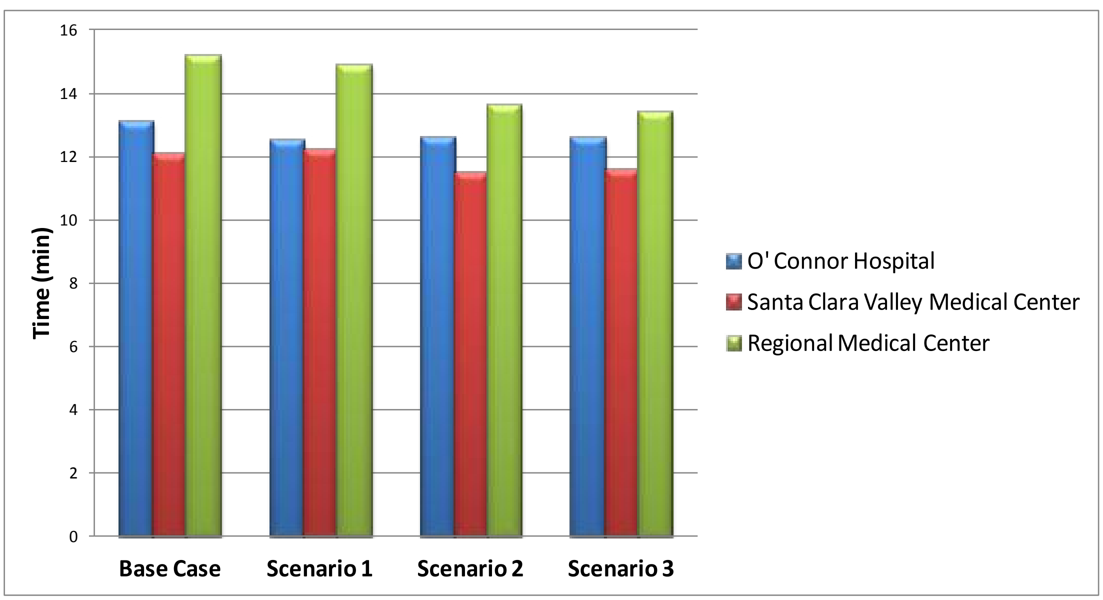


Figure 29. Travel Time from the IRS Building to Primary Hospitals

Ambulances traveling from the IRS building should be dispatched to Santa Clara Valley Medical Center in the base case and Scenarios 2 and 3. O' Connor Hospital would be the next best option; the travel time differences for the two hospitals are only about a minute or less, as shown in Figure 29.

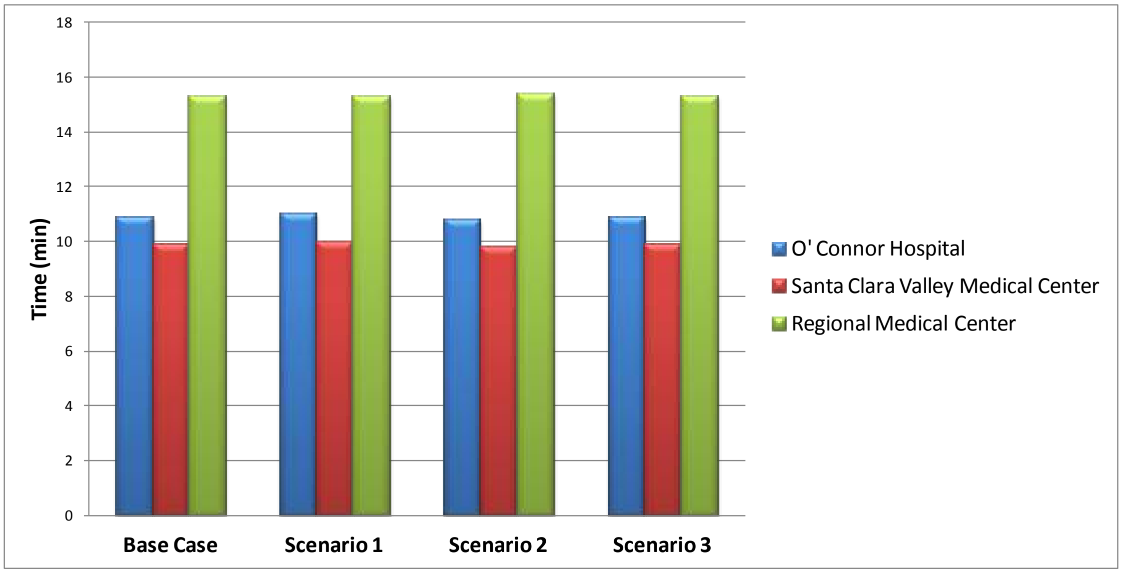


Figure 30. Travel Time from the State of California Building to Primary Hospitals

Travel time from the State of California building at 100 Paseo de San Antonio was consistently shortest for Santa Clara Valley Medical Center in all of the scenarios. However, Figure 30 shows that the time to O' Connor Hospital was only one minute or less greater than the time to Santa Clara Valley Medical Center. Therefore, O' Connor Hospital would be the second best option for patients dispatched from the State of California building.

Travel Times from Fire Stations to Disaster Areas

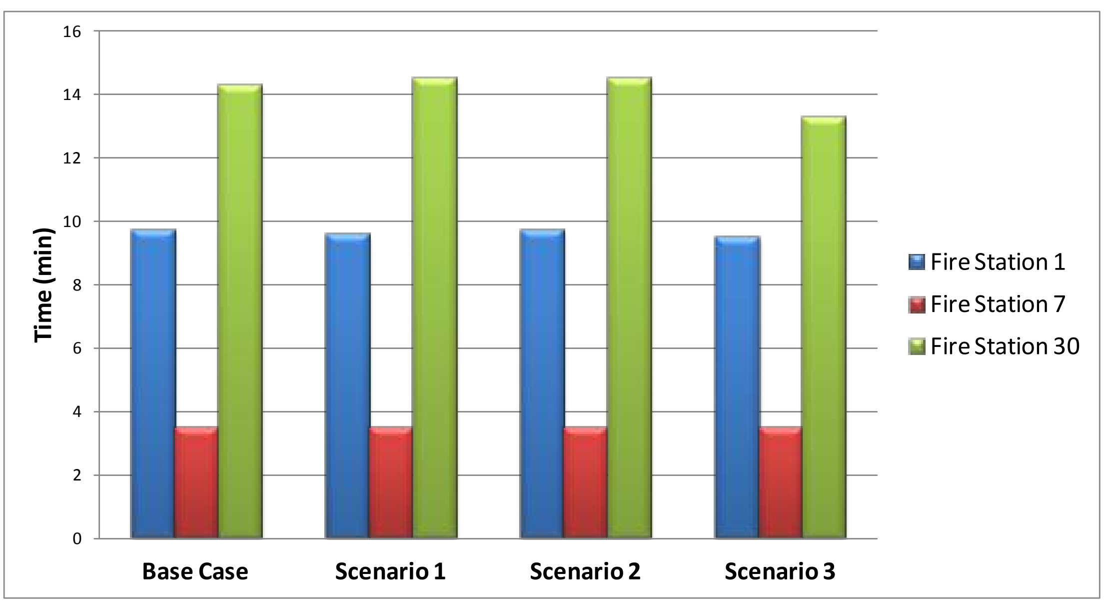


Figure 31. Travel Times from Fire Stations to HP Pavilion

As shown in Figure 31, Fire Station 7 should be the primary responder to a disaster at HP Pavilion in all of the simulation scenarios; its response time was consistently about 7 minutes shorter than that of the next closest fire station, Fire Station 30.

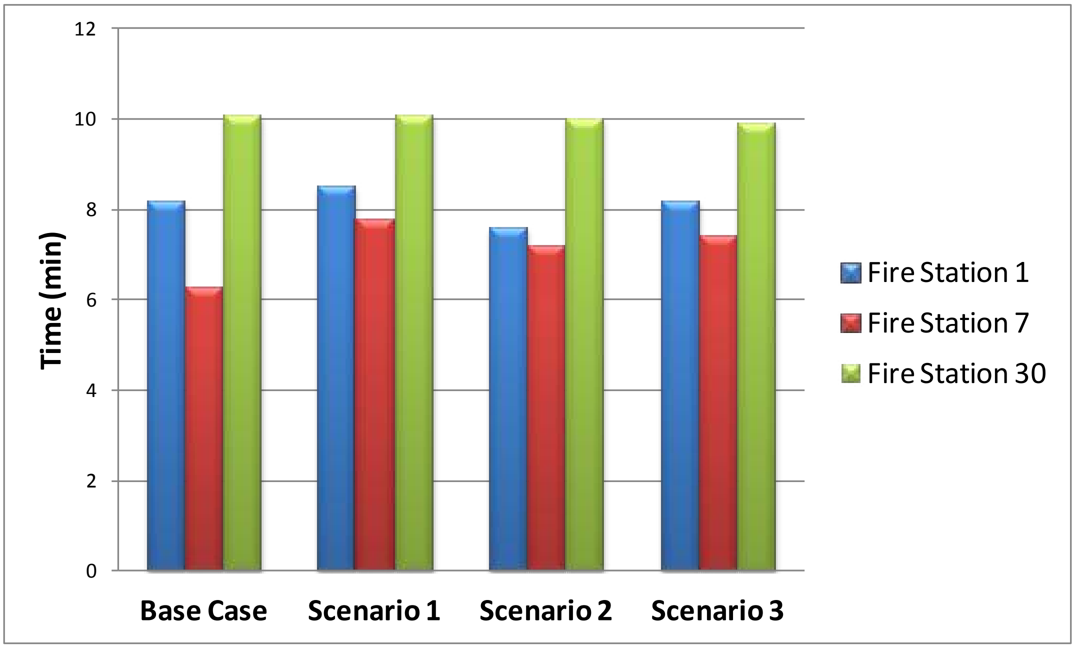


Figure 32. Travel Times from Fire Stations to the San José Convention Center

Travel times to the San José Convention Center were clearly shortest for Fire Station 7, as shown in Figure 32. The travel times from Fire Station 7 were shorter than those from Fire Station 1 by about one to two minutes for each scenario. Therefore, in all the simulation scenarios, Fire Station 7 should be the primary responder to the San José Convention Center.

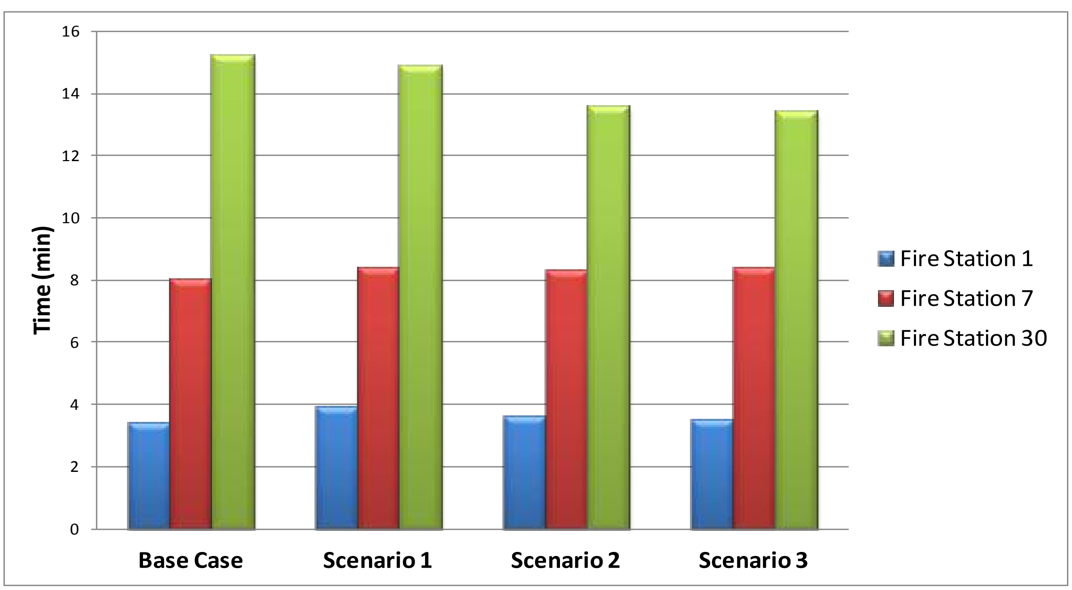


Figure 33. Travel Times from Fire Stations to the IRS Building

Fire Station 1's proximity to the IRS building (only 0.2 miles) makes it the first choice for all of the scenarios. Fire Station 7 was not even a close second—the travel time from Fire Station 7 was approximately 5 minutes greater than that from Fire Station 1, as shown in Figure 33.

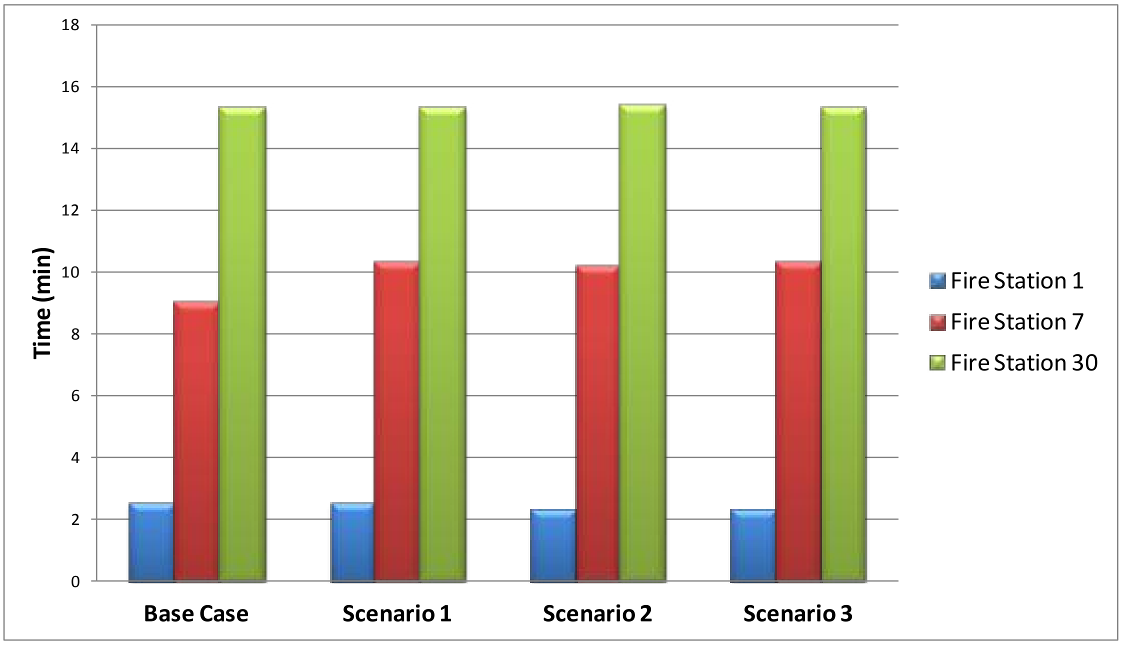


Figure 34. Travel Times from Fire Stations to the State of California Building

For the State of California building, Fire Station 1 would offer the shortest travel time in all scenarios, around 2 minutes. Travel times from the next closest fire station, Fire Station 7, were approximately 6.5 minutes longer for each scenario.

TRAVEL TIMES FOR EVACUEES

The average travel times for the evacuees leaving the four disaster locations to reach their destinations are shown in Table 15. Destinations for each origin are different specified exit points on the modeled network.

Table 15. Travel Times for Evacuees to Reach Their Destinations

	Travel Time (minutes)			
Origin	**Base Case**	**Scenario 1**	**Scenario 2**	**Scenario 3**
HP Pavilion	14.0	17.6	12.4	9.8
San José Convention Center	5.3	4.9	5.5	5.0
IRS building	16.6	12.7	12.2	12.6
State of California building	7.8	7.3	5.7	6.5

While specific destinations are not listed, Table 15 shows the improving or worsening travel times from the disaster locations. The longer travel time from HP Pavilion for Scenario 1 is caused by the incident closing a lane of traffic toward the I-280 SB and NB on-ramps. If the objective of the evacuation plan is to evacuate HP Pavilion, Scenario 2 might be the best option, which includes contraflow lanes designed specifically to alleviate the congestion anticipated from vehicles exiting from HP Pavilion. Evacuee travel time away from HP Pavilion was approximately 6 minutes shorter in Scenario 2 than in Scenario 1. However, the contraflow lanes did not reduce the travel time from HP Pavilion to the vehicles' intended destinations better than Scenario 3, in which vehicular traffic from the parking lots was reduced by 30%. An unintended consequence of the contraflow lanes was the rerouting of vehicles onto adjacent streets, which directly affected evacuees' travel time from the San José Convention Center. However, since the increase in travel time is less than a minute (from 4.9 minutes to 5.5 minutes), it may be an acceptable alternative. Scenario 3 had the fastest travel times from all the disaster areas in the simulation, except for Scenario 2's HP Pavilion trips, in which contraflow lanes assisted evacuees' departure from the area.

DIFFERENCES AMONG THE MEAN TRAVEL TIMES (STATISTICAL ANALYSIS)

The preliminary assessment described above shows that significant transit support would be needed to evacuate the general public most efficiently, while roads would mostly be used by emergency personnel. However, these general inferences need to be verified by statistical tests. As noted earlier, the averages of travel times were obtained using ten simulation runs, and the base case scenario is essentially the "do-nothing" scenario. The statistical test was conducted using the average of the total travel times for the emergency vehicles and the evacuees. Hence, a lower value implies quicker evacuation and faster response. The travel times were compared through a two-sample t-test (one side/one tail), which was conducted for each pair of plans to test if there was indeed a significant difference between their means. The t-value was estimated using following equation:

$$\frac{\left(\overline{X_n} - \overline{Y_m}\right) - (\mu_1 - \mu_2)}{\hat{\sigma}\sqrt{\frac{1}{n} + \frac{1}{m}}} \tag{2}$$

where

$\overline{X_n}$ = Mean value of 10 samples in the first specified scenario

$\overline{Y_m}$ = Mean value of 10 samples in the second specified scenario being compared to n=number of observations for the first specified scenario

m = number of observations for the first specified scenario

μ_1 = real mean of the first specified scenario

μ_2 = real mean of the second specified scenario

$\hat{\sigma}$ = Pooled estimate of the sample standard deviation

In this study, the null hypothesis (H_0) was the population's mean $\mu_1 \leq \mu_2$ against an alternative hypothesis (H_1; $\mu_1 > \mu_2$). This essentially predicts that the first scenario's times are greater than those in the second scenario.

In this study, the null hypothesis (H_0) was the population's mean $\mu_1 \leq \mu_2$ against an alternative hypothesis (H_1; $\mu_1 > \mu_2$). This essentially predicts that the first scenario's times are greater than those in the second scenario.

In testing the difference between the means of the base case and Scenario 1, the null hypothesis was that the mean value from the base case minus the mean value from Scenario 1 was less than or equal to zero. If it was zero, there was no significant difference between the two plans. The alternative hypothesis was that the mean value from the base case was larger than that from Scenario 1. Both the base case and Scenario 1 had ten values, with mean values of 5.7 and 6.4 minutes, respectively. The mean difference between the scenarios was estimated in to be –0.34 minutes. Therefore, using Equation 2, the t-value was found to be –1.76. The p-value was calculated from these estimates. For this study, the simulation achieved 95% confidence when the value of α was 0.05. That means the interval will contain the true parameter with 95% confidence, and only 5% of all values would exceed this interval. The significant mean difference between the base case and Scenario 1 is shown in Figure 35.

```
Two-sample t-test and CI: Base case vs. Scenario 1
             N     Mean    StDev    SE Mean
Base case   10     5.700   0.262     0.083
Scenario 1  10     6.040   0.552     0.17

Difference = mu (Base case) - mu (Scenario 1)
Estimate for difference:  -0.340
95% CI for difference:  (-0.746, 0.066)
t-test of difference = 0 (vs not =): t-value = -1.76  p-value = 0.096  DF = 18
Both use pooled StDev = 0.4323
```

Figure 35. Significant Mean Difference Between the Base Case and Scenario 1

From the comparison between the base case and Scenario 1 in Figure 35, the null hypothesis was not rejected. The p-value was 0.096, which is greater than the α value of 0.05. Therefore, the null hypothesis was not rejected at the 95% confidence interval, meaning that there was not enough evidence to conclude that the base case as a whole performed significantly worse than Scenario 1 in terms of travel time.

The same procedure was repeated to verify the difference between the base case and Scenario 2. The output from the statistical test is shown in Figure 36.

Two sample t-test and CI: Base case vs. Scenario 2

	N	mean	StDev	SE mean
Base Case	10	5.700	0.262	0.083
Scenario 2	10	5.640	0.617	0.20

Difference = mu (Base case) - mu (Scenario 2)
Estimate for difference: 0.060
95% CI for difference: (-0.385, 0.505)
t-test of difference = 0 (vs not =): t-value = 0.28 p-value = 0.780 DF = 18
Both use pooled StDev = 0.4740

Figure 36. Significant Mean Difference Between the Base Case and Scenario 2

Figure 36 shows that the null hypothesis cannot be rejected, since the p-value was 0.78, which is greater than the α value of 0.05.

The identical procedure was performed to validate the difference between the base case and Scenario 3. The output for the comparison is displayed in Figure 37.

Two sample t-test and CI: Base case vs. Scenario 3

	N	mean	StDev	SE mean
Base Case	10	5.700	0.262	0.083
Scenario 2	10	5.130	0.359	0.11

Difference = mu (Base case) - mu (Scenario 3)
Estimate for difference: 0.570
95% CI for difference: (-0.274, 0.866)
t-test of difference = 0 (vs not =): t-value = 4.05 p-value = 0.010 DF = 18
Both use pooled StDev = 0.3416

Figure 37. Significant Mean Difference Between the Base Case and Scenario 3

Figure 37 shows the statistical summary of the differential mean test, assuming equal variance. Since the p-value was 0.01, which is close to zero and is less than the α value of 0.05, the null hypothesis can be rejected. Therefore, it can be concluded that the mean travel time in the base case network is larger than that in Scenario 3, which means that public vehicles in the base case needed more time to discharge and emergency vehicles needed more time to reach their destinations than in Scenario 3.

The statistical tests showed that Scenario 3 enabled emergency vehicles and evacuees to reach their intended destinations in the fastest time. It indicates the role mass transit can play in urban areas, not only in terms of the daily commute, but also in executing an effective mass evacuation. In Scenario 3, 30% of the evacuations were assumed to be on mass transit, but a higher proportion would further reduce the pressure on the roads, clearing them for the emergency responders.

V. CONCLUSIONS, EMERGENCY MANAGEMENT APPLICATIONS, AND FUTURE SCOPE

CONCLUSIONS

In this study, simulation modeling was applied to investigate evacuation strategies and scenarios for a human caused disaster in downtown San José and to generate a replicable approach to evacuation planning. A microscopic simulation model of the downtown street network was developed in VISSIM. Google Maps and the manual observation of the network were used to code the network for factors such as lane configurations and traffic signals. The network was coded to have evening peak hour volumes to represent the worst-case traffic scenario.

The base case scenario included near-simultaneous terrorist bombings at four downtown San José locations: HP Pavilion on Santa Clara Street, the IRS building on Market Street, the Convention Center on Almaden Boulevard, and the State of California building at 100 Paseo de San Antonio. Three hospitals and three fire stations were identified as locations for the emergency responders. The primary hospitals to which patients from the disaster would be transported were O' Connor Hospital, Valley Medical Center, and the Regional Medical Center. The fire stations were the origins for the emergency responders, and the four terrorist targets were the destinations. The terrorist targets were also the origins for evacuees (general public), with their destinations being different exit points on the network.

The simulation model was used to identify efficient routing strategies for four different scenarios, chosen to investigate different complications or potential improvements that could be made in the event of a large-scale terrorist attack. The fastest route for each of the four scenarios was chosen after averaging the travel times from ten simulation runs. These fastest routes were for the evacuees exiting the downtown, ambulances traveling to the hospitals from the disaster locations, and fire vehicles traveling to the disaster locations from nearby fire stations.

In the base case scenario, the most severe traffic bottlenecks occurred along Santa Clara Street and Montgomery Street, as vehicles exiting from the surrounding HP Pavilion parking lots attempted to flee the area. The Santa Clara Street bottleneck began at the intersection of Santa Clara Street and Cahill Street and continued as far as Market Street. The worst traffic in the Montgomery Street bottleneck occurred from the intersection of Montgomery Street and Santa Clara to the I-280 on- and off-ramps.

In alternative Scenario 1, contraflow lanes on Montgomery Street/Bird Avenue helped to reduce the bottleneck on Montgomery Street and subsequently reduced the bottleneck on Santa Clara Street as well, since fewer cars were able to turn onto Santa Clara Street from Autumn Street. Any bottleneck directly associated with implementing contraflow lanes in this location can be alleviated by the fact that the reversal begins at the intersection of Park Avenue and Montgomery Street. In Scenario 2, in addition to providing two contraflow lanes for the general public to exit the disaster area, one of the lanes immediately adjacent to the contraflow lanes was used only for emergency vehicle access to HP Pavilion.

However, this did not seem to produce shorter travel times than that in scenarios without the emergency vehicle-only lane.

As expected, reducing the number of evacuating vehicles on the road was the most efficient way to reduce travel times. In Scenario 3, where 30% of the traffic was diverted to transit via the Diridon Station Transit Center, the least congestion was encountered by the remaining evacuees and emergency responders. While this is a logical conclusion, putting it into practice and implementing a plan in which drivers abandon their vehicles in a car-oriented society would be difficult. It would help if emergency responders and emergency-response planners could advertise their plan in a way that effectively communicates the advantages of using transit in a disaster situation. If transit is not available (possibly due to attacks on the station or on the tracks), the contraflow lanes will be helpful. Emergency professionals may be able to devise even more effective scenarios that can be evaluated using the simulation model developed here. The real goal of this research was not to identify the best possible strategy but to demonstrate how any evacuation and response strategy can be evaluated using the model.

EMERGENCY MANAGEMENT APPLICATIONS

In the United States, CAD systems are used to dispatch most emergency-response vehicles to the scene of an event. These systems integrate community maps with overlays of fire station locations and information on real-time locations of patrolling police cars and ambulances, generally based on vehicle locator systems. The computer-based maps enable the dispatcher to quickly select the closest emergency-response vehicles that are in service and available to take a call.

For the most part, neither the CAD maps nor the information available in the emergency-response vehicles uses GPS technology for routing to the scene of an event or call for service. Likewise, intelligent transportation system (ITS) data obtained, for example, by road sensors and traffic cameras, are not generally integrated into the CAD decision systems. Rather, the emergency responders are responsible for being familiar with the district in which they operate, including knowing about alleys and shortcuts, current traffic repairs blocking lanes or streets, and special events in the community that would impact traffic flows (Seal, 2012). Rather than using computer support, the fire captain, police officer, or ambulance driver selects the route to a call based on experience with that transportation node.

Figure 38. Emergency Vehicles are Dispatched Using CAD

Although the model developed in this research can provide enhanced information for pre-event vehicle routing, the time to develop a specific model for the relevant section of a community is too great for real-time disaster application. Modeling is useful for pre-event planning, training, and exercising purposes, but it offers no assistance in the real-time management of an no-notice event. By the time the modeling determines which strategy to use to manage traffic, it is usually too late to make the changes to the streets, as the population in the affected area is likely to begin to move immediately. Setting up barricades to create contraflow, block freeway exits, or create emergency vehicle-only lanes requires pre-planning and notice to be successful (Seal, 2012).

Simulation modeling of traffic patterns and disaster-induced changes can have useful applications in several aspects of emergency management. During emergencies, a community's emergency operations center may benefit from traffic circulation information collected through the ITS. Such data might include real-time broadcasts from traffic cameras and traffic flow speeds from road sensors. In communities like Montgomery County, MD, the traffic management center and the emergency operations center are colocated with the emergency dispatch center to enhance information sharing. Models of key nodes or areas of special concern could be warehoused by the traffic management center and used to estimate disaster impacts on the traffic circulation in the community.

Development of disaster circulation patterns and evacuation plans for specific communities can begin with the use of simulation models. Emergency planners can postulate traffic management modifications and use a model to test their effects. Such simulations are useful for designing new streets or street modifications that decrease the supply of available travel lanes, such as bike lanes, carpool lanes, or bus lanes. Simulations are also useful in determining how best to augment travel lanes for special-events management, peak commute management, or evacuation.

Once a design is selected, the traffic managers can determine what signage or traffic-control devices need to be installed to support emergency changes to road usage. For example, electronic signboards can be installed to designate street lanes for contraflow during evacuations, special events, or even commute hours. The Coronado Bridge in San Diego, California, moves K-rail twice each day to create extra lanes in the heaviest commute direction and fewer lanes in the less-traveled direction. The city of Santa Clara, California, has overhead, two-sided traffic signals that use red and green lights to designate which lanes can be used in each direction of travel on heavily traveled commute routes. The colors are easily changed during special events and high traffic periods or in the event of an accident on the road. Simulations can enable evacuation planners to determine which streets would benefit from contraflow lanes under specific conditions and then install permanent traffic-control devices to support the rapid conversion of the streets' directional flow.

Modeling can also assist emergency planners in creating more meaningful and realistic training. For example, training on evacuation management for a hazardous materials event can start with the simulation model showing normal traffic for the area at a given time of day. The effects of different traffic management options in response to the need to evacuate the population at risk can be demonstrated to teach traffic managers and emergency responders about how different strategies change the flow of traffic. By seeing the difference between contraflow and limited access, students can better understand the impact of their choices under disaster conditions. Limited access from flooding could be added to the model to show how it limits traffic rerouting options for an area around a gas pipeline leak or a tanker truck accident, while the addition of contraflow on another street could demonstrate the degree of congestion relief obtained. A model allows the instructor to manipulate community conditions and then test traffic flow in different scenarios.

Modeling and simulation can also contribute to emergency management exercises involving traffic flow. During an exercise, a traffic simulation using a VISSIM model can show how decisions made by the participants impact traffic flow in the community as the scenario unfolds. For example, the closing of freeway ramps can be included in the model, which will then show the resulting backups on the freeway. The effects of implementing contraflow can similarly be demonstrated. This ability to model the outcome of traffic-flow decisions can help exercise participants appreciate how one or two decisions can enhance the flow of traffic during an evacuation or can make matters significantly worse.

The simulation model developed here can be used by emergency planners to revise strategies and evacuation scenarios to determine what works best for any given disaster. It allows for the evaluation of evacuation scenarios for the downtown area in general, as well as for specific events and locations. The scenarios can be used to add factors such as the damage to the road system caused by an attack to determine which evacuation strategies would be most effective. Planners can also postulate the impact on evacuation routes of hurricanes, tsunamis, flooding, sea-level rise, and loss of infrastructure through seismic shaking or human caused damage.

With the model developed here, emergency planners can analyze more scenarios for downtown San José with little additional work. While application of the model to other communities would require the creation of new data for the area of analysis, this research provides insight into the best model to use.

FUTURE TRAFFIC PLANNING STUDIES

The results of this research can also serve as a basis for further research into disaster planning. Knowing the time horizon of an evacuation, as well as the inclusion of more area, would be helpful. In this study, attempts were made to create a network encompassed by Highway 101, I-880, and I-280 (a 20-square-mile area) with all roads coded. However, the traffic assignments could not be made to converge, because of the many details and the large amount of traffic.

Increasing the modeled area might make it impossible to model the network in the detail attained here. Mesoscopic modeling, such as cell-transmission modeling, might be used in that case. Observations during the VISSIM simulation indicated that even after background traffic had mostly diminished, queues would take some time to clear the network. Therefore, a potential investigation could delve deeper into the data to estimate a point in time where queues have successfully cleared the network from an emergency management standpoint.

The simulated downtown San José network could be used for other applications as well. The quality of traffic flow in downtown San José could be examined through an application such as the two-fluid model. Any proposed changes to the network, such as lane-widening or one-way streets, could be easily coded into the existing VISSIM model, and the resulting quality of traffic flow could be represented with new two-fluid model parameters. This could help assess the impact of newly proposed improvements on the traffic flow in the entire network.

APPENDIX A: GEH STATISTICS

The following tables display the data used to determine the GEH statistics for the five iterations during the calibration and validation period.

GEH Statistic Initial-Run Summary

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Almaden and San Carlos	NbR	132	158	2.17	122	142	164	142	134	135	113	121	122	115	140
	NbT	285	348	3.56	298	286	284	272	304	296	271	265	278	275	303
	NbL	69	88	2.10	69	75	69	68	73	62	72	68	65	72	70
	EbR	217	209	0.54	220	227	227	207	204	212	215	216	218	203	237
	EbT	826	759	2.37	840	825	805	789	829	793	857	823	815	881	825
	EbL	198	184	1.01	180	188	211	169	206	180	197	216	215	218	197
	SbR	103	100	0.29	109	111	94	96	115	97	106	106	101	96	101
	SbT	1009	1017	0.25	1042	1043	920	1015	986	1034	1053	986	1015	1005	1000
	SbL	113	104	0.89	113	111	104	95	111	116	123	105	123	126	119
	WbL	120	106	1.33	120	126	119	109	121	140	134	113	105	108	127
	WbT	588	514	3.16	586	583	599	601	597	550	614	580	579	594	586
	WbR	94	83	1.22	106	83	94	104	103	89	90	65	104	105	96
Almaden and Park	NbR	34	36	0.37	31	35	30	29	40	25	41	34	35	37	35
	NbT	223	237	0.93	232	226	241	193	229	213	201	220	237	242	218
	NbL	35	37	0.36	29	21	29	33	42	37	32	44	39	38	39
	EbR	116	117	0.13	131	117	101	103	125	110	116	128	114	116	110
	EbT	83	86	0.37	69	79	84	89	75	95	87	79	88	83	81
	EbL	97	105	0.79	85	98	111	94	84	85	91	107	109	105	99
	SbR	87	86	0.10	99	85	97	91	70	83	85	94	82	81	89
	SbT	955	965	0.33	983	987	856	957	920	976	1015	922	955	958	975
	SbL	43	48	0.70	46	35	38	39	37	52	41	54	43	50	41
	WbL	178	163	1.17	169	189	183	170	192	186	169	169	195	171	168
	WbT	112	104	0.79	106	106	125	104	101	119	132	107	97	122	115
	WbR	68	60	0.98	71	63	74	59	60	74	77	80	54	64	70

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Market and Santa Clara	NbR	47	41	0.93	49	62	47	50	37	41	57	49	46	41	40
	NbT	276	231	2.85	264	306	296	272	277	292	269	278	270	258	259
	NbL	79	69	1.14	78	83	90	59	77	78	84	79	88	76	75
	EbR	119	114	0.49	124	110	120	112	111	111	124	146	113	121	120
	EbT	613	581	1.29	605	627	587	639	607	612	612	576	646	611	617
	EbL	92	87	0.51	86	102	97	68	96	84	91	93	99	83	111
	SbR	125	80	4.48	116	118	107	116	141	127	120	136	132	130	137
	SbT	886	760	4.40	876	906	892	879	913	880	885	930	866	888	832
	SbL	79	118	3.93	105	70	60	76	79	77	93	84	71	74	80
	WbL	107	90	1.68	104	107	106	91	124	121	98	129	103	99	91
	WbT	448	395	2.56	428	414	408	421	639	429	449	442	431	430	433
	WbR	91	80	1.20	88	90	82	79	94	89	98	91	119	89	83

GEH Statistic Iteration 1 Summary

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Almaden and San Carlos	NbR	132	158	2.16	124	142	164	142	134	135	113	121	122	115	140
	NbT	285	348	3.57	296	286	284	272	304	296	271	265	278	275	303
	NbL	69	88	2.10	69	75	69	68	73	62	72	68	65	72	70
	EbR	217	209	0.53	218	227	227	207	204	212	215	216	218	203	237
	EbT	826	759	2.36	839	825	805	789	829	793	857	823	815	881	825
	EbL	198	184	1.01	181	188	211	169	206	180	197	216	215	218	197
	SbR	103	100	0.31	111	111	94	96	115	97	106	106	101	96	101
	SbT	1009	1017	0.26	1040	1043	920	1015	986	1034	1053	986	1015	1005	1000
	SbL	113	104	0.88	112	111	104	95	111	116	123	105	123	126	119
	WbL	120	106	1.33	119	126	119	109	121	140	134	113	105	108	127
	WbT	589	514	3.18	593	583	599	601	597	550	614	580	579	594	586
	WbR	94	83	1.20	104	83	94	104	103	89	90	65	104	105	96

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Almaden and Park	NbR	34	36	0.37	31	35	30	29	40	25	41	34	35	37	35
	NbT	223	237	0.95	228	226	241	193	229	213	201	220	237	242	218
	NbL	35	37	0.36	29	21	29	33	42	37	32	44	39	38	39
	EbR	115	117	0.14	130	117	101	103	125	110	116	128	114	116	110
	EbT	83	86	0.35	71	79	84	89	75	95	87	79	88	83	81
	EbL	97	105	0.80	84	98	111	94	84	85	91	107	109	105	99
	SbR	87	86	0.10	99	85	97	91	70	83	85	94	82	81	89
	SbT	955	965	0.33	982	987	856	957	920	976	1015	922	955	958	975
	SbL	43	48	0.69	47	35	38	39	37	52	41	54	43	50	41
	WbL	178	163	1.17	169	189	183	170	192	186	169	169	195	171	168
	WbT	112	104	0.79	106	106	125	104	101	119	132	107	97	122	115
	WbR	68	60	0.98	71	63	74	59	60	74	77	80	54	64	70
Market and Santa Clara	NbR	47	41	0.94	50	62	47	50	37	41	57	49	46	41	40
	NbT	277	231	2.86	266	306	296	272	277	292	269	278	270	258	259
	NbL	79	69	1.13	77	83	90	59	77	78	84	79	88	76	75
	EbR	119	114	0.49	124	110	120	112	111	111	124	146	113	121	120
	EbT	612	581	1.27	598	627	587	639	607	612	612	576	646	611	617
	EbL	92	87	0.51	86	102	97	68	96	84	91	93	99	83	111
	SbR	125	80	4.47	114	118	107	116	141	127	120	136	132	130	137
	SbT	886	760	4.40	879	906	892	879	913	880	885	930	866	888	832
	SbL	79	118	3.92	106	70	60	76	79	77	93	84	71	74	80
	WbL	107	90	1.70	106	107	106	91	124	121	98	129	103	99	91
	WbT	423	395	1.38	427	414	408	421	369	429	449	442	431	430	433
	WbR	91	80	1.20	88	90	82	79	94	89	98	91	119	89	83

GEH Statistic Iteration 2 Summary

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Almaden and San Carlos	NbR	131	158	2.21	122	140	164	140	134	133	113	120	124	116	140
	NbT	285	348	3.55	298	286	284	273	300	297	272	267	280	274	303
	NbL	69	88	2.17	69	74	69	66	72	61	71	69	64	72	70
	EbR	217	209	0.54	220	223	227	207	200	215	213	216	224	204	237
	EbT	826	759	2.37	840	828	805	790	829	791	858	823	812	881	825
	EbL	197	184	0.97	180	189	211	168	205	180	198	216	209	218	197
	SbR	102	100	0.23	109	112	94	96	112	96	105	105	103	92	101
	SbT	1009	1017	0.27	1042	1050	920	1016	979	1030	1057	978	1024	998	1000
	SbL	113	104	0.84	113	112	104	93	109	117	124	105	118	126	119
	WbL	120	106	1.33	120	126	119	109	121	140	134	113	107	106	127
	WbT	588	514	3.16	586	584	599	599	597	548	616	585	578	591	586
	WbR	95	83	1.24	106	85	94	103	103	89	91	66	105	104	96
Almaden and Park	NbR	34	36	0.42	31	35	30	28	40	25	40	34	35	36	35
	NbT	223	237	0.92	232	225	241	194	228	214	202	221	237	242	218
	NbL	35	37	0.29	29	22	29	33	40	38	37	44	39	38	39
	EbR	115	117	0.21	131	118	101	102	118	111	117	127	115	112	110
	EbT	83	86	0.37	69	76	84	91	74	97	87	79	84	87	81
	EbL	89	105	1.60	85	103	111	95	85	85	92	108	11	108	99
	SbR	87	86	0.16	99	85	97	92	70	86	85	94	82	83	89
	SbT	955	965	0.34	983	996	856	955	917	972	1019	916	958	953	975
	SbL	43	48	0.73	46	34	38	39	37	52	41	54	43	49	41
	WbL	178	163	1.17	169	189	183	170	192	185	168	169	196	172	168
	WbT	112	104	0.80	106	106	125	105	102	119	130	108	98	122	115
	WbR	68	60	1.01	71	64	74	59	60	73	77	81	54	66	70

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Market and Santa Clara	NbR	48	41	0.98	49	61	47	50	37	44	57	49	47	42	40
	NbT	276	231	2.83	264	307	296	270	277	291	269	279	268	257	259
	NbL	79	69	1.11	78	83	90	58	78	77	84	79	88	74	75
	EbR	119	114	0.50	124	109	120	112	111	111	126	146	114	121	120
	EbT	612	581	1.27	605	622	587	632	603	610	610	582	651	614	617
	EbL	92	87	0.55	86	100	97	68	99	84	93	95	98	83	111
	SbR	125	80	4.47	116	115	107	116	141	129	117	137	133	130	137
	SbT	885	760	4.37	876	904	892	876	913	876	881	934	868	888	832
	SbL	79	118	3.90	105	70	60	77	80	79	92	84	71	74	80
	WbL	106	90	1.63	104	103	106	85	123	122	99	129	103	102	91
	WbT	423	395	1.39	428	417	408	426	366	429	447	440	431	429	433
	WbR	92	80	1.26	88	90	82	82	95	90	99	91	120	88	83

GEH Statistic Iteration 3 Summary

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Almaden and San Carlos	NbR	131	158	2.21	122	140	164	140	134	133	113	120	124	116	140
	NbT	285	348	3.55	298	286	284	273	300	297	272	267	280	274	303
	NbL	69	88	2.17	69	74	69	66	72	61	71	69	64	72	70
	EbR	217	209	0.54	220	223	227	207	200	215	213	216	224	204	237
	EbT	826	759	2.37	840	828	805	790	829	791	858	823	812	881	825
	EbL	197	184	0.97	180	189	211	168	205	180	198	216	209	218	197
	SbR	102	100	0.23	109	112	94	96	112	96	105	105	103	92	101
	SbT	1009	1017	0.27	1042	1050	920	1016	979	1030	1057	978	1024	998	1000
	SbL	113	104	0.84	113	112	104	93	109	117	124	105	118	126	119
	WbL	120	106	1.33	120	126	119	109	121	140	134	113	107	106	127
	WbT	588	514	3.16	586	584	599	599	597	548	616	585	578	591	586
	WbR	95	83	1.24	106	85	94	103	103	89	91	66	105	104	96

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Almaden and Park	NbR	34	36	0.42	31	35	30	28	40	25	40	34	35	36	35
	NbT	223	237	0.92	232	225	241	194	228	214	202	221	237	242	218
	NbL	35	37	0.29	29	22	29	33	40	38	37	44	39	38	39
	EbR	115	117	0.21	131	118	101	102	118	111	117	127	115	112	110
	EbT	83	86	0.37	69	76	84	91	74	97	87	79	84	87	81
	EbL	98	105	0.66	85	103	111	95	85	85	92	108	111	108	99
	SbR	87	86	0.16	99	85	97	92	70	86	85	94	82	83	89
	SbT	955	965	0.34	983	996	856	955	917	972	1019	916	958	953	975
	SbL	43	48	0.73	46	34	38	39	37	52	41	54	43	49	41
	WbL	178	163	1.17	169	189	183	170	192	185	168	169	196	172	168
	WbT	112	104	0.80	106	106	125	105	102	119	130	108	98	122	115
	WbR	68	60	1.01	71	64	74	59	60	73	77	81	54	66	70
Market and Santa Clara	NbR	48	41	0.98	49	61	47	50	37	44	57	49	47	42	40
	NbT	276	231	2.83	264	307	296	270	277	291	269	279	268	257	259
	NbL	79	69	1.11	78	83	90	58	78	77	84	79	88	74	75
	EbR	110	114	0.34	124	109	120	112	11	111	126	146	114	121	120
	EbT	612	581	1.27	605	622	587	632	603	610	610	582	651	614	617
	EbL	92	87	0.55	86	100	97	68	99	84	93	95	98	83	111
	SbR	125	80	4.47	116	115	107	116	141	129	117	137	133	130	137
	SbT	885	760	4.37	876	904	892	876	913	876	881	934	868	888	832
	SbL	79	118	3.90	105	70	60	77	80	79	92	84	71	74	80
	WbL	106	90	1.63	104	103	106	85	123	122	99	129	103	102	91
	WbT	423	395	1.39	428	417	408	426	366	429	447	440	431	429	433
	WbR	92	80	1.26	88	90	82	82	95	90	99	91	120	88	83

GEH Statistic Iteration 4 Summary

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Almaden and San Carlos	NbR	132	158	2.20	124	140	165	140	134	133	113	120	124	116	138
	NbT	285	348	3.55	296	286	286	273	300	297	272	267	280	274	302
	NbL	69	88	2.19	69	74	69	66	72	61	71	69	64	72	68
	EbR	217	209	0.56	218	223	228	207	200	215	213	216	224	204	241
	EbT	825	759	2.36	839	828	803	790	829	791	858	823	812	881	825
	EbL	197	184	0.94	181	189	208	168	205	180	198	216	209	218	195
	SbR	103	100	0.25	111	112	96	96	112	96	105	105	103	92	100
	SbT	1008	1017	0.28	1040	1050	916	1016	979	1030	1057	978	1024	998	1002
	SbL	113	104	0.82	112	112	103	93	109	117	124	105	118	126	119
	WbL	120	106	1.34	119	126	120	109	121	140	134	113	107	106	128
	WbT	588	514	3.16	593	584	597	599	597	548	616	585	578	591	583
	WbR	95	83	1.25	104	85	94	103	103	89	91	66	105	104	99
Almaden and Park	NbR	33	36	0.45	31	35	28	28	40	25	40	34	35	36	35
	NbT	223	237	0.93	228	225	243	194	228	214	202	221	237	242	218
	NbL	35	37	0.30	29	22	28	33	40	38	37	44	39	38	39
	EbR	114	117	0.26	130	118	99	102	118	111	117	127	115	112	107
	EbT	83	86	0.37	71	76	80	91	74	97	87	79	84	87	83
	EbL	98	105	0.70	84	103	108	95	85	85	92	108	111	108	98
	SbR	87	86	0.13	99	85	95	92	70	86	85	94	82	83	88
	SbT	955	965	0.34	982	996	854	955	917	972	1019	916	958	953	978
	SbL	43	48	0.70	47	34	39	39	37	52	41	54	43	49	41
	WbL	178	163	1.17	169	189	183	170	192	185	168	169	196	172	168
	WbT	112	104	0.80	106	106	125	105	102	119	130	108	98	122	115
	WbR	68	60	1.01	71	64	74	59	60	73	77	81	54	66	70

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Market and Santa Clara	NbR	48	41	1.00	50	61	47	50	37	44	57	49	47	42	40
	NbT	276	231	2.85	266	307	298	270	277	291	269	279	268	257	259
	NbL	78	69	1.08	77	83	88	58	78	77	84	79	88	74	75
	EbR	120	114	0.51	124	109	120	112	111	111	126	146	114	121	121
	EbT	611	581	1.23	598	622	587	632	603	610	610	582	651	614	613
	EbL	92	87	0.53	86	100	97	68	99	84	93	95	98	83	109
	SbR	125	80	4.45	114	115	109	116	141	129	117	137	133	130	135
	SbT	885	760	4.37	879	904	889	876	913	876	881	934	868	888	831
	SbL	79	118	3.89	106	70	59	77	80	79	92	84	71	74	81
	WbL	106	90	1.65	106	103	107	85	123	122	99	129	103	102	91
	WbT	423	395	1.37	427	417	407	426	366	429	447	440	431	429	431
	WbR	92	80	1.27	88	90	83	82	95	90	99	91	120	88	83

GEH Statistic Iteration 5 Summary

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Almaden and San Carlos	NbR	132	158	2.20	124	140	165	140	134	133	113	120	124	116	138
	NbT	285	348	3.55	296	286	286	273	300	297	272	267	280	274	302
	NbL	69	88	2.19	69	74	69	66	72	61	71	69	64	72	68
	EbR	217	209	0.56	218	223	228	207	200	215	213	216	224	204	241
	EbT	825	759	2.36	839	828	803	790	829	791	858	823	812	881	825
	EbL	197	184	0.94	181	189	208	168	205	180	198	216	209	218	195
	SbR	103	100	0.25	111	112	96	96	112	96	105	105	103	92	100
	SbT	1008	1017	0.28	1040	1050	916	1016	979	1030	1057	978	1024	998	1002
	SbL	113	104	0.82	112	112	103	93	109	117	124	105	118	126	119
	WbL	120	106	1.34	119	126	120	109	121	140	134	113	107	106	128
	WbT	588	514	3.16	593	584	597	599	597	548	616	585	578	591	583
	WbR	95	83	1.25	104	85	94	103	103	89	91	66	105	104	99

Roadway/Intersection	Movement Direction	Simulation	Actual	GEH Statistic	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
Almaden and Park	NbR	33	36	0.45	31	35	28	28	40	25	40	34	35	36	35
	NbT	223	237	0.93	228	225	243	194	228	214	202	221	237	242	218
	NbL	35	37	0.30	29	22	28	33	40	38	37	44	39	38	39
	EbR	114	117	0.26	130	118	99	102	118	111	117	127	115	112	107
	EbT	83	86	0.37	71	76	80	91	74	97	87	79	84	87	83
	EbL	98	105	0.70	84	103	108	95	85	85	92	108	111	108	98
	SbR	87	86	0.13	99	85	95	92	70	86	85	94	82	83	88
	SbT	955	965	0.34	982	996	854	955	917	972	1019	916	958	953	978
	SbL	43	48	0.70	47	34	39	39	37	52	41	54	43	49	41
	WbL	178	163	1.17	169	189	183	170	192	185	168	169	196	172	168
	WbT	112	104	0.80	106	106	125	105	102	119	130	108	98	122	115
	WbR	68	60	1.01	71	64	74	59	60	73	77	81	54	66	70
Market and Santa Clara	NbR	48	41	1.00	50	61	47	50	37	44	57	49	47	42	40
	NbT	276	231	2.85	266	307	298	270	277	291	269	279	268	257	259
	NbL	78	69	1.08	77	83	88	58	78	77	84	79	88	74	75
	EbR	120	114	0.51	124	109	120	112	111	111	126	146	114	121	121
	EbT	611	581	1.23	598	622	587	632	603	610	610	582	651	614	613
	EbL	92	87	0.53	86	100	97	68	99	84	93	95	98	83	109
	SbR	125	80	4.45	114	115	109	116	141	129	117	137	133	130	135
	SbT	886	760	4.38	879	904	889	876	913	879	881	934	868	888	831
	SbL	79	118	3.89	106	70	59	77	80	79	92	84	71	74	81
	WbL	106	90	1.65	106	103	107	85	123	122	99	129	103	102	91
	WbT	423	395	1.37	427	417	407	426	366	429	447	440	431	429	431
	WbR	92	80	1.27	88	90	83	82	95	90	99	91	120	88	83

APPENDIX B: TRAVEL TIME SUMMARY FOR CALIBRATION AND VALIDATION

Travel Time Summary (min)														
Roadway	Actual	Percent Error	Simulation Average	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
I-280 NB	3.43	-3.3%	3.3	3.4	3.2	3.4	3.3	3.3	3.2	3.2	3.3	3.4	3.5	3.3
I-280 SB	4.15	-3.2%	4.0	4	3.9	4.1	4	4	4	4.1	4.1	4	4	4
Hwy 87 NB	3.15	-2.5%	3.1	3	3.1	3.1	3	3.1	3.1	3.1	3	3.1	3.1	3.1
Hwy 87 SB	3.15	7.1%	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.3	3.3	3.4	3.3

Travel Time Summary for Iteration 1 (min)														
Roadway	Actual	Percent Error	Simulation Average	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
I-280 NB	3.43	-3.79%	3.3	3.4	3.2	3.4	3.3	3.3	3.2	3.2	3.3	3.4	3.3	3.3
I-280 SB	4.15	-3.18%	4.0	4	3.9	4.1	4	4	4	4.1	4.1	4	4	4
Hwy 87 NB	3.15	-1.88%	3.1	3.2	3.1	3.1	3	3.1	3.1	3.1	3	3.1	3.1	3.1
Hwy 87 SB	3.15	7.07%	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.3	3.3	3.4	3.3

Travel Time Summary for Iteration 2 (min)														
Roadway	Actual	Percent Error	Simulation Average	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
I-280 NB	3.43	-3.79%	3.3	3.4	3.2	3.4	3.2	3.4	3.2	3.1	3.1	3.5	3.5	3.3
I-280 SB	4.15	-1.86%	4.1	3.9	4.2	4.1	4.1	4	4.3	4.2	4.1	4	3.9	4
Hwy 87 NB	3.15	-1.88%	3.1	3.2	3	3.1	3.1	3.2	3.1	3	3	3.1	3.1	3.1
Hwy 87 SB	3.15	7.07%	3.4	3.4	3.3	3.4	3.4	3.4	3.4	3.4	3.3	3.4	3.4	3.3

Travel Time Summary for Iteration 3 (min)														
Roadway	Actual	Percent Error	Simulation Average	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
I-280 NB	3.43	-3.79%	3.3	3.4	3.2	3.4	3.2	3.4	3.2	3.1	3.1	3.5	3.5	3.3
I-280 SB	4.15	-1.42%	4.090909091	4.1	4.2	4.1	4.1	4	4.3	4.2	4.1	4	3.9	4
Hwy 87 NB	3.15	-2.45%	3.072727273	3	3	3.1	3.1	3.2	3.1	3	3	3.1	3.1	3.1
Hwy 87 SB	3.15	7.07%	3.372727273	3.4	3.3	3.4	3.4	3.4	3.4	3.4	3.3	3.4	3.4	3.3

Travel Time Summary for Iteration 4 (min)

Roadway	Actual	Percent Error	Simulation Average	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
I-280 NB	3.43	-4.59%	3.3	3.4	3.2	3.2	3.2	3.4	3.2	3.1	3.1	3.5	3.5	3.2
I-280 SB	4.15	-2.08%	4.1	3.9	4.1	4.1	4.1	4	4.3	4.2	4.1	4	3.9	4
Hwy 87 NB	3.15	-1.59%	3.1	3.2	3.1	3.1	3.1	3.2	3.1	3	3	3.1	3.1	3.1
Hwy 87 SB	3.15	7.36%	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.3	3.4	3.4	3.3

Travel Time Summary for Iteration 5 (min)

Roadway	Actual	Percent Error	Simulation Average	Seed 1	Seed 191	Seed 42	Seed 198	Seed 2626	Seed 500	Seed 5430	Seed 52	Seed 681	Seed 266	Seed 8734
I-280 NB	3.43	-4.32%	3.3	3.4	3.2	3.3	3.2	3.4	3.2	3.1	3.1	3.5	3.5	3.2
I-280 SB	4.15	-2.52%	4.0	4	3.9	4	4.1	4	4.3	4.2	4.1	4	3.9	4
Hwy 87 NB	3.15	-1.59%	3.1	3.2	3.1	3.1	3.1	3.2	3.1	3	3	3.1	3.1	3.1
Hwy 87 SB	3.15	7.07%	3.4	3.4	3.4	3.3	3.4	3.4	3.4	3.4	3.3	3.4	3.4	3.3

APPENDIX C: PEAK HOUR TRAFFIC COUNTS IN DOWNTOWN SAN JOSÉ

Node	Intersection	Peak	Peak Hour	NB			EB			SB			WB			Count Date
				L	T	R	L	T	R	L	T	R	L	T	R	
3013	87/JULIAN (E) *	AM	8:00-9:00	76	414	56	100	511	0	391	603	0	0	473	137	9/17/2008
3013	87/JULIAN (E) *	PM	4:45-5:45	407	352	41	117	328	0	162	317	0	0	1156	126	9/17/2008
3014	87/JULIAN (W)	AM	7:45-8:45	0	0	0	0	398	21	338	158	129	74	655	327	9/17/2008
3014	87/JULIAN (W)	PM	5:00-6:00	0	0	0	0	837	25	172	87	75	165	376	1084	9/17/2008
3015	87/SANTA CLARA	AM	7:45-8:45	397	0	1266	0	522	0	0	0	0	0	560	0	9/17/2008
3015	87/SANTA CLARA	PM	4:45-5:45	243	0	495	0	635	0	0	0	0	0	589	0	9/17/2008
3032	280/BIRD (N)	AM	7:30-8:30	331	1077	0	0	0	0	0	546	176	254	5	517	9/16/2008
3032	280/BIRD (N)	PM	5:00-6:00	170	401	0	0	0	0	0	1297	572	690	12	248	9/16/2008
3033	280/BIRD (S)	AM	7:15-8:15	0	1013	391	309	2	93	390	465	0	0	0	0	9/16/2008
3033	280/BIRD (S)	PM	5:00-6:00	0	373	233	210	14	409	586	1044	0	0	0	0	9/16/2008
3059	ALAMEDA/RACE	AM	7:45-8:45	1	579	66	6	369	215	25	11	1	135	715	10	9/24/2008
3059	ALAMEDA/RACE	PM	5:00-6:00	11	304	107	0	730	508	10	7	0	183	488	0	9/24/2008
3061	ALMADEN/SAN CARLOS	AM	8:00-9:00	162	1506	179	77	440	39	97	233	46	80	549	128	9/30/2008
3061	ALMADEN/SAN CARLOS	PM	4:45-5:45	88	348	158	184	759	209	104	1017	100	106	514	83	9/30/2008
3066	AUTUMN/SANTA CLARA	AM	7:45-8:45	232	151	113	29	391	0	18	0	40	0	836	46	9/24/2008
3066	AUTUMN/SANTA CLARA	PM	5:00-6:00	85	58	68	25	564	0	23	0	88	0	621	51	9/24/2008
3077	BIRD/SAN CARLOS	AM	7:30-8:30	212	886	132	95	280	112	35	370	38	35	233	29	9/16/2008
3077	BIRD/SAN CARLOS	PM	4:45-5:45	124	304	127	70	505	293	75	1030	81	209	370	25	9/16/2008
3107	MARKET/SAN CARLOS	AM	7:30-8:30	353	1186	18	70	292	84	54	208	59	0	285	38	10/9/2008
3107	MARKET/SAN CARLOS	PM	5:00-6:00	115	184	2	78	374	145	96	860	86	0	357	21	10/9/2008
3112	MONTGOMERY/SANTA CLARA	AM	7:30-8:30	0	0	0	0	432	88	0	0	0	133	1010	0	9/24/2008
3112	MONTGOMERY/SANTA CLARA	PM	5:00-6:00	0	0	0	0	612	249	0	0	0	188	716	0	9/24/2008
3209	87/WOZ	AM	7:30-8:30	0	143	0	134	0	21	0	66	0	0	0	0	3/11/2008
3209	87/WOZ	PM	5:00-6:00	0	146	0	166	0	42	0	197	0	0	0	0	3/11/2008
3227	ALAMEDA/JULIAN	AM	7:45-8:45	0	1157	77	0	0	0	122	478	0	48	0	158	5/17/2006
3227	ALAMEDA/JULIAN	PM	4:45-5:45	0	638	69	0	0	0	127	1098	0	119	0	166	5/17/2006
3230	ALAMEDA/STOCKTON	AM	7:45-8:45	0	0	1	132	428	4	75	0	42	1	608	259	5/17/2006
3230	ALAMEDA/STOCKTON	PM	4:45-5:45	1	1	1	74	628	1	205	1	191	0	542	79	5/17/2006

Node	Intersection	Peak	Peak Hour	NB			EB			SB			WB			Count Date
				L	T	R	L	T	R	L	T	R	L	T	R	
3231	ALAMEDA/SUNOL	AM	7:45-8:45	46	3	60	6	445	21	5	5	6	26	660	9	2/24/2009
3231	ALAMEDA/SUNOL	PM	4:45-5:45	30	5	39	13	536	53	11	7	12	76	600	20	2/24/2009
3244	ALMADEN/WOZ	AM	7:45-8:45	87	1642	80	14	30	30	43	129	22	18	53	95	3/11/2008
3244	ALMADEN/WOZ	PM	5:00-6:00	50	264	73	26	90	227	137	1461	29	61	51	42	3/11/2008
3249	ALMADEN/PARK	AM	8:00-9:00	215	974	45	340	72	60	27	122	85	12	46	28	2/12/2009
3249	ALMADEN/PARK	PM	5:00-6:00	37	237	36	105	86	117	48	965	86	163	104	60	3/12/2009
3252	ALMADEN/SANTA CLARA(E)	AM	8:00-9:00	154	578	122	199	1246	0	0	0	0	56	334	83	3/12/2008
3252	ALMADEN/SANTA CLARA(E)	PM	5:00-6:00	111	226	118	182	971	1	0	0	0	161	425	126	3/12/2008
3263	AUTUMN/JULIAN	AM	7:45-8:45	23	35	215	10	347	9	28	4	12	46	318	102	5/18/2006
3263	AUTUMN/JULIAN	PM	4:45-5:45	20	12	85	10	447	13	82	14	19	96	395	49	5/18/2006
3266	AUZERAIS/BIRD	AM	7:30-8:30	196	1155	117	20	40	155	47	430	29	63	38	12	2/19/2009
3266	AUZERAIS/BIRD	PM	5:00-6:00	129	577	77	23	57	230	72	1261	32	152	44	26	2/19/2009
3267	AUZERAIS/DELMAS	AM	7:45-8:45	0	0	0	0	64	86	9	92	20	24	37	0	1/10/2007
3267	AUZERAIS/DELMAS	PM	5:00-6:00	0	0	0	0	57	59	92	395	70	34	73	0	1/10/2007
3268	AUZERAIS/LINCOLN	AM	7:30-8:30	90	604	27	13	31	49	15	153	21	25	59	24	2/25/2009
3268	AUZERAIS/LINCOLN	PM	4:45-5:45	33	262	30	14	70	81	28	495	28	46	64	39	2/25/2009
3269	AUZERAIS/MERIDIAN	AM	7:30-8:30	0	1058	5	0	0	0	1	574	0	8	0	17	5/3/2006
3269	AUZERAIS/MERIDIAN	PM	4:30-5:30	0	643	15	0	0	0	7	1124	0	4	0	7	5/3/2006
3270	AUZERAIS/RACE	AM	7:45-8:45	5	199	45	19	1	4	64	100	2	45	1	86	2/25/2009
3270	AUZERAIS/RACE	PM	4:45-5:45	7	250	87	3	2	1	110	261	17	62	3	68	2/25/2009
3271	AUZERAIS/WOZ	AM	7:45-8:45	53	167	0	50	0	48	0	19	11	0	0	9	2/18/2009
3271	AUZERAIS/WOZ	PM	5:00-6:00	102	202	0	23	0	130	0	79	30	8	1	7	2/18/2009
3304	BIRD/VIRGINIA	AM	7:30-8:30	17	1071	40	39	16	5	231	261	18	42	7	289	2/24/2009
3304	BIRD/VIRGINIA	PM	5:00-6:00	29	394	53	31	9	4	316	1283	36	46	11	133	2/24/2009
3417	COLEMAN/TAYLOR	AM	7:30-8:30	180	843	48	224	554	102	175	395	52	78	482	159	3/29/2007
3417	COLEMAN/TAYLOR	PM	4:45-5:45	167	516	63	113	274	70	245	801	114	162	519	145	2/21/2007
3445	DELMAS/PARK	AM		43	235	341	0	323	27	80	129	41	18	50	0	4/29/2008
3445	DELMAS/PARK	PM		77	365	249	0	121	46	49	306	70	121	323	0	4/29/2008
3446	DELMAS/SAN CARLOS	AM	8:00-9:00	0	0	0	0	374	41	23	72	62	18	261	0	1/10/2007

Node	Intersection	Peak	Peak Hour	NB			EB			SB			WB			Count Date
				L	T	R	L	T	R	L	T	R	L	T	R	
3446	DELMAS/SAN CARLOS	PM	4:45-5:45	0	0	0	0	428	106	35	468	203	40	338	0	1/10/2007
3489	FIFTH/SANTA CLARA	AM	7:45-8:45	0	0	0	55	396	0	15	0	17	0	589	114	4/8/2009
3489	FIFTH/SANTA CLARA	PM	5:00-6:00	0	0	0	21	745	0	41	0	28	0	493	33	4/8/2009
3491	FIRST/STREET JAMES	AM	7:45-8:45	0	485	20	44	456	0	0	0	0	0	0	0	3/8/2007
3491	FIRST/STREET JAMES	PM	4:30-5:30	0	232	30	53	710	0	0	0	0	0	0	0	3/8/2007
3494	FIRST/HAWTHORNE	AM	8:00-9:00	0	336	0	9	0	0	0	191	2	0	0	0	2/14/2007
3494	FIRST/HAWTHORNE	PM	4:45-5:45	0	297	0	15	0	4	0	374	9	0	0	0	2/14/2007
3505	FIRST/RANKIN	AM	7:45-8:45	1	335	0	5	0	4	0	225	13	0	0	0	2/14/2007
3505	FIRST/RANKIN	PM	5:00-6:00	1	291	0	13	0	7	0	449	14	0	0	0	2/14/2007
3511	FIRST/SAN FERNANDO	AM	8:00-9:00	21	167	34	23	211	0	0	0	0	0	179	57	2/15/2007
3511	FIRST/SAN FERNANDO	PM	5:00-6:00	2	153	28	31	390	0	0	0	0	0	198	71	2/15/2007
3512	FIRST/SAN SALVADOR	AM	8:00-9:00	4	256	37	28	60	0	0	0	6	3	54	36	2/15/2007
3512	FIRST/SAN SALVADOR	PM	4:45-5:45	2	138	43	14	75	7	3	22	24	7	132	61	2/15/2007
3539	FOURTH/SAN FERNANDO	AM	8:00-9:00	0	0	0	0	374	109	68	412	62	132	125	0	3/8/2007
3539	FOURTH/SAN FERNANDO	PM	5:00-6:00	0	0	0	0	311	144	70	1064	96	258	244	0	3/8/2007
3541	FOURTH/SANTA CLARA	AM	8:00-9:00	0	0	0	0	407	142	56	303	79	116	461	0	4/8/2009
3541	FOURTH/SANTA CLARA	PM	5:00-6:00	0	0	0	0	625	252	125	800	56	130	378	0	4/8/2009
3543	FOURTH/STREET JOHN	AM	7:45-8:45	0	0	0	0	69	159	13	361	59	44	155	0	3/7/2007
3543	FOURTH/STREET JOHN	PM	5:00-6:00	0	0	0	0	135	133	24	1013	82	57	147	0	3/7/2007
3571	HANCHETT/PARK	AM	7:30-8:30	43	869	3	91	18	36	9	434	25	13	15	7	9/20/2005
3571	HANCHETT/PARK	PM	5:00-6:00	49	374	5	36	18	58	13	826	75	10	23	10	9/20/2005
3605	JULIAN/MARKET	AM	7:30-8:30	45	843	0	0	0	0	0	393	88	124	455	258	3/11/2008
3605	JULIAN/MARKET	PM	5:00-6:00	110	473	0	0	0	0	0	882	386	323	462	139	3/11/2008
3606	JULIAN/MONTGOMERY	AM	7:45-8:45	9	4	7	14	296	8	19	5	8	12	308	44	3/6/2008
3606	JULIAN/MONTGOMERY	PM	4:45-5:45	10	6	25	13	395	5	48	3	25	16	302	22	3/6/2008
3608	JULIAN/STOCKTON	AM	7:45-8:45	11	310	60	24	193	23	140	121	13	32	146	175	5/18/2006
3608	JULIAN/STOCKTON	PM	4:45-5:45	26	147	63	16	169	19	204	315	48	111	185	101	5/18/2006
3653	LINCOLN/SAN CARLOS	AM	7:30-8:30	389	214	107	14	352	99	19	64	20	31	332	17	2/24/2009
3653	LINCOLN/SAN CARLOS	PM	4:45-5:45	89	68	76	24	590	230	11	213	36	82	490	20	2/24/2009
3667	MARKET/SAN FERNANDO	AM	7:45-8:45	86	953	56	29	159	33	59	184	29	37	149	36	4/19/2007

Node	Intersection	Peak	Peak Hour	NB			EB			SB			WB			Count Date
				L	T	R	L	T	R	L	T	R	L	T	R	
3667	MARKET/SAN FERNANDO	PM	5:00-6:00	43	230	76	18	239	140	127	940	44	71	164	57	3/28/2007
3668	MARKET/PARK	AM	7:30-8:30	0	1083	0	0	0	88	0	265	117	0	0	0	2/21/2007
3668	MARKET/PARK	PM	5:00-6:00	0	471	0	0	0	161	0	1220	133	0	0	0	4/19/2007
3669	MARKET/SAN SALVADOR	AM	7:15-8:15	39	1222	37	50	0	8	66	326	82	19	17	54	3/7/2007
3669	MARKET/SAN SALVADOR	PM	4:45-5:45	1	234	34	20	8	20	47	1172	37	73	10	68	4/17/2007
3670	MARKET/SANTA CLARA	AM	7:45-8:45	87	517	30	75	550	189	54	266	58	67	326	100	4/2/2009
3670	MARKET/SANTA CLARA	PM	5:00-6:00	69	231	41	87	581	114	118	760	80	80	395	90	4/2/2009
3689	MERIDIAN/PARK	AM	7:15-8:15	789	0	89	0	249	293	0	0	0	142	360	0	3/7/2007
3689	MERIDIAN/PARK	PM	5:00-6:00	378	0	138	0	414	480	0	0	0	169	239	0	3/7/2007
3693	MERIDIAN/SAN CARLOS	AM	7:45-8:45	336	668	194	94	464	116	86	227	34	169	549	123	3/7/2007
3693	MERIDIAN/SAN CARLOS	PM	5:00-6:00	99	375	255	125	1085	284	229	470	59	307	724	54	3/7/2007
3709	MONTGOMERY/PARK	AM		251	707	160	29	107	207	17	227	36	32	85	10	4/29/2008
3709	MONTGOMERY/PARK	PM		121	208	52	14	107	192	15	736	43	208	138	18	4/29/2008
3730	PARK/SUNOL	AM		14	44	9	30	283	8	48	42	19	9	286	43	4/29/2008
3730	PARK/SUNOL	PM		18	50	18	22	239	25	59	124	34	11	251	31	4/29/2008
3731	PARK/WOZ	AM		14	111	55	97	567	78	0	0	0	23	47	68	4/29/2008
3731	PARK/WOZ	PM		20	145	53	91	289	19	0	0	0	109	402	167	4/29/2008
3732	PARK/RACE	AM	7:30-8:30	35	479	13	105	248	18	32	209	25	24	309	126	2/25/2009
3732	PARK/RACE	PM	5:00-6:00	28	271	44	97	343	33	102	503	67	44	233	51	2/25/2009
3748	RACE/SAN CARLOS	AM	7:30-8:30	77	218	29	168	423	62	54	119	135	20	589	195	2/24/2009
3748	RACE/SAN CARLOS	PM	5:00-6:00	100	126	44	191	826	84	113	206	253	77	554	64	2/24/2009
3763	SAN CARLOS/WOZ	AM	8:00-9:00	29	104	94	132	289	6	36	19	14	14	207	79	2/12/2009
3763	SAN CARLOS/WOZ	PM	5:00-6:00	48	57	90	60	399	6	25	51	83	38	353	56	3/12/2009
3775	SAN PEDRO/SANTA CLARA	AM	7:30-8:30	6	42	11	58	697	85	6	36	13	21	560	39	3/6/2007
3775	SAN PEDRO/SANTA CLARA	PM	5:00-6:00	35	51	31	66	748	42	19	70	57	16	553	30	4/17/2007
3782	SANTA CLARA/SECOND	AM	7:45-8:45	0	0	0	0	433	86	15	110	29	64	573	0	3/7/2007
3782	SANTA CLARA/SECOND	PM	5:00-6:00	0	0	0	0	700	174	45	298	49	103	514	0	3/7/2007
3794	SECOND/STREET JAMES	AM	7:45-8:45	0	0	0	10	267	20	36	121	0	0	0	0	3/6/2007
3794	SECOND/STREET JAMES	PM	5:00-6:00	0	0	0	6	486	25	111	282	0	0	0	0	3/6/2007

Node	Intersection	Peak	Peak Hour	NB			EB			SB			WB			Count Date
				L	T	R	L	T	R	L	T	R	L	T	R	
3817	STOCKTON/TAYLOR	AM	7:30-8:30	54	41	272	7	469	24	71	13	14	145	415	140	3/10/2009
3817	STOCKTON/TAYLOR	PM	4:45-5:45	76	15	248	9	582	68	71	27	8	333	640	54	3/10/2009
3906	SAN CARLOS/SUNOL	AM		34	24	24	62	248	48	5	21	6	49	251	66	4/30/2008
3906	SAN CARLOS/SUNOL	PM		68	31	80	90	375	79	9	16	9	82	381	112	4/30/2008
3960	RACE/SADDLE RACK	AM	7:30-8:30	22	268	0	122	0	13	0	78	86	0	0	0	5/4/2006
3960	RACE/SADDLE RACK	PM	4:45-5:45	48	216	0	137	0	13	0	247	139	0	0	0	5/4/2006
3969	AUZERAIS/SUNOL	AM	7:30-8:30	9	9	21	5	69	6	13	22	7	33	98	21	2/19/2009
3969	AUZERAIS/SUNOL	PM	4:00-5:00	3	7	46	2	166	5	14	19	21	15	101	16	2/19/2009
4038	GUADALUPE/TAYLOR	AM	7:30-8:30	500	0	1281	94	344	290	140	0	49	621	337	90	3/16/2005
4038	GUADALUPE/TAYLOR	PM	4:00-5:00	371	0	994	27	393	410	138	0	93	1098	357	121	3/16/2005
4042	COLEMAN/GUADALUPE PARKWAY	AM	7:30-8:30	0	0	0	26	440	0	28	0	9	0	942	163	3/29/2007
4042	COLEMAN/GUADALUPE PARKWAY	PM	5:00-6:00	0	0	0	22	1052	0	111	0	21	0	457	54	3/29/2007
4070	COLEMAN/SANTA TERESA	AM	7:45-8:45	64	0	24	0	459	16	0	0	0	19	922	0	3/29/2007
4070	COLEMAN/SANTA TERESA	PM	5:00-6:00	44	0	50	0	1007	108	0	0	0	31	446	0	3/29/2007
4071	AUTUMN/COLEMAN	AM	7:45-8:45	12	0	24	0	458	17	0	0	1	32	957	1	3/29/2007
4071	AUTUMN/COLEMAN	PM	5:00-6:00	18	0	49	0	1055	32	0	0	0	75	418	1	3/29/2007
4072	COLEMAN/SAN JOES MARKET	AM	7:45-8:45	85	0	4	125	482	48	0	0	1	26	952	1	3/29/2007
4072	COLEMAN/SAN JOES MARKET	PM	5:00-6:00	279	0	58	54	1017	227	0	0	1	78	355	0	3/29/2007

APPENDIX D: TURNING MOVEMENTS FOR THE BASE CASE SCENARIO

			SB on/off flow		NB on/off flow				
			SC: 39						
			NS: Cahill						
			EW: Santa Clara						
			43	50	8	63			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
	576	←					↖	58	0
	0	↗					←	490	
EB on/off flow	800	→					↙	58	EB on/off flow
	120	↘					→	838	0
			↓	↖	↑	↗			
			228	43	5	30			
			SB on/off flow		NB on/off flow				
			0		-37				

Intersection: Cahill and Santa Clara

			SB on/off flow		NB on/off flow				
			SC: 38						
			NS: Montgomery						
			EW: Santa Clara						
			0	0	0	0			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	606	←					↖	0	0
	0	↗					←	606	
EB on/off flow	589	→					↙	188	EB on/off flow
0	249	↘					→	589	0
			↓	↖	↑	↗			
			437	0	0	0			
			SB on/off flow		NB on/off flow				
			0		0				

Intersection: Montgomery and Santa Clara

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 14						
			NS: Montgomery						
			EW: San Fernando						
			15	650	72	0			
WB on/off flow		0	↙	↓	↘	↑			WB on/off flow
0	115	←					↖	0	0
	0	↗					←	100	
EB on/off flow	300	→					↙	50	EB on/off flow
0	150	↘					→	372	0
			↓	↖	↑	↗			
			850	0	0	0			
			SB on/off flow		NB on/off flow				
			0		0				

Intersection: Montgomery and San Fernando

		SB on/off flow		NB on/off flow				
		0		0				
		SC: 9						
		NS: Montgomery						
		EW: Park						
		43	736	15	240			
		↙	↓	↘	↑			WB on/off flow
302	←					↖	18	0
14	↗					←	138	
107	→					↙	208	EB on/off flow
192	↘					→	174	0
		↓	↖	↑	↗			
		1136	121	208	52			
		SB on/off flow		NB on/off flow				
		0		0				

Intersection: Montgomery and Park

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 1						
			NS: Bird						
			EW: San Carlos						
			81	1030	75	399			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
	575	←					↖	25	0
	70	↗					←	370	
EB on/off flow	505	→					↙	209	EB on/off flow
	261	↘					→	707	0
			↓	↖	↑	↗			
			1500	124	304	127			
			SB on/off flow		NB on/off flow				
			0		0				

Intersection: Bird and San Carlos

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 66						
			NS: Bird						
			EW: 280 WB						
			572	928	0	649			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
	768	←					↖	248	
	0	↗					←	0	
EB on/off flow	0	→					↙	702	EB on/off flow
	0	↘					→	0	
			↓	↖	↑	↗			
			1630	196	401	0			
			SB on/off flow		NB on/off flow				
			0		0				

Intersection: Bird and I-280 WB

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 67		Int#: 2				
			NS: Bird						
			EW: 280 EB						
			0	1044	586	597			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
	0	←					↖	0	
	224	↗					←	0	
EB on/off flow	0	→					↙	0	EB on/off flow
	409	↘					→	819	
			↓	↖	↑	↗			
			1453	0	373	233			
			SB on/off flow		NB on/off flow				
			182		48				

Intersection: Bird and I-280 EB

			SB on/off flow		NB on/off flow				
			0		0				
			SC: N/A		Int#: 1				
			NS: Bird						
			EW: Virginia						
			36	1283	316	558			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
	76	←					↖	133	
	31	↗					←	11	
EB on/off flow	9	→					↙	46	EB on/off flow
	4	↘					→	378	
			↓	↖	↑	↗			
			1333	29	394	53			

Intersection: Bird and Virginia

			SB on/off flow		NB on/off flow				
			SC: 40						
			NS: Montgomery						
			EW: Julian						
			25	3	48	41			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
	337	←					↖	22	0
	13	↗					←	302	
EB on/off flow	395	→					↙	16	EB on/off flow
	5	↘					→	468	0
			↓	↖	↑	↗			
			24	10	6	25			
			SB on/off flow		NB on/off flow				

Intersection: Montgomery and Julian

					SB on/off flow		NB on/off flow						
					SC: 7								
					NS: Pleasant								
					EW: Julian								
					0	0	394	111					
WB on/off flow					↙	↓	↘	↑				WB on/off flow	
0			340	←					↖	111		0	
			0	↗					←	340			
EB on/off flow			468	→					↙	0		EB on/off flow	
0			0	↘					→	862		0	
					↓	↖	↑	↗					
					0	0	0	0					
					SB on/off flow		NB on/off flow						

Intersection: Pleasant and Julian

					SB on/off flow		NB on/off flow						
					SC: 41								
					NS: Hwy 87 (W)								
					EW: Julian								
					75	87	172	1084					
WB on/off flow					↙	↓	↘	↑				WB on/off flow	
0			451	←					↖	1084		0	
			0	↗					←	376			
EB on/off flow			837	→					↙	220		EB on/off flow	
0			25	↘					→	445		0	
			*273 vehicles go		↓	↖	↑	↗					
			onto the onramp		332	0	0	0					
			273										
					SB on/off flow		NB on/off flow						

Intersection: Hwy 87 (W) and Julian

					SB on/off flow		NB on/off flow						
					SC: 42								
					NS: Hwy 87 (E)								
					EW: James/Julian								
			*Below is the		0	317	162	757					
WB on/off flow			freeway volume		↙	↓	↘	↑					
0			1680	←					↖	126		WB on/off flow	
			117	↗					←	1156		0	
EB on/off flow			328	→					↙	0			
0			0	↘					→	686		EB on/off flow	
					↓	↖	↑	↗				0	
					0	407	352	41					
					*The above volume is Notre Dame Ave.								
					SB on/off flow		NB on/off flow						

Intersection: Hwy 87 (E) and Julian

			SB on/off flow		NB on/off flow				
			SC: 43						
			NS: Market						
			EW: James						
			0	1000	145	282			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	0	←					↖	0	0
	50	↗					←	0	
EB on/off flow	500	→					↙	0	EB on/off flow
0	100	↘					→	675	0
			↓	↖	↑	↗			
			1100	0	232	30			
			SB on/off flow		NB on/off flow				
			0		0				

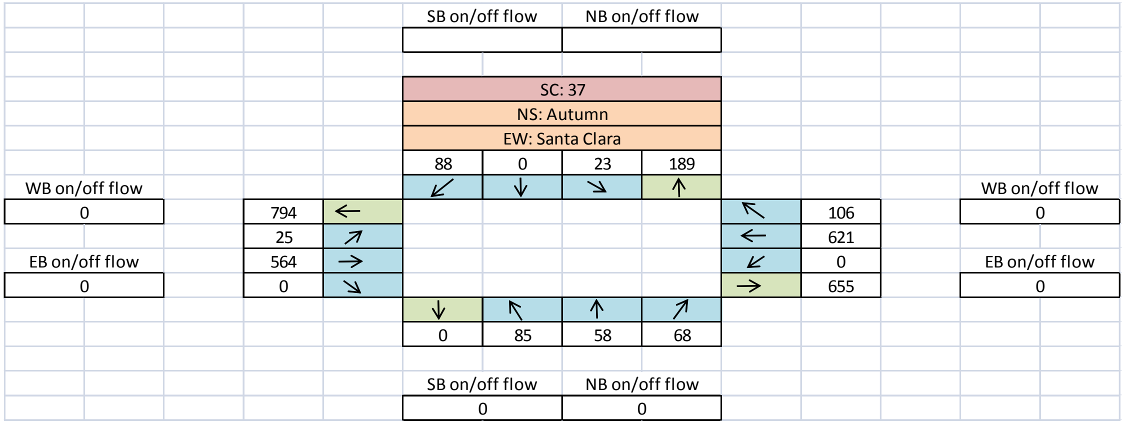
Intersection: Market and Street James

			SC: 43		Int#: 24				
			NS: 1st						
			EW: James						
			0	0	0	285			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	0	←					↖	0	0
	53	↗					←	0	
EB on/off flow	710	→					↙	0	EB on/off flow
0	0	↘					→	740	0
			↓	↖	↑	↗			
			0	0	232	30			
			SB on/off flow		NB on/off flow				
					0				

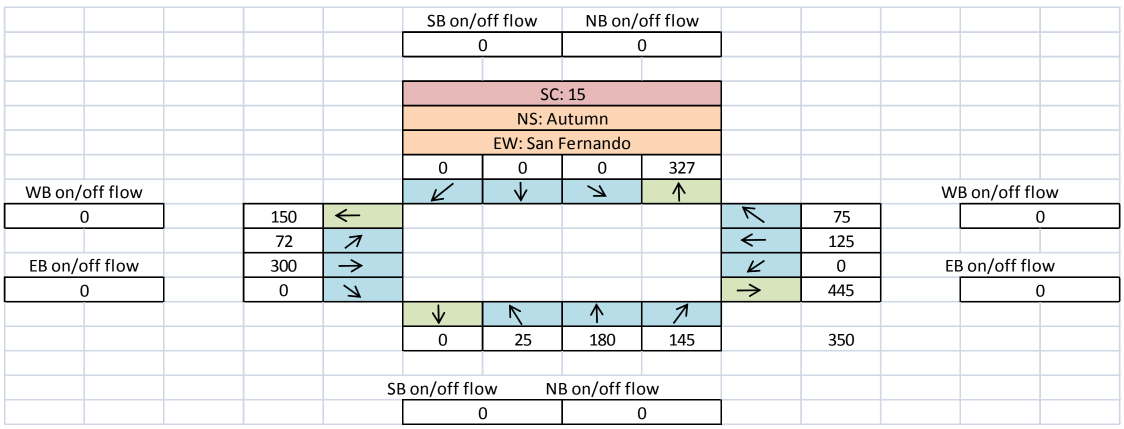
Intersection: 1st and James

			SC: 43		Int#: 24				
			NS: 4th						
			EW: James						
			0	900	121	0			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	0	←					↖	0	0
	0	↗					←	0	
EB on/off flow	750	→					↙	0	EB on/off flow
0	81	↘					→	871	-871
	831		↓	↖	↑	↗			
			981	0	0	0			
			SB on/off flow		NB on/off flow				
			0		0				

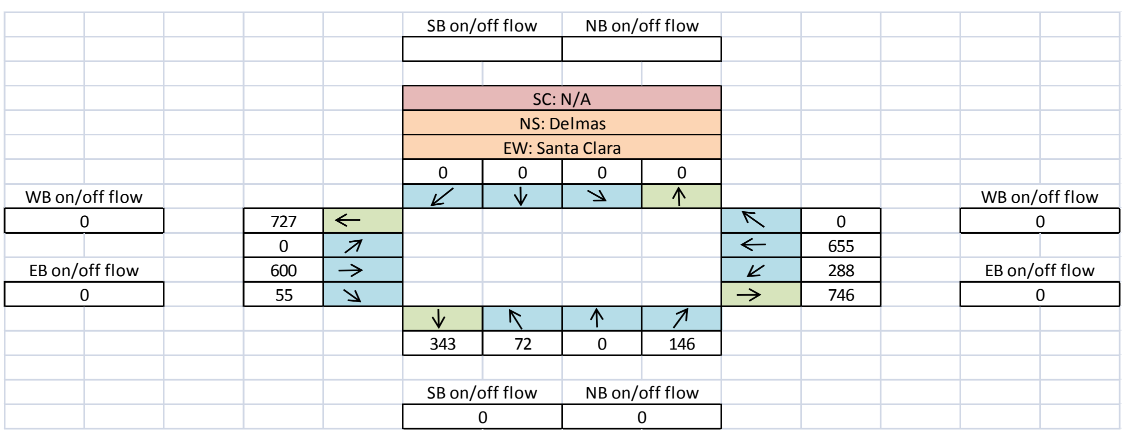
Intersection: 4th and James



Intersection: Autumn and Santa Clara



Intersection: Autumn and San Fernando



Intersection: Delmas and Santa Clara

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 16						
			NS: Delmas						
			EW: San Fernando						
			50	300	50	250			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	100	←					↖	200	0
	50	↗					←	50	
EB on/off flow	500	→					↙	200	EB on/off flow
0	50	↘					→	550	0
			↓	↖	↑	↗			
			550	0	0	0			
			SB on/off flow		NB on/off flow				
			0		0				

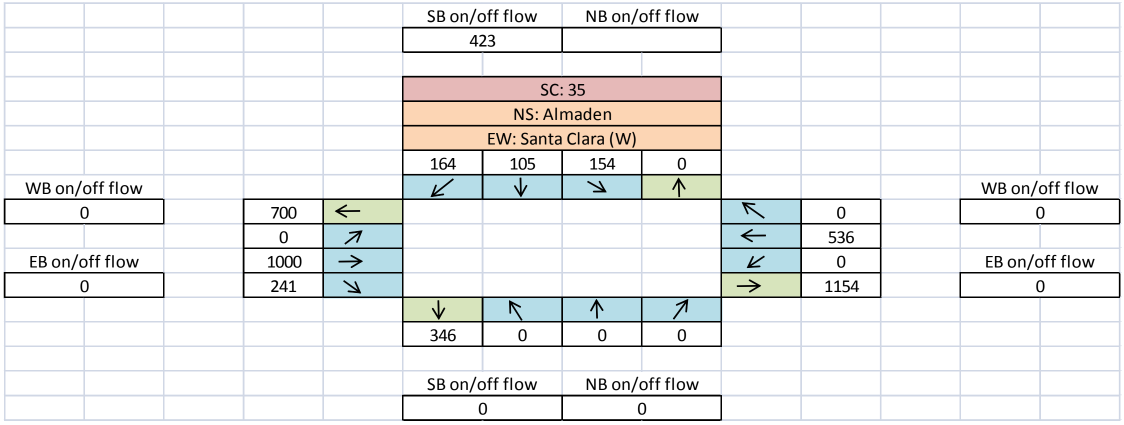
Intersection: Delmas and San Fernando

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 2						
			NS: Delmas						
			EW: Park						
			77	365	249	306			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	470	←	The above volume is the freeway offramp				↖	0	0
	0	↗					←	323	
EB on/off flow	121	→					↙	121	EB on/off flow
0	46	↘					→	419	0
			↓	↙	↓	↘			
			838	70	306	49	*The volumes to the right are Delmas St. SB		
			SB on/off flow		NB on/off flow			174	
			0		-425				

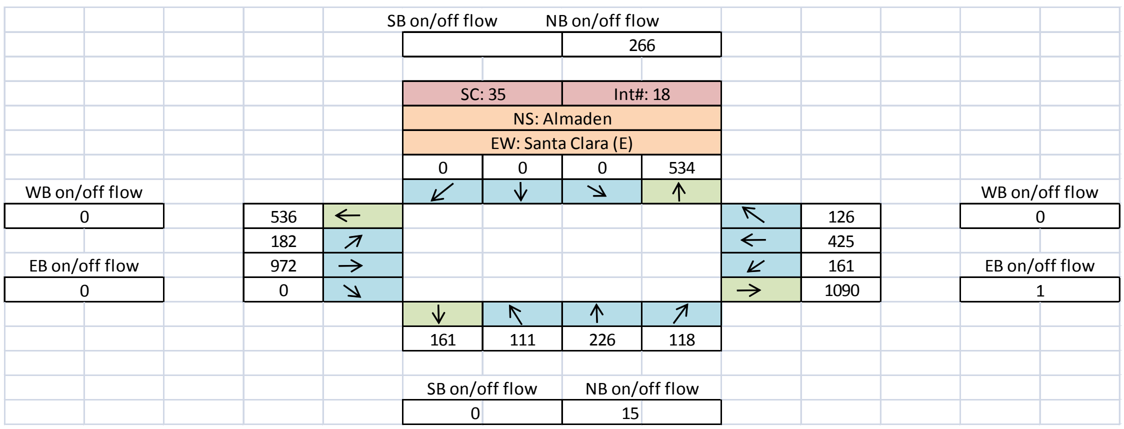
Intersection: Delmas and Park

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 2						
			NS: Delmas						
			EW: San Carlos						
			203	468	35	0			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	541	←					↖	0	0
	0	↗					←	338	
EB on/off flow	428	→					↙	40	EB on/off flow
0	106	↘					→	463	0
			↓	↖	↑	↗			
			614	0	0	0			
			SB on/off flow		NB on/off flow				

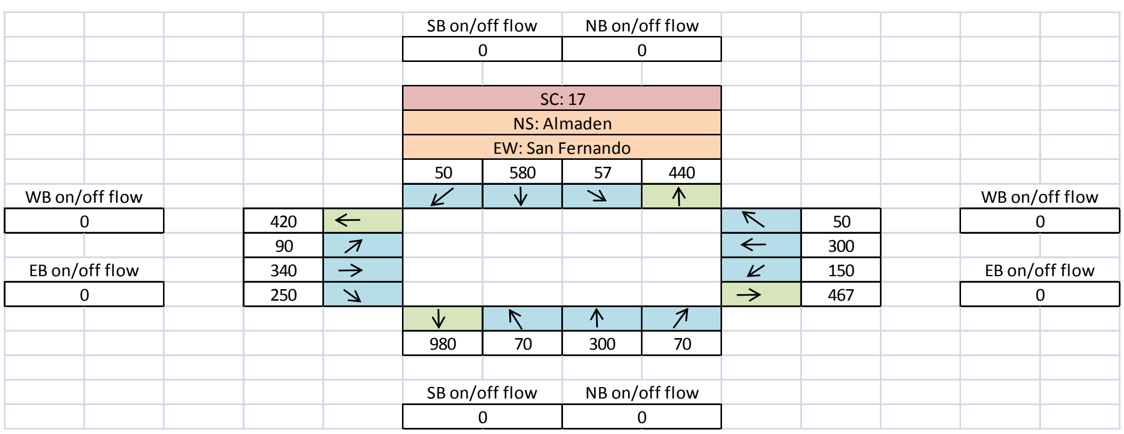
Intersection: Delmas and San Carlos



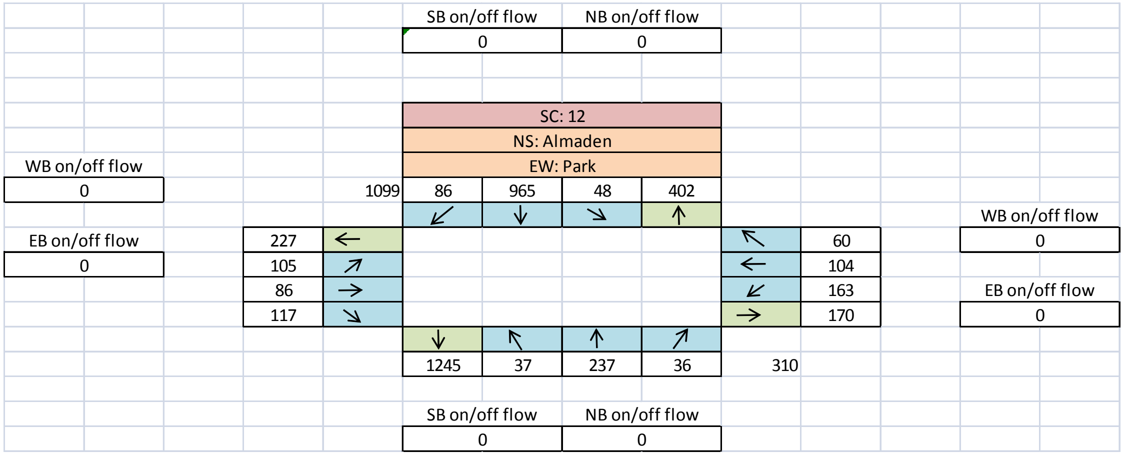
Intersection: Almaden and Santa Clara (W)



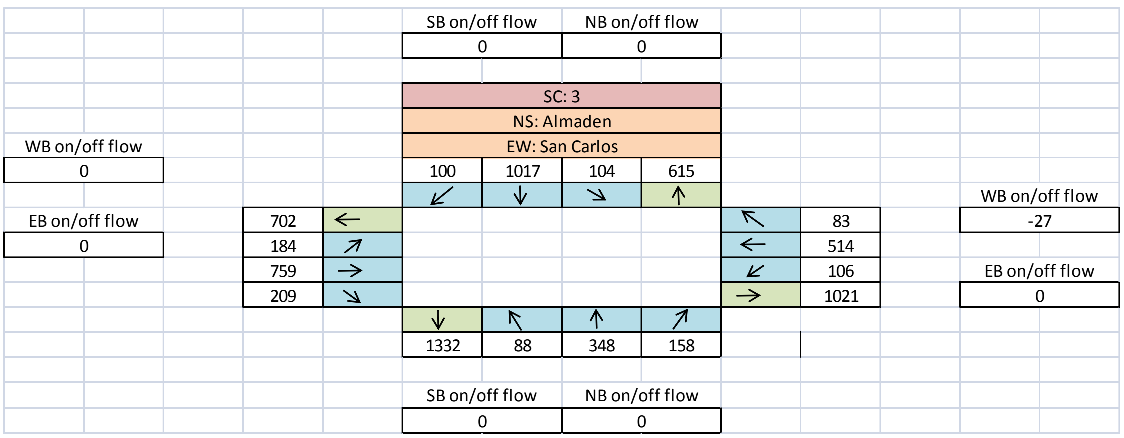
Intersection: Almaden and Santa Clara (E)



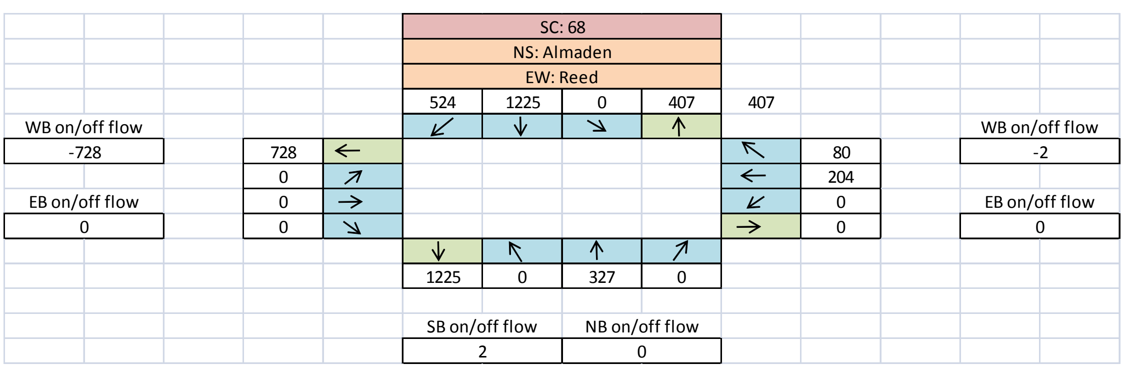
Intersection: Almaden and San Fernando



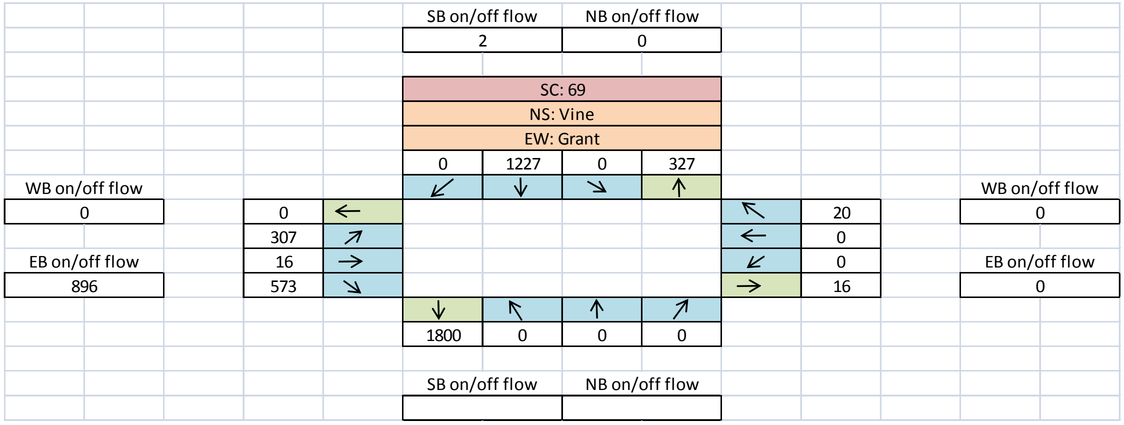
Intersection: Almaden and Park



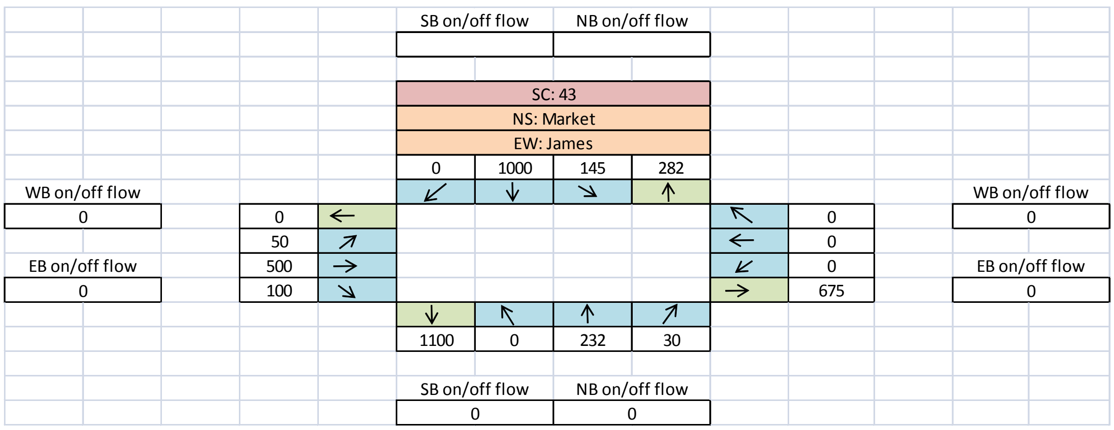
Intersection: Almaden and San Carlos



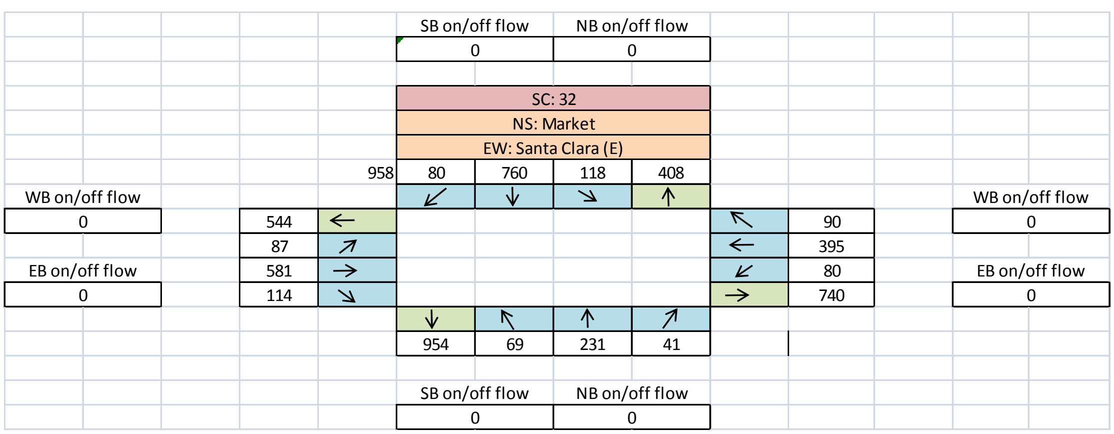
Intersection: Almaden and Reed



Intersection: Vine and Grant



Intersection: Market and Street James



Intersection: Market and Santa Clara (E)

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 18						
			NS: Market						
			EW: San Fernando						
			44	940	127	305			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	251	←					↖	57	0
	18	↗					←	164	
EB on/off flow	239	→					↙	71	EB on/off flow
0	140	↘					→	442	0
			↓	↖	↑	↗			
	397		1151	43	230	76			
			SB on/off flow		NB on/off flow				
			0		0				

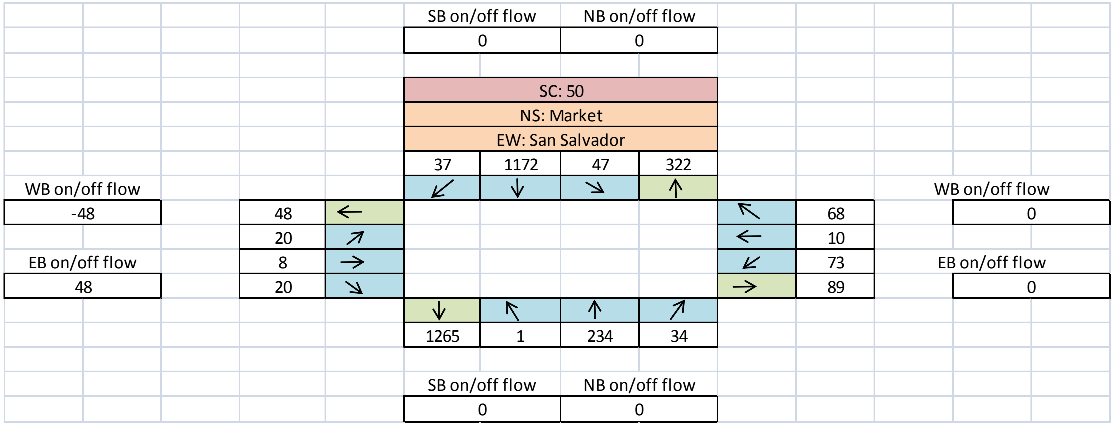
Intersection: Market and San Fernando

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 13						
			NS: Market (W side)						
			EW: Park						
			133	1018	0	0			
WB on/off flow			↙	↓	↘	↑			
0	133	←					↖	0	
	0	↗					←	0	
EB on/off flow	0	→					↙	0	
0	161	↘					→	0	
			↓	↖	↑	↗			
			1179	0	0	0			
			SB on/off flow		NB on/off flow				
			0		0				

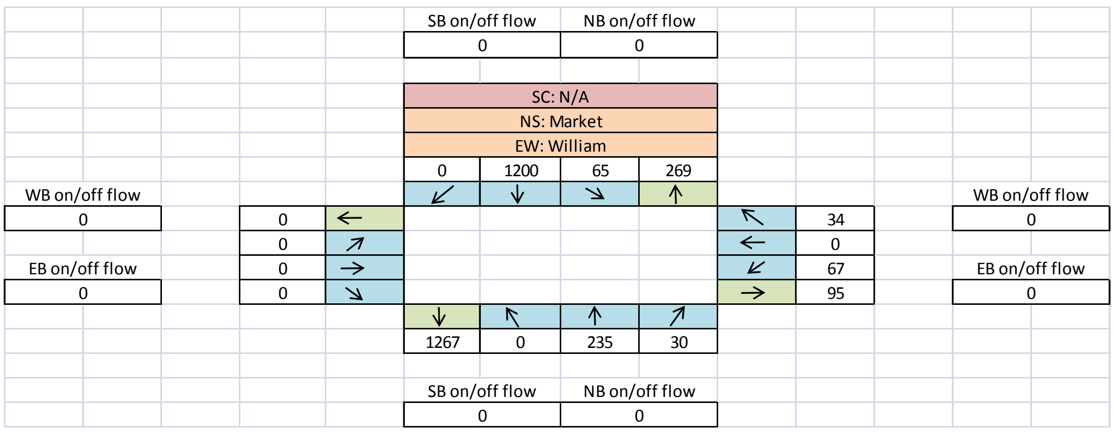
Intersection: Market (W side) and Park

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 4						
			NS: Market						
			EW: San Carlos						
			86	860	96	283			
WB on/off flow			↙	↓	↘	↑			
0	558	←					↖	21	
	78	↗					←	357	
EB on/off flow	374	→					↙	0	
0	145	↘					→	472	
			↓	↖	↑	↗			
			1005	115	184	2			
			SB on/off flow		NB on/off flow				
			0		0				

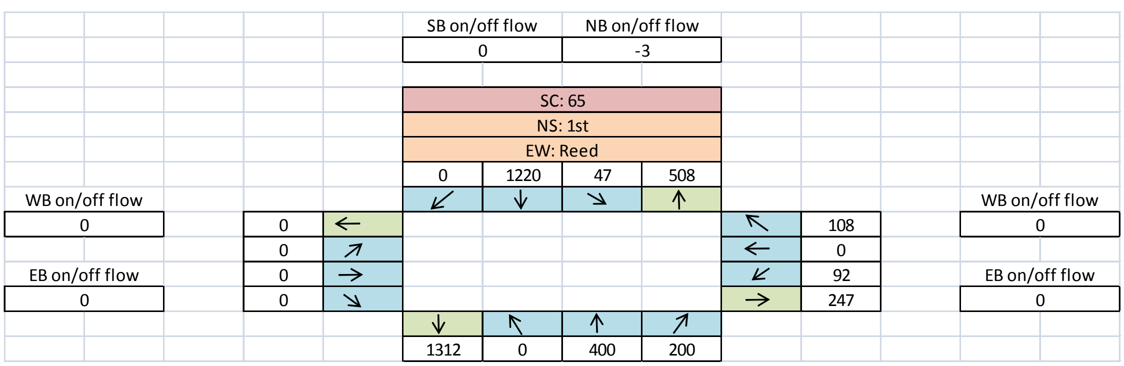
Intersection: Market and San Carlos



Intersection: Market and San Salvador



Intersection: Market and William



Intersection: 1st and Reed

			SC: 44						
			NS: 1st						
			EW: James						
			0	0	0	285			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	0	←					↖	0	0
	53	↗					←	0	
EB on/off flow	710	→					↙	0	EB on/off flow
0	0	↘					→	740	0
			↓	↖	↑	↗			
			0	0	232	30			
			SB on/off flow		NB on/off flow				
					0				

Intersection: 1st and James

			SB on/off flow		NB on/off flow				
					0				
			SC: 31						
			NS: 1st						
			EW: Santa Clara (E)						
			0	0	0	448			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	565	←					↖	90	0
	87	↗					←	445	
EB on/off flow	653	→					↙	0	EB on/off flow
0	0	↘					→	880	0
			↓	↖	↑	↗			
			0	120	271	227			
			SB on/off flow		NB on/off flow				
			0		1				

Intersection: 1st and Santa Clara (E)

			SB on/off flow		NB on/off flow				
			0		0				
			SC: 19		Int#: ?				
			NS: 1st						
			EW: San Fernando						
			0	0	0	255			
WB on/off flow			↙	↓	↘	↑		269	WB on/off flow
0	200	←					↖	71	0
	31	↗					←	198	
EB on/off flow	390	→					↙	0	EB on/off flow
0	0	↘					→	418	0
			↓	↖	↑	↗			
			0	2	153	28			
			SB on/off flow		NB on/off flow				
			0		0				

Intersection: 1st and San Fernando

				SB on/off flow		NB on/off flow				
				0		0				
				SC: 5						
				NS: 1st						
				EW: San Carlos						
				0	0	0	268			
WB on/off flow				↙	↓	↘	↑			WB on/off flow
0		378	←					↖	20	0
		48	↗					←	378	
EB on/off flow		375	→					↙	0	EB on/off flow
0		49	↘					→	431	0
				↓	↖	↑	↗			
				49	0	200	56			
				SB on/off flow		NB on/off flow				
				0		0				

Intersection: 1st and San Carlos

				SB on/off flow		NB on/off flow				
				0		0				
				SC: 51						
				NS: 1st						
				EW: San Salvador						
				24	22	3	213			
WB on/off flow				↙	↓	↘	↑			WB on/off flow
0		158	←					↖	61	0
		14	↗					←	132	
EB on/off flow		75	→					↙	7	EB on/off flow
0		7	↘					→	121	0
				↓	↖	↑	↗			
				36	2	138	43			
				SB on/off flow		NB on/off flow				
				0		0				

Intersection: 1st and San Salvador

				SC: 6						
				NS: 4th						
				EW: James						
				0	900	121	0			
WB on/off flow				↙	↓	↘	↑			WB on/off flow
0		0	←					↖	0	0
		0	↗					←	0	
EB on/off flow		750	→					↙	0	EB on/off flow
0		81	↘					→	871	-871
				↓	↖	↑	↗			
				981	0	0	0			
				SB on/off flow		NB on/off flow				
				0		0				

Intersection: 4th and James

			SB on/off flow		NB on/off flow				
			0						
			SC: 28						
			NS: 4th						
			EW: Santa Clara (E)						
			56	800	125	0			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	434	←					↖	0	
	0	↗					←	378	
EB on/off flow	625	→					↙	130	EB on/off flow
0	252	↘					→	750	
			↓	↖	↑	↗			
			1182	0	0	0			
			SB on/off flow		NB on/off flow				
			0						

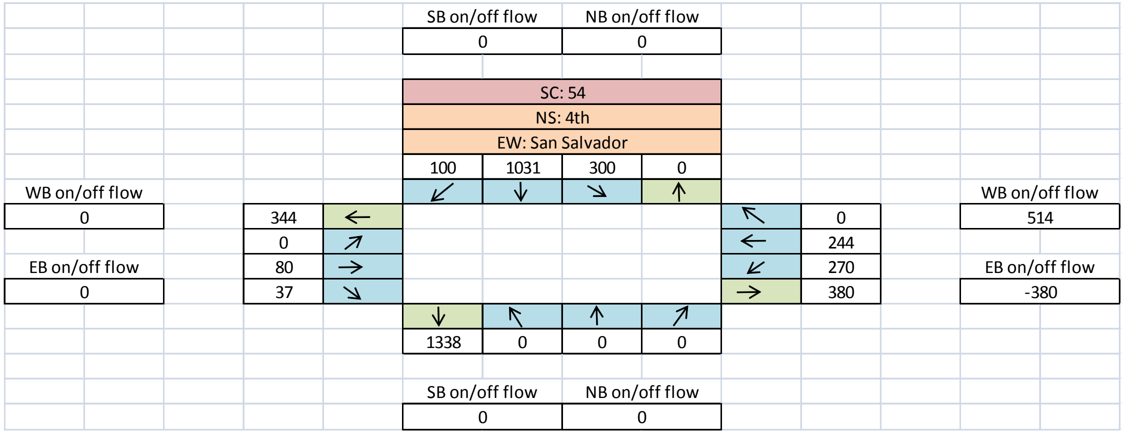
Intersection: 4th and Santa Clara

			SB on/off flow		NB on/off flow				
			0						
			SC: 22						
			NS: 4th						
			EW: San Fernando						
			96	1064	70	0			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	340	←					↖	0	502
	0	↗					←	244	
EB on/off flow	311	→					↙	258	EB on/off flow
0	144	↘					→	381	-381
			↓	↖	↑	↗			
			1466	0	0	0			
			SB on/off flow		NB on/off flow				
			0						

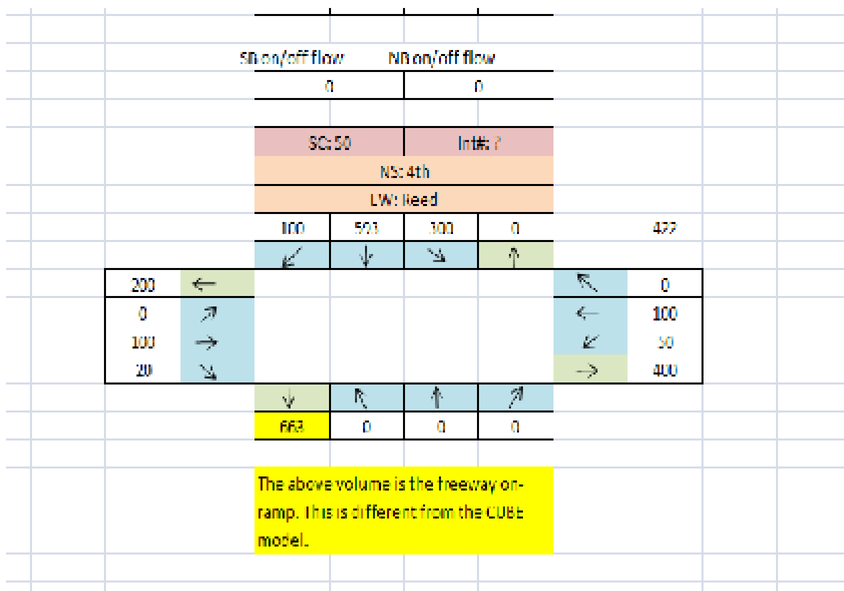
Intersection: 4th and San Fernando

			SB on/off flow		NB on/off flow				
			0						
			SC: 8						
			NS: 4th						
			EW: San Carlos						
			266	1200	0	0			
WB on/off flow			↙	↓	↘	↑			WB on/off flow
0	266	←					↖	0	#REF!
	0	↗					←	0	
EB on/off flow	0	→					↙	0	EB on/off flow
0	431	↘					→	0	0
			↓	↖	↑	↗			
			1631	0	0	0			
			SB on/off flow		NB on/off flow				
			0		0				

Intersection: 4th and San Carlos



Intersection: 4th and San Salvador



Intersection: 4th and Reed

APPENDIX E: DYNAMIC-ASSIGNMENT RESULTS

This appendix presents the results of the attempts to run a 48 x 48 OD matrix that was created for the purpose of dynamic assignment in VISSIM. The “From to” row indicates the real time that is simulated, which in this case is 4:00 to 5:00 pm. The “Factor” row is the scale factor for the network. The “Number of network objects” is the number of zones within the network, while the “Network object numbers” is the reference on which the later summaries depend.

```
$V;D3
* From  to
16.00 17.00
* Factor
1.00
*
* Cal Poly
* 01/31/11
* Number of network objects
48
* Network object numbers
     1     2     3     4     5     6     7     8     9    10
    11    12    13    14    15    16    17    18    19    20
    21    22    23    24    25    26    27    28    29    30
    31    32    33    34    35    36    37    38    39    40
    41    42    43    44    45    46    47    48
* Obj 1 Sum = 68.000
 0.000  2.000  2.000  2.000  2.000  2.000  2.000  1.000  1.000  1.000
 1.000  1.000  2.000  1.000  2.000  1.000  1.000  2.000  2.000  2.000
 1.000  0.000  1.000  2.000  0.000  1.000  1.000  2.000  1.000  1.000
 1.000  1.000  1.000  1.000  1.000  0.000  0.000  1.000  1.000  1.000
 1.000  0.000  2.000 13.000  0.000  4.000  0.000  0.000
* Obj 2 Sum = 867.000
 1.000  0.000 21.000 11.000 21.000 21.000  1.000  1.000  5.000  2.000
 1.000  1.000  3.000  2.000 21.000  1.000  5.000 21.000  1.000 21.000
```

1.000 0.000 1.000 1.000 0.000 1.000 2.000 1.000 21.000 21.000
1.000 1.000 21.000 1.000 1.000 0.000 0.000 21.000 481.000 1.000
1.000 0.000 21.000 66.000 0.000 41.000 0.000 0.000
* Obj 3 Sum = 929.000
1.000 11.000 0.000 11.000 22.000 22.000 22.000 1.000 4.000 4.000
1.000 1.000 4.000 1.000 22.000 1.000 1.000 22.000 2.000 22.000
1.000 0.000 1.000 2.000 0.000 2.000 4.000 2.000 22.000 22.000
1.000 1.000 22.000 1.000 22.000 0.000 0.000 22.000 482.000 10.000
22.000 22.000 22.000 22.000 0.000 49.000 0.000 0.000
* Obj 4 Sum = 583.000
0.000 14.000 14.000 0.000 14.000 1.000 14.000 1.000 5.000 4.000
1.000 1.000 5.000 2.000 14.000 1.000 5.000 14.000 4.000 14.000
1.000 0.000 1.000 1.000 0.000 1.000 2.000 1.000 14.000 14.000
1.000 1.000 14.000 1.000 14.000 0.000 0.000 14.000 279.000 10.000
14.000 14.000 14.000 14.000 0.000 30.000 0.000 0.000
* Obj 5 Sum = 2352.000
1.000 28.000 56.000 42.000 0.000 56.000 1.000 1.000 6.000 1.000
1.000 1.000 5.000 3.000 56.000 1.000 1.000 56.000 2.000 56.000
1.000 0.000 1.000 2.000 0.000 2.000 1.000 5.000 56.000 56.000
1.000 1.000 56.000 1.000 56.000 0.000 0.000 326.000 1025.000 10.000
56.000 56.000 56.000 56.000 0.000 154.000 0.000 0.000
* Obj 6 Sum = 1222.000
1.000 15.000 29.000 29.000 29.000 0.000 29.000 1.000 8.000 5.000
29.000 1.000 1.000 4.000 29.000 1.000 2.000 29.000 3.000 29.000
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* Obj 7 Sum = 291.000
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* Obj 8 Sum = 160.000

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* Obj 9 Sum = 1297.000

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* Obj 10 Sum = 6552.000

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* Obj 11 Sum = 799.000

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* Obj 12 Sum = 1550.000

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* Obj 13 Sum = 677.000

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* Obj 14 Sum = 793.000

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* Obj 15 Sum = 1303.000

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* Obj 16 Sum = 793.000

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* Obj 17 Sum = 467.000

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* Obj 18 Sum = 2141.000
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* Obj 19 Sum = 1472.000
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* Obj 20 Sum = 8964.000
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* Obj 21 Sum = 1214.000
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* Obj 22 Sum = 1126.000
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* Obj 23 Sum = 0.000

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* Obj 24 Sum = 284.000

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* Obj 25 Sum = 322.000

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* Obj 26 Sum = 0.000

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* Obj 27 Sum = 1504.000

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* Obj 28 Sum = 211.000

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* Obj 29 Sum = 5500.000
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* Obj 30 Sum = 879.000
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* Obj 31 Sum = 804.000
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* Obj 32 Sum = 1492.000
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* Obj 33 Sum = 1340.000
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* Obj 34 Sum = 423.000
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* Obj 35 Sum = 1759.000
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* Obj 36 Sum = 129.000
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* Obj 37 Sum = 1173.000
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* Obj 38 Sum = 5334.000
123.000 6.000 1.000 10.000 384.000 33.000 9.000 0.000 133.000 71.000
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* Obj 39 Sum = 7847.000
184.000 20.000 1.000 15.000 196.000 0.000 14.000 0.000 196.000 98.000
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* Obj 40 Sum = 164.000
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* Obj 41 Sum = 1547.000
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* Obj 42 Sum = 1000.000
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* Obj 43 Sum = 999.000
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* Obj 44 Sum = 254.000

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* Obj 45 Sum = 2945.000

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* Obj 46 Sum = 0.000

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* Obj 47 Sum = 622.000

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* Obj 48 Sum = 156.000

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ABBREVIATIONS AND ACRONYMS

CAD	Computer Aided Dispatch
EOP	Emergency Operations Plan
FHWA	Federal Highway Administration
GIS	Geographic Information Systems
GPS	Global Positioning System
GUI	Graphical User Interface
HGV	Heavy Gross Vehicle
HOV	High Occupancy Vehicle
INTRAS	Integrated Traffic Simulator
IRS	Internal Revenue Service
OREMS	Oak Ridge Evacuation Model System
PeMS	Performance Measurement System
SJDOT	San José Department of Transportation

GLOSSARY OF TERMS

GEH Statistic	A formula used in traffic engineering and traffic modeling to compare two sets of traffic volumes. The statistic gets its name from Geoffrey E. Havers, who invented it in the 1970s while working as a transport planner in London, England.
HP Pavilion	Hewlett-Packard Pavilion, where numerous public events are held.
I-280	Interstate 280 is a north-south directional freeway that begins in San Francisco and goes south to San José. After traveling in an east-west direction through San José, it terminates at the south end of I-680.
BART	Bay Area Rapid Transit serves the San Francisco Bay Area in a semi-circle from San Francisco International Airport north to San Francisco, east to Oakland, and south to Fremont. An extension to southern Fremont is under construction, and an extension to San José is planned.
GUI	Graphical user interface, which allows users to interact with electronic devices using images rather than text commands.
DOT	The Department of Transportation, which operates at both the federal and state levels. The federal DOT oversees federal highway, air, rail-road, mass transit, maritime, and other transportation administration functions. The state DOTs are responsible for highway, bridge, rail, mass transit, and general aviation transportation planning and construction and maintenance of the state highway system.
PeMS	Performance Measurement System, a project conducted by the Department of Electrical Engineering and Computer Sciences at the University of California, Berkeley, with the cooperation of the California Department of Transportation, California Partners for Advanced Transit and Highways, and Berkeley Transportation Systems.
IRS	Internal Revenue Service, the U.S. government agency responsible for tax collection and tax-law enforcement.

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