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SIMULATION AND CONTINUANCE OF OPERATION FOR THE USE OF TRANSIT (LYNX) TO BE USED IN EMERGENCY EVACUATION INCIDENTS

By

NOOR ELMITINY
B. S. Cairo University Faculty of Engineering, 2003

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Civil and Environmental Engineering in the College of Engineering and Computer Science at the University of Central Florida Orlando, Florida

Summer Term
2006
ABSTRACT

The evacuation planning has become an important issue addressed by many research studies and publications aiming to improve the security of the daily life for our public inside the United States of America. The main objective of this research was to address the growing need for evacuation planning using traffic simulation. With increased interests and awareness in emergency evacuation and first responder access to emergencies in public locations (airports, transit stations, ports or stadiums), the traffic simulation can be helpful in orchestrating the traffic flow during emergencies. Related to this issue, Federal Transit Administration has issued a large number of publications and guidelines concerning emergency preparedness and incident management. These guidelines are used to develop a simulation-based activity to evaluate the current plan and alternative plans for the deployment of transit during an emergency situation. A major task for this project is to study the effect of evacuation on the surrounding traffic network and help the local transit company (LYNX) to evaluate their evacuation plan and consider different possibilities without the risk and cost of actual evacuation drills. A set of different scenarios and alternatives for each scenario were simulated and studied to reach the best possible evacuation strategy. The main findings were evacuation as pedestrians have less impact on traffic network and rerouting decreases the congestion resulting from the evacuation process.
ACKNOWLEDGMENTS

I would like to acknowledge many people who helped me complete my work successfully, starting by my family: father Dr. Mohamad Rashad Elmitiny, my sisters Shereen and Esraa for their moral support during my study time, my advisor Dr. Essam Radwan for really being the most helping and guiding advisor a student can ask for, Dr. Hesham Mahgoub and his family who really supported me more than I could have ever imagined, to Shankar Rmasamy and in addition to those mentioned above I would really like to thank the University of Central Florida Group of faculty and students for being the very supportive and cooperative. And to every one that contributed to having this work see the light by either supporting scientifically or morally.
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CHAPTER ONE:
INTRODUCTION AND OBJECTIVES

Traffic simulation tools are becoming more attractive in studying traffic issues. With the advances in computers and simulation techniques, it is now possible to model any roadway network and simulate traffic flow on these roads in a very realistic fashion. This enables traffic engineers and transportation planners to investigate the effect of hypothetical changes in the network geometry and traffic control strategies on traffic performance. With increased interests and awareness in emergency evacuation and first responder access to emergencies in public locations (airports, transit stations, ports or stadiums), traffic simulation can be helpful in orchestrating traffic flow during emergencies.

1.1. Problem Statement

The issue of emergency preparedness has been a major concern of our nation for the last few years. As the threats grow stronger and more frequent, the need for highly effective preparedness plans is critical to manage the operation and safety of the people’s daily life activities. The issue of safety and emergency preparedness need to be specially addressed in the transportation field from the research viewpoint. That is because transportation is the spinal cord of any nation’s economy and daily activities.

It was recognized by many authorities especially the FTA-Federal Transit Administration- that public transportation is a very sensitive member of the transportation
infrastructure. Because it involves dealing with large population daily and any threat to a public transportation could lead to a disastrous number of casualties. Considering this, the Federal Transit Administration has developed “The Public Transportation System Security and Emergency Preparedness Guide” to support the activities of public transportation to increase and mitigate their preparedness among many other guides and documents which aims for better and safer transit environment.

Based on this FTA’s guidelines, this project was proposed to help the local public transit company of Orlando metropolitan City “LYNX” to evaluate and test their emergency preparedness plans and also to evaluate different response alternatives.

1.2. Objective

The main objective of this research was to address the growing need for evacuation planning using traffic simulation. With increased interests and awareness in emergency evacuation and first responder access to emergencies in public locations (airports, transit stations, ports or stadiums), traffic simulation can be helpful in orchestrating the traffic flow during emergencies.

Related to this issue, Federal Transit Administration has issued large number of publications and guidelines concerning emergency preparedness and incident management. These guidelines were used to develop a simulation-based activity to evaluate the current plan and alternative plans for the deployment of transit during an...
emergency situation and to study the effect of evacuation on the surrounding traffic network.

The goal is to assist the personnel of the local transit operation company of the city of Orlando ‘LYNX’ with its safety and security guidelines and evaluate their current preparedness plans and different response scenarios. Through following the FTA guidelines to help against any type of threat that might jeopardize the safety of travelers aiming to increase the safety of transit transportation facilities.

1.3. Description of Tasks

There are three tasks to this study and they are as following:

1.3.1. Task 1: Data Acquisition

Aerial photography or bitmap image for the geometric layout of the Downtown Orlando was obtained from Google Earth. The traffic counts and signal timings for the Orlando downtown area were provided by the City of Orlando.

1.3.2. Task 2: Network Coding

A traffic simulation model for Orlando downtown was developed using the traffic simulation software VISSIM. VISSIM is designed to perform microscopic traffic flow
simulation for traffic and transit movements and modeling of vehicle actuated signal operations. The network included 28 signals (27 actuated and 1 pre-timed) and 23 traffic entry points. The network was calibrated and validated to represent the real world traffic.

1.3.3. Task 3: Test Scenarios and Analysis

VISSIM model was used to evacuate the LYNX bus depot located in Downtown Orlando during an emergency situation. We assumed to evacuate 2000 LYNX personnel and passengers at the depot either by foot to a nearby garage or by utilizing the buses available at the depot to the basketball arena. The maximum number of buses available during the incident was assumed to be ten. Some scenarios utilized all the available buses and evacuated the rest of the Evacuees on foot. Other scenarios utilized half of the available buses and evacuated the rest of the Evacuees on foot. While other scenarios didn’t use any buses at all and evacuated all the Evacuees on foot without utilizing the available buses. Some of these scenarios were also run with rerouting traffic away from the incident area to reduce its impact on surrounding traffic.
CHAPTER TWO:
LITERATURE REVIEW

An extensive literature review was performed on the available references that address similar issues or issues that are related to this area of research. This is very important to elaborate research approaches and alternatives that can be followed in this research. The most relevant resources of literature are summarized as follows.

2.1. Emergency Incidents Guidelines publications

Lately the United States of America released the need of various emergency preparedness measures. This has encouraged the research in the area of emergency preparedness, response and after effect resulting form the threat. The Regional Emergency Coordination Plan (RECP) prepared by the Metropolitan Washington Council of Government Task Force on Homeland Security and Emergency Preparedness highlights the need for regional coordination in the event of future incident or emergency. The plan mainly addresses the transportation operation during a possible emergency incident and the issue of moving people around the or out of the regional area and also moving the resources needed to the affected area (RECP, 2002).

According to the Homeland Security point of perspective the area of emergency preparedness contains four main points: preparedness, response, mitigation and recovery. And to further explain mitigation it is taking measures that can reduce the effect of an
incident on the overall system and reduce the time of recovery. Mitigation measures are also very important to reduce the risk of life or property loss.

The stages of a threat were defined by the Federal Transit Administration (FTA) in their National Transit Response Model are listed in Table 1.

Table 1: Threat Level/Attack/Recovery Systems Approach

<table>
<thead>
<tr>
<th>Color</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Low threat level</td>
</tr>
<tr>
<td>Blue</td>
<td>General threat level</td>
</tr>
<tr>
<td>Yellow</td>
<td>Elevated threat level</td>
</tr>
<tr>
<td>Orange</td>
<td>High threat level</td>
</tr>
<tr>
<td>Red</td>
<td>Severe threat level</td>
</tr>
<tr>
<td>Black</td>
<td>Actual Attack</td>
</tr>
<tr>
<td>Purple</td>
<td>Recovery</td>
</tr>
</tbody>
</table>

The Black and Purple designations are interpreted as follows: Black indicates that an attack is underway against a specific transit agency or within the agency's immediate geographic area. The Black state is entered only when an attack has occurred. Black includes the immediate post-attack time period when the transit agency may be responding to casualties, assisting in evacuations, inspecting and securing transit
facilities, or helping with other tasks directed by the local emergency management authority.

Purple indicates the recovery of transit service after an attack has occurred. Purple includes restoration of levels of service, routes, and schedules, repairing or reopening facilities, adjustment of staff work schedules and duty assignments, responding to customer inquiries about services, and other activities necessary to restore transit service. The Purple state follows the Black state and may also exist for short time periods when the agency is transitioning from a higher threat condition to a lower threat condition (e.g., from Red to Orange). The Purple state will coexist with the prevailing threat condition. In other words, business recovery (Purple) will be accomplished while maintaining the prevailing readiness status (e.g., Orange protective measures).

Each level of threat got a complete set of measures recommended by the Federal Transit Administration Transit Threat Level Response Recommendation.

Preparedness mainly means the scope and magnitude of the threat anticipated. That means the activity of developing an emergency response plan and training employees for the projected measures of response.

Response assumes that an incident has already happened and studies the possible effects on the agencies and people subjected directly or indirectly to the threat. Also studies the ways of dispatching emergency response vehicles effectively.
And last but not least the recovery which manes after the threat is over how long would its effect last and the time needed for the under attacked facility to go back to its full operational power. Minimizing this time may greatly reduce the harmful effect of the threat.

The transportation system plays a vital role in all phases of emergency threat response. The transportation network is responsible for getting the responders to the affected area and getting the public to safety without conflicting any of the two roles (ITA America, 2002).

This important role of transportation in the emergency operation management is reflected through the large number of publication and guidelines issued by different agencies to address this issue. The Federal Transit Administration has issued a large number of publications in this matter. The most relevant to this research are “Protecting Public Surface Transportation against Terrorism and Serious Crime: Continuing Research on Best Security Practices” (Brian Michael Jenkins and Larry N. Gersten 2001) study continues earlier research on best security practices. It examines security practices in effect at public surface transportation facilities in Tokyo and London—both targets of terrorist attacks—and in the San Francisco Bay Area and the Santa Clara Valley of California.

Also “The Public Transportation System Security and Emergency Preparedness Planning Guide” has been prepared to support the activities of public transportation systems to
plan for and respond to major security threats and emergencies. It emphasizes the importance of developing critical relationships, preparing strategies and policies, and setting training and funding priorities. It offers practical guidance for planning effectively, spending wisely, and making the public transportation infrastructure safer.

This Guide builds on a previous Federal Transit Administration (FTA) publication, the Transit System Security Program Planning Guide. This Guide is based on research to identify practical steps that systems can take to be better prepared for all emergencies. These recommendations support the industry’s commitment to prevent those events that can be prevented and to minimize the impact of those that cannot. Emphasizing balanced, common sense measures, this Guide helps transportation systems answer many questions.

FTA Office of Research Demonstration and Innovation FTA Office of Program Management issued report “Transit Security Design Considerations” in 2004. This report provides security design guidance on three major transit system components – bus vehicles, rail vehicles, and transit infrastructure. It provides a resource for transit agency decision makers, members of design, construction and operations departments, security and law enforcement personnel and consultants and contractors, in developing an effective and affordable security strategy following the completion of a threat and vulnerability assessment and development of a comprehensive plan. Developed by the Federal Transit Administration in collaboration with transit industry public and private sector stakeholders, these design considerations provide actionable steps that transit agency staff can select from to create a security strategy.
2.2. Review of previous research

The remarkable work by Stamatiadis and Culton (Stamatiadis, 1999) used computer simulation models to test different routes that could be used to divert traffic from a freeway, upstream of an incident, to other streets and back to the freeway, downstream of the incident using computer simulation/optimization models like PASSER II-90, TRANSYT-7F and TRAF-NETSIM. In their work they considered different routes and three MOEs, i.e., delay, average speed, and move/total time ratio. Using these MOEs, different route choices were tested and recommendations were developed for the most efficient routes.

In their work, Dia and Cottman (Dia, 2003) evaluated the benefits of ITS technologies on incident management by using a simulation approach. Several microscopic simulation models are now capable of modeling a variety of ITS-related features such as vehicle detectors, adaptive traffic control, coordinated traffic signals, ramp metering, static and dynamic route guidance, incident management, probe vehicles, and dynamic message signs. The results of the analysis suggest that a reduction of single lane incident duration from 30 to 15 minutes provides a 12% increase in average travel speed and 31% decrease in time spent in queue.

A number of studies are reported in the literature using traffic simulation to estimate transportation network performance under evacuation. In a study by Theodoulou, for
example, (Theodoulou, 2003) contra flow operations were tested as a means of traffic flow regulation in case of an emergency using CORSIM. The basic aim was to develop a plan that could evacuate an area under hurricane threat in the minimum time possible. Ultimately, an optimum plan was developed based on travel times and roadway capacity. In another study, Pal and Greattinger developed a microscopic evacuation simulation model in which GIS was used to define the road network, population, and area being evacuated. The OREMS simulation software was used modeled the effect of evacuation on the traffic network (Pal, 2003).

Some studies looked into simulation as a means for determining the termination point of the contra flow operations. This is a very important issue in contra flow operations as the merging of vehicles in opposite direction can lead to congestion and accidents. In a study by Yu Yik Lim (Lim, 2003), the CORSIM model was used to simulate contra flow operations and test different termination points. It was concluded that exiting ramps upstream of the termination point reduce the conflicts and delay and is a better option as compared to one lane closure operation, which can create bottleneck conditions.

Agent-based modeling also has been used to simulate emergency evacuation plans. Using agent based simulation, Xuwei Chen (Chen, 2003) tested simultaneous and staged evacuation strategies for different roadway networks. The simulation was done using the microscopic simulation model PARAMICS. For the staged evacuation scenario, the considered area was divided into four zones. Multiple simulations were run on different types of networks after deciding upon the rules. The results showed that the effectiveness
of staged evacuation depends upon the type of roadway network available and the population density of the area. The results also confirmed that if there is no congestion on the roadway then simultaneous evacuation is a good option. Otherwise, staged evacuation using certain sequences helps to reduce the total evacuation time and improve network performance.

Another agent-based micro simulation technique was used by Church and Sexton (Church, 2002), to investigate how evacuation time can be affected by different evacuation scenarios. Evacuation scenarios considered include opening alternative exits, changing number of vehicles leaving a household, and applying different traffic control plans were tested. In another study, Batty et al. (Batty, 2002) used an agent base simulation model to study the changing of routes during a carnival event held for two days in a year. These studies demonstrated how appropriate traffic control can effectively address congestion and safety issues. Moreover, these studies showed that environment and other external factors have an impact on individual behavior and, in turn, influence the collective behavior, thus affecting the effectiveness of the evacuation plan.

In an effort to overcome limitations of microscopic simulation models in considering parameters such as population density, land use, etc. Essam Radwan et al. developed a macroscopic simulation model and applied it to study evacuations in case of natural disasters (e.g., hurricanes). Different evacuation times were found while keeping destination volumes and origin volumes optimum for different options. Then the option with the lowest evacuation time was further developed (Radwan, 2003).
A few other modeling efforts reported in the literature concentrated on emergency response planning. A good example is the work by Ali Haghani et al. (Haghani, 2003) who developed a simulation model to evaluate a real time emergency medical service vehicle response system. This system uses real time information to assist the emergency vehicle dispatchers to assign vehicles and route them through the least congested routes. The model works with a dynamic network wherein nodes can be added as required by treating each vehicle as a moving node. Different assignment strategies are available such as First Called, First Served, Nearest Origin Assignment, and Flexible Assignment Strategy. This work offers a useful tool for improving the emergency response capability of the first responders and confirms that dynamic travel time information and dispatching strategies help to significantly minimize the emergency response time.

The work of Virginia P. Sisiopiku et al addressed the effect of incident on a network and presented the results of a case study that developed and tested responses to several hypothetical transportation emergencies in the Birmingham, Alabama region. The purpose was to demonstrate the usefulness of micro-simulation modeling in developing and refining appropriate response plans. First, the CORSIM traffic simulation software was utilized to create a regional transportation model comprising the major traffic corridors in the Birmingham area. An innovation in this process included the development of computer code that automated the merging of multiple CORSIM files into one integrated transportation network. Then, the regional model was used to test and evaluate various emergency management strategies in response to hypothetical incidents.
in the Birmingham area. Emergency incidents considered include a traffic accident on a major freeway, a building evacuation in downtown Birmingham, and traffic influx into Birmingham due to an emergency at Anniston Army Depot. Response strategies evaluated include traffic diversion, signal optimization, access restriction, and emergency routing. Appropriate measures of effectiveness (MOEs) were selected to support the assessment process at the region-wide or corridor-level. Candidate response actions were compared and evaluated on the basis of these MOEs and recommendations were developed on best practices and future needs. The project was successful in showcasing the utility of microscopic traffic simulation for regional emergency preparedness and assisting regional transportation officials and public safety agencies in considering effective traffic management strategies in the event of an actual regional emergency.
3.1. Methodology

The methodology of this research can be described as follows:

1. Acquiring background aerial photo maps for the area.
2. Coding the network by identifying the location of intersections, stopping lines, auxiliary lanes and allowed directions of travel.
3. Coding signals at the intersections. Inserting time operation tables and different phasing.
4. Organizing the traffic volume data into two sets, one set used to code the model and the other set used to check the accuracy of the model.
5. Entering traffic volumes and turning movements split at intersections.
6. calibrating the model to represent the real world traffic.
7. Validating model accuracy. Comparing the traffic volume, travel time and queues of the model with the real world.
8. Running scenarios.

The following flow chart in Figure 1 explains the research methodology phases.
Collect Data: Background aerial maps, traffic controls and volumes

Code geometric features of network in VISSIM

Code the traffic control characteristics of the network

Organize input data

Code the input simulation data

Check network output and behavior

Compare with the real network

Develop and run scenarios

Analyze and evaluate Results

Figure 1: Methodology flow chart.
3.2. Traffic Simulation Tool

There is large number of traffic simulators available on the market. Some of these are developed in the United States like CORSIM and WATSIM and others like VISSIM and PARAMICS are marketed by European software developers. VISSIM was selected for this study because of its capability of simulating pedestrian movement. VISSIM is a microscopic simulation model. It is a powerful tool available for simulating multi-modal traffic flows, including cars, trucks, buses, heavy rail, trams, LRT, bicyclists and pedestrians. Its flexible network structure allows the modeling of any type of geometric configuration or unique operational/driver behavior encountered within the transportation system. The model does not require origin and destination data for traffic movement. Turning volumes at the intersection can be used for traffic flow. Also the signal controller engine is separated from the simulation engine making the model behave as real as possible because of the independence of the signals from the traffic.

Networks in VISSIM consists of number of links between each two intersections connected by link connectors each connector can be specified to carry a certain type of traffic like for example right turning vehicles only.

VISSIM is a component of the PTV Vision® suite. VISSIM is used for a host of traffic and transit (public transport) simulation needs. Common applications include:

- Freeway and arterial corridor studies.
- Sub area planning studies.
- Evacuation planning.
- Freeway management strategy development.
- Traffic calming schemes.
- Light rail/bus rapid transit studies.
- Transit signal priority evaluations.
- Transit center/bus mall designs.
- Railroad grade crossing analyses.
- Environmental impact studies.
- Intelligent Transportation Systems (ITS) assessments.
- Current and future traffic management schemes.
- Airport studies for landside and airside traffic.

Among the main reasons to use this software is first it simulates the pedestrian behavior. For example if a link is identified as a footpath or a pedestrian walk, it will distribute the pedestrians in the available space without lanes that is to say you will have three or more people walking side by side followed by only two people with only the constrain of the total width of the footpath. The simulation snap shot shown in Figure 2 elaborates the degree of flexibility that VISSIM allows for the pedestrians as you see the distribution in both directions, the direction of travel and the transversal to that.
VISSIM is designed with high degree of flexibility that allows the user to code different scenarios and also allows the mix between more than one mode of transportation. For example one can mix traffic with busses and pedestrians. So the vehicles will be yielding to the pedestrians and the passenger cars will form the majority of the traffic and also you have buses that follow a certain schedule with stops and loading time. Also VISSIM has an independent traffic control engine that in case of actuated signals will collect the data of loop counters and then change the traffic signals behavior independently from the traffic generation engine. All these reasons made VISSIM a very good candidate to be used in our research.
CHAPTER FOUR:
BACKGROUND MAPS AND DATA COLLECTION

4.1. Simulation area selection

As microscopic traffic simulation was used in this research an adequate selection of the network size was essential. Because traffic simulation follows the behavior of traveling vehicles in a one by one approach and simulates the behavior of each individual component of the network this makes micro simulation very computer resources’ demanding and tends to be impractical for very large networks. Thus the network had to be large enough to allow proper presentation of traffic behavior and allow enough flexibility for traffic rerouting as intended. But at the same time the network size has to be manageable from the simulation effectiveness point of view.

Examining the City of Orlando neighborhoods map one would notice that the Central Business District is distributed between districts 5 and 3 to the west of I-4. As the LYNX headquarter building located in district 5, the area selected to be modeled was the Central Business District in district five plus a sufficient area selected to the east of I-4 because it served as an excellent safety zone that the traffic can be redirected to. Figure 3 shows an overview map of the area which is bound by the Amelia Street from the north and Central Boulevard from the south and Paramore Avenue from the east to Rosalind Avenue from the west.
Figure 3: Simulated area-Orlando CBD

The network area simulated is composed of Amelia Street, Livingston street, Robinson street, Washington street and Central street as east-west links and Paramore avenue, Hugey street, Garland avenue, Orange avenue, Magnolia street and Rosalind avenue as north-south links. Some of these roads are one way travel only and the others are two way travel roads in our network. Table 2 lists the roads simulated in the Orlando downtown area and their direction of travel descriptions.
Table 2: Roads simulated from the Orlando Downtown area and their description

<table>
<thead>
<tr>
<th>East West Travel Roads</th>
<th>North-South Travel roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road (link) Name</td>
<td>Description</td>
</tr>
<tr>
<td>Amelia street</td>
<td>Two Way</td>
</tr>
<tr>
<td>Livingston street</td>
<td>Two Way</td>
</tr>
<tr>
<td>Robinson street</td>
<td>Two Way</td>
</tr>
<tr>
<td>Washington street</td>
<td>Two Way</td>
</tr>
<tr>
<td>Central street</td>
<td>Two Way</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data collection for the simulated area was an essential part of the simulation process. The input data required to build VISSIM network are as follows:

- Background maps.
- Signal timings.
- Traffic volumes.

4.2. **Aerial maps**

Background maps were collected from online digital mapping service sites as it was only needed for visual recognition by the user. The jpg digital photos proved to be efficient in the resolution, determining the number of lanes and recognizing the location of the stop bar lines at the intersection. Figure 4 shows part of the aerial photo used in the network. From that map we can determine the number of lanes, the location of the stop bar and even whether the road is two way road or one way road. The aerial maps were collected from the online website [http://www.terraserver.com/](http://www.terraserver.com/).
4.3. Signal timings and operation tables

Traffic control locations were identified within the study area during the field trip. The City of Orlando Department of Transportation provided detailed signal operation tables for the Orlando downtown area. Signals were coded as actuated or semi-actuated traffic controller (28 counts) and pre-timed signals (1 count). Figure 5 shows controller timing for Amelia and Magnolia Avenue intersection in the study network. It gives the total number of phases and its direction, minimum and Maximum green time and other needed data required for coding signals.
4.4. Traffic volumes

Traffic volumes for Downtown Orlando data were also acquired from the City of Orlando Department of Transportation. Traffic volumes during the afternoon peak hour operation starting from 5:00 pm till 6:00 pm were used for the study. Traffic volume data was detailed to the level of traffic turning maneuver percentages at the intersections. An example of the traffic volume count at Amelia and Paramore avenue intersection presentation is shown in Figure 6.
Figure 6: Traffic volume at Amelia and Parramore Avenue intersection
CHAPTER FIVE:
NETWORK CODING AND SIMULATION

The model consists of a number of links that represent roads and carry the network features like number of lanes. Traffic signals and traffic volumes were coded for the afternoon peak in this simulation. Coding the network and inputting the proper traffic volumes and signal operation timings is imperative to duplicate the real world into the computer microscopic simulation model. This can be achieved by changing behavior of drivers and physical characteristics of the vehicle. This is an important phase of the project and also the most time extensive task. Because the accuracy of this phase leads to the over all accuracy of the study and also going through the different variables of driver behavior like gap acceptance and aggressiveness to emulate the real world is a time and effort extensive task.

5.1. Data input in VISSIM

Links and connectors are the coding units of a traffic network in VISSIM as mentioned earlier. As it is recommended in the manual the portion of the road between intersections was coded as separate link and then connected at the intersection to the other approaches using connectors. Each connector is for a certain turning maneuver. This means that a four legged intersection of two way roads with no turning maneuvers prohibited requires 12 connectors to fully complete the intersection geometric coding as Shown in Figure 7.
Figure 7: Turning maneuver connectors at an intersection at a typical four legged intersection

Next input is the traffic data. VISSIM allows the input of traffic volumes as volume from the network entry points and the turning maneuver split percentages at the intersections. Turning movement decision that influence the volume of vehicles that pass through must be placed apart from the actual turning position to give the driver enough time to change his routing behavior. This means that the decision point must at least be one time step ahead of the connector. This allows the model to assign the exact turning volumes and give the vehicles enough time to make the lane change required before turning.

Then each intersection has to be controlled by proper set of yield decision points to make the vehicles yield for pedestrians on right turn or to look for gaps in the opposing traffic.
in case of permissive left turns. This is because the conflicting connectors in VISSIM may share the same space visually but in the computer calculations they are two different connectors that need to be related through the proper priority rules. Example of a priority rule use is shown in Figure 8. The purple marked vehicle is waiting to make a left turn but according to the priority rule it will not make the left turn till an adequate gap is found in the on coming through stream shown here as the east west traffic in yellow.

Figure 8: Vehicle stopped at an intersection waiting for sufficient gap to make a left turn

Then the signals and signal heads were coded using NEMA as external controller. This controller is in North America release of VISSIM and emulates common signal controller
used here. With this controller VISSIM can simulate fully actuated signal control as well as coordinated and semi-actuated coordinated signal control. VISSIM allows the coding of an independent signal head for each lane so the similar signals should be grouped carefully and their alternate detectors must be numbered in an organized manner to facilitate the signal coding process. A good approach would be assigning signal numbers in more than one digit according to the number of signals that are present in the model. For example in our network we have 28 intersections and the signals numbers were assigned as two digits number with the first number representing the East West street of the intersection and the second digit representing the North South street of the intersection. This facilitates the reading of the output files and determining the position of an intersection in case of an error in signal head. Also it is recommended to have same detectors number as its corresponding signal head. This is another consistency measure that minimizes the room for error in the network coding phase. RTOR (Right Turn on Red) was coded to allow the right lane vehicles to turn right when the signal is red. In VISSIM this stop sign is named RTOR stop sign and it must be connected to the signal head of its lane and only works during the time signal head is red.

Signal time operation should include every possible description of the signal time table. In case of actuated signals the operating rings, alternate phases, maximum green, minimum green and overlapping phases were coded accurately. NEMA interface responsible for accurate signal operation in the model is shown in Figure 9.
Data collection points were placed at the locations desired to provide adequate output for accuracy checking and comparing alternatives.

5.2. Required number of runs

The objective of model calibration is to get the best match possible between model performance estimates and field measurements of performance. However, there is a limit to the amount of time and effort that anyone can put into eliminating error in the model. A point is reached when dimensioning returns yields small improvement in accuracy by large time and effort and time investment. Thus the analyst needs to know when to stop.
Micro-simulation models would produce unrealistically regimented simulations with all drivers moving at the same time and in the same way, if it were not for randomization. The simple rules used to move vehicles in a micro-simulation do not realistically reproduce the wide range of human behavior observed in the real world. Random variables are used to produce a plausible range of human behavior from the simple rules (Richard Dowling, et al. 2002). Computer software uses a random number generator to generate the necessary set of random variables. The generator requires a starting number, or “seed” to produce a unique sequence of numbers. The same seed, used with the same generating routine, on the same computer will produce the same sequence of numbers for use in the random variables, every time. Thus, a single micro-simulation model run is like rolling the dice only once. In order to find out the average conditions it is necessary to run the micro-simulation model several times with different random number seeds and then average the results of the different runs.

In order to determine the number (N) of simulation model runs, one need to know the mean and standard deviation of a number of performance measures from simulation results. These are unknown before running the simulation and vary from one model to another based on the size and complexity of the simulated facility. Ten simulation runs were executed and then required number of runs according to the mean and standard deviation of these ten runs were calculated from:

\[
N = \left( t_{\alpha/2} \times \frac{\sigma}{\mu \times \varepsilon} \right)^2
\]

Where:
\( \mu = \) mean of the of already conducted simulation runs performance measure.

\( \sigma = \) Standard deviation of the performance measure.

\( \varepsilon = \) Allowable error specified as fraction of the mean.

\( t_{\nu,\alpha/2} = \) critical value of the t-distribution at the confidence interval of \( \alpha \).

\( \nu = \) degree of freedom of t-distribution.

\( \alpha = \) confidence interval of the t-distribution.

This calculation was conducted on traffic volumes as they were in the main measure used to determine the degree of accuracy of the model. The highest number of runs produced by the statistical formula must be used. If the current number of runs is already larger than this value, the simulation of this scenario is ended. Otherwise one additional run is performed and then the required number of runs needs to be recalculated (Lianyu, et al. 2003)

The flow chart to determine the number of simulation runs is shown in Figure 10.
Start

Original Ten Runs

Calculate the mean and standard deviation of each performance

Calculate the required number of runs for each performance measure

Is count number enough?

YES

End

Additional one simulation run

Figure 10: Chart showing the determination of number of runs

The network was simulated in VISSIM using ten seed values 15, 25, 42, 81, 86, 102, 428, 617, 713 and 905 chosen randomly for the calibration of the peak traffic counts and compared to the observed field data as will be shown later in the report.
The statistical evaluation criterions were computed for the average of the 10 runs and a sample computation for the station 18 is as follows:

\[ N=10, \mu=233, \sigma=14.813 \text{ and at } \alpha=5\% \varepsilon=5\% \]

\[ t_{v,\alpha/2,\varepsilon} = t_{10-1,0.05,0.05}=2.262 \]

\[
N = \left( t_{v,\alpha/2} \times \frac{\sigma}{\mu \times \varepsilon} \right)^2
\]

\[
N = \left( 2.262 \times \frac{14.813}{233 \times 0.05} \right)^2 = 8
\]

Table 3 shows the results of the first time ten simulation runs and calculated number of runs needed according to the mean and standard deviation of the simulated counts.
Table 3: Determination of Number of simulation runs

<table>
<thead>
<tr>
<th>Location</th>
<th>SEED 905</th>
<th>SEED 713</th>
<th>SEED 617</th>
<th>SEED 428</th>
<th>SEED 102</th>
<th>SEED 86</th>
<th>SEED 81</th>
<th>SEED 42</th>
<th>SEED 25</th>
<th>SEED 15</th>
<th>MENA</th>
<th>STD</th>
<th>N(Runs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>585</td>
<td>663</td>
<td>600</td>
<td>582</td>
<td>577</td>
<td>585</td>
<td>587</td>
<td>602</td>
<td>585</td>
<td>585</td>
<td>595</td>
<td>24.940</td>
<td>4</td>
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<tr>
<td>2</td>
<td>1766</td>
<td>1642</td>
<td>1776</td>
<td>1753</td>
<td>1649</td>
<td>1782</td>
<td>1792</td>
<td>1714</td>
<td>1711</td>
<td>1766</td>
<td>1735</td>
<td>54.164</td>
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</tr>
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<td>3</td>
<td>316</td>
<td>330</td>
<td>331</td>
<td>323</td>
<td>326</td>
<td>330</td>
<td>334</td>
<td>282</td>
<td>330</td>
<td>316</td>
<td>322</td>
<td>15.334</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>1666</td>
<td>1765</td>
<td>1627</td>
<td>1620</td>
<td>1627</td>
<td>1681</td>
<td>1635</td>
<td>1704</td>
<td>1719</td>
<td>1666</td>
<td>1671</td>
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<td>524</td>
<td>610</td>
<td>582</td>
<td>567</td>
<td>591</td>
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<td>619</td>
<td>589</td>
<td>601</td>
<td>589</td>
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<td>615</td>
<td>604</td>
<td>624</td>
<td>617</td>
<td>661</td>
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<td>610</td>
<td>624</td>
<td>616</td>
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<td>237</td>
<td>238</td>
<td>246</td>
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<td>546</td>
<td>572</td>
<td>569</td>
<td>593</td>
<td>528</td>
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<td>569</td>
<td>573</td>
<td>561</td>
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<td>1879</td>
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<td>804</td>
<td>794</td>
<td>777</td>
<td>782</td>
<td>791</td>
<td>808</td>
<td>760</td>
<td>782</td>
<td>789</td>
<td>804</td>
<td>789</td>
<td>14.510</td>
<td>1</td>
</tr>
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<td>954</td>
<td>957</td>
<td>951</td>
<td>13.741</td>
<td>0</td>
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<td>1098</td>
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<td>1064</td>
<td>1059</td>
<td>1078</td>
<td>1172</td>
<td>1041</td>
<td>1122</td>
<td>1045</td>
<td>1098</td>
<td>1080</td>
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<tr>
<td>14</td>
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<td>833</td>
<td>932</td>
<td>827</td>
<td>830</td>
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<td>921</td>
<td>921</td>
<td>860</td>
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<td>42.988</td>
<td>5</td>
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<tr>
<td>15</td>
<td>875</td>
<td>791</td>
<td>805</td>
<td>812</td>
<td>763</td>
<td>875</td>
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<td>889</td>
<td>875</td>
<td>875</td>
<td>848</td>
<td>50.544</td>
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<td>16</td>
<td>611</td>
<td>599</td>
<td>626</td>
<td>652</td>
<td>645</td>
<td>618</td>
<td>683</td>
<td>618</td>
<td>717</td>
<td>611</td>
<td>638</td>
<td>37.113</td>
<td>7</td>
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<td>17</td>
<td>772</td>
<td>743</td>
<td>714</td>
<td>749</td>
<td>731</td>
<td>680</td>
<td>697</td>
<td>674</td>
<td>720</td>
<td>772</td>
<td>725</td>
<td>34.812</td>
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<td>18</td>
<td>245</td>
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<td>227</td>
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<td>220</td>
<td>219</td>
<td>245</td>
<td>233</td>
<td>14.813</td>
<td>8</td>
</tr>
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<td>19</td>
<td>214</td>
<td>211</td>
<td>229</td>
<td>210</td>
<td>213</td>
<td>237</td>
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<td>211</td>
<td>194</td>
<td>214</td>
<td>213</td>
<td>12.961</td>
<td>8</td>
</tr>
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<td>20</td>
<td>38</td>
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<td>35</td>
<td>39</td>
<td>38</td>
<td>34</td>
<td>36</td>
<td>38</td>
<td>38</td>
<td>37</td>
<td>1.799</td>
<td>5</td>
</tr>
</tbody>
</table>
5.3. Calibration

Calibration is the adjustment of traffic behavior and characteristics to account for the data not taken in consideration during the model building phase because they are considered to be of less relevance to the traffic behavior and that no one can simulate all the factors that can possibly affect traffic behavior (Richard Dowling, 2002).

The following method to start calibrating the model was suggested by (Richard Dowling, 2002, “Guidelines for Applying Traffic Micro simulation Modeling Software”). Before proceeding to calibration it is necessary to ensure that the model input data has been entered correctly. Error checking involves reviews of the coded network, the coded demands, and the default parameters. The steps involved in error checking are:

1. Review of vehicle parameters.
2. Review link attributes.
3. Review intersection attributes.
4. Review demand inputs.
5. Run model at very low volumes to identify errors.
6. Trace selected vehicles through the network.

Connectors were checked to ensure the flow of traffic from one link to another through visual inspection of the simulation. By tracing different vehicles through the network the adequate time needed for the model warm up time was determined. Measuring the time needed for a vehicle to enter the network and leave through the longest route possible in
the network. Randomly selected 35 vehicles yielded an average time 11.2 min of travel to clear the network with standard deviation equal 1.1 and desired accuracy of 20 sec. at 90% level of confidence the sample size required was equal to 30 vehicles. As shown in the following equation.

\[ N = \left( \frac{z_{\alpha/2}S}{H} \right)^2 = \left( \frac{1.645 \times 1.1}{0.33} \right)^2 = 29.5 \approx 30 \]

Where:

\( N \)=Sample size

\( S \)=sample standard deviation

\( H \)=accuracy

\( \alpha \)=degree of significance

\( Z \)=statistical variable

Thus a 15 min warm up time was used to transfer the model’s running condition from the initial empty network state to a balanced saturated state. This is under the assumption that the time needed for a vehicle to complete the longest route in the network during the running time is more than enough for the network to reach equilibrium. This stabilized the simulation and enough vehicles were generated during the peak hour. Comparison between the simulated data and field data was done to ensure that the model simulates the real life conditions. Twenty locations were selected (shown in Figure 11) to compare volumes. After changing parameters like vehicle following behavior, lane change parameters and speed we were able to get results closer to actual traffic volumes. But we
still were getting queues at the intersection a condition we did not observe in the field we checked the signal logic and gave appropriate green time to the blocked direction. This alleviated the congestion problem tremendously and we got the queues very comparable to the actual queues. Table 4 shows the comparison between the actual and simulated traffic counts (average of ten runs) for the 20 locations selected with error less than 10%.

Figure 11: Twenty locations used for Calibration.
Table 4: Comparison between Actual and Simulation Traffic Volumes

<table>
<thead>
<tr>
<th>Location</th>
<th>Direction</th>
<th>Actual Volume (veh/hr)</th>
<th>Simulated Volume (veh/hr)</th>
<th>Difference</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>North</td>
<td>569</td>
<td>595</td>
<td>26</td>
<td>4.4%</td>
</tr>
<tr>
<td>2</td>
<td>North</td>
<td>1764</td>
<td>1735</td>
<td>-29</td>
<td>1.7%</td>
</tr>
<tr>
<td>3</td>
<td>North</td>
<td>347</td>
<td>322</td>
<td>-25</td>
<td>7.8%</td>
</tr>
<tr>
<td>4</td>
<td>East</td>
<td>1791</td>
<td>1671</td>
<td>-120</td>
<td>7.2%</td>
</tr>
<tr>
<td>5</td>
<td>North</td>
<td>590</td>
<td>589</td>
<td>-1</td>
<td>0.2%</td>
</tr>
<tr>
<td>6</td>
<td>North</td>
<td>239</td>
<td>265</td>
<td>26</td>
<td>9.8%</td>
</tr>
<tr>
<td>7</td>
<td>North</td>
<td>557</td>
<td>616</td>
<td>59</td>
<td>9.6%</td>
</tr>
<tr>
<td>8</td>
<td>North</td>
<td>223</td>
<td>245</td>
<td>-22</td>
<td>9.0%</td>
</tr>
<tr>
<td>9</td>
<td>North</td>
<td>522</td>
<td>561</td>
<td>39</td>
<td>7.0%</td>
</tr>
<tr>
<td>10</td>
<td>North</td>
<td>2028</td>
<td>1879</td>
<td>-149</td>
<td>7.9%</td>
</tr>
<tr>
<td>11</td>
<td>South</td>
<td>743</td>
<td>789</td>
<td>46</td>
<td>5.8%</td>
</tr>
<tr>
<td>12</td>
<td>South</td>
<td>926</td>
<td>951</td>
<td>25</td>
<td>2.6%</td>
</tr>
<tr>
<td>13</td>
<td>South</td>
<td>1028</td>
<td>1080</td>
<td>52</td>
<td>4.8%</td>
</tr>
<tr>
<td>14</td>
<td>South</td>
<td>887</td>
<td>869</td>
<td>-18</td>
<td>2.1%</td>
</tr>
<tr>
<td>15</td>
<td>South</td>
<td>877</td>
<td>848</td>
<td>-29</td>
<td>3.4%</td>
</tr>
<tr>
<td>16</td>
<td>South</td>
<td>684</td>
<td>638</td>
<td>-46</td>
<td>7.2%</td>
</tr>
<tr>
<td>17</td>
<td>South</td>
<td>676</td>
<td>725</td>
<td>49</td>
<td>6.8%</td>
</tr>
<tr>
<td>18</td>
<td>South</td>
<td>213</td>
<td>233</td>
<td>20</td>
<td>8.6%</td>
</tr>
<tr>
<td>19</td>
<td>South</td>
<td>215</td>
<td>213</td>
<td>-2</td>
<td>0.9%</td>
</tr>
<tr>
<td>20</td>
<td>East</td>
<td>35</td>
<td>37</td>
<td>2</td>
<td>5.4%</td>
</tr>
</tbody>
</table>

From Table 4, the output of the model were considered to be satisfactory and as according to Brockfeld, et al. (Brockfeld, 2004), an error of 12 to 30 percent cannot be suppressed in case of microscopic models. Since the accuracy shown by the model is under this acceptable limit then the decision was made that the model has reached a proper stage of accuracy and represents the real world situation.

5.4. Validation

After calibration process was finished the model was tested for other operation measures. This step is called validation and is used to make sure that the model behavior changes in
a similar manner to that of the real world traffic under the change in the traffic conditions. In this research since the traffic volume was used as an input and a calibration measure, the travel time was used to prove the validity of the model it is very important to inspect the real world to get a feeling of traffic behavior in the area desired to be simulated. This was done by comparing traffic parameters like travel times and queues lengths at different locations.

The model was validated for the travel time by the use of probe vehicles (also known as floating car). Obtaining link travel time by the probe vehicle technique is considered as one of the most efficient and accurate method. Travel time validation was done by measuring the travel time from point A to point B and comparing it to the simulated travel time. Several trips were made within the downtown area and the travel time was estimated from different origins to different destinations. These data was then compared to the simulated travel time data to check the model’s validity. Three major roads of the downtown Orlando; Garland Avenue, Orange Avenue and Rosalind Avenue were chosen for the trip time measurement. Each link’s travel time was measured from Central St. intersection to the Amelia St. intersection. Figure 12 shows the layout of the area visited for the travel time measurement. Table 5 shows the comparison between the travel time measured using probe vehicle and the simulated travel time.
Figure 12: Layout of the Orlando Downtown visited for travel time measurement

<table>
<thead>
<tr>
<th>Route (link)</th>
<th>Garland Ave.</th>
<th>Orange Ave.</th>
<th>Rosalind Ave.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Travel time</td>
<td>127 sec</td>
<td>506 sec</td>
<td>130 sec</td>
</tr>
<tr>
<td>Travel time in simulation</td>
<td>115.8 sec</td>
<td>522 sec</td>
<td>122.3 sec</td>
</tr>
<tr>
<td>Difference</td>
<td>11.2 sec</td>
<td>16 sec</td>
<td>7.7 sec</td>
</tr>
<tr>
<td>% Error</td>
<td>8.82%</td>
<td>3.20%</td>
<td>5.90%</td>
</tr>
</tbody>
</table>

It is believed that with percentage errors less than 10% one may conclude that the model now have reached the desirable level of accuracy. The next step is to modify the input
conditions to generate different scenarios. The network characteristics reflecting the current conditions named as the base case scenario is to be compared against other proposed scenarios that result from unexpected or unusual conditions. The following section documents such scenarios.
CHAPTER SIX:

SCENARIOS

6.1. Traffic Simulation and Scenarios:

The validated Orlando Downtown area model was used to simulate traffic incident conditions and evacuation conditions. The project team discussed with the LYNX officials numerous scenarios and their response actions, and evacuation destination points and the means of evacuating people from the depot. These discussions resulted in developing the scenarios. It was agreed that the TD Waterhouse Arena located at the west side of the network would be the most appropriate destination for evacuation by buses due to its large parking lot. The relative location of the Arena and LYNX depot is shown in Figure 13. As for the pedestrian evacuation, a safe shelter to any of the surrounding multistory parking garages available in the area was considered available. There is garages available in proximity of the building one on the west side of the depot on Orange street, another one to the south side on Livingston street, and a third one to East side of Hugey Avenue. Locations of the three garages used in the study are shown on Figure 14.
Figure 13: Overview of the origin and destination of the Evacuated buses

Figure 14: Locations of the surrounding garages
6.2. Rerouting traffic

The concept of rerouting traffic is to direct the traffic that was originally intended to use the area under attack to alternate links and therefore reducing congestion of the overall network and at the same time providing fast track route for the emergency responders to get to the affected area. This will be done either by the local police authority that can reroute the traffic or by ITS technologies such as VMS (variable massage signs).

The rerouting targeted the traffic population that can benefit most from rerouting or in other words the traffic that will suffer the highest delay if no rerouting was applied. This traffic group was the traffic heading North on Garland Avenue. This group of vehicles will reach the intersection of Amelia and Garland and get stuck during the evacuation process. To avoid this, traffic was rerouted through the west side of the network by taking them north through Paramore Avenue and back on Amelia Avenue. This will distribute the traffic over a larger area of network leading to a reduced negative effect of evacuation. Figure 15 gives the detailed illustration of the rerouting plan.
6.3. Different scenarios

The scenarios assumed 2000 persons to be evacuated during an evacuation incident and the maximum number of buses that can be practically used in evacuation was 10 with the capacity of 50 passengers per bus. For each scenario the network performance measure will be compared to the base scenario to evaluate the effect of the incident on the traffic network and try to identify which of these scenarios is the best response operation alternative. Also the evacuation time was a factor in evaluating different scenarios.

The network performance measures are total network delay, average network speed, total travel time, total travel distance and number of vehicles. Total network delay is total time lost as a result of congestion or traffic light in the network compared to the free speed state of this network. The average network speed is the average travel speed of all
vehicles that traveled in the network during the designated time. Total travel time is the sum of time vehicle spent in the network while in motion, like wise the total travel distance is the sum of total miles traveled in the network during the same portion of time and the number of vehicles. The number of vehicles is a good a check for scenarios consistency because the queues buildup can block the network traffic generation entrances preventing the generation of the right volume of traffic during the simulation time. Blocking the traffic from entering the network will result in a false decrease of the delay as the number of vehicles counted and stopped is fewer than the real number. The easiest solution in this case is to extend the input links to accommodate the extra queues and make sure no network entrance is blocked at any time of the simulation.

6.3.1. Base case scenario

The current state of the network was called base case scenario in this study. This was simply the network showing the current traffic conditions without any incident. The characteristics of this case are to be used as datum to which the other scenarios were to be compared. The network performance measures are shown in Table 6.

<table>
<thead>
<tr>
<th>Table 6: Network Performance base case (no incident)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vehicles</td>
</tr>
<tr>
<td>Total Distance Traveled</td>
</tr>
<tr>
<td>Total Travel Time</td>
</tr>
<tr>
<td>Average Network Speed</td>
</tr>
<tr>
<td>Total network Delay</td>
</tr>
</tbody>
</table>
6.3.2. **Block all streets Scenario 1**

This is the most likely scenario to happen in case of a disaster threat at a building the size of LYNX bus depot in a downtown area. This scenario assumed that the local police authority would resolve to block all the traffic in the area around the building. The performance measures of this situation are listed in Table 7.

Table 7: Network performance block all streets scenario

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vehicles</td>
<td>11453</td>
</tr>
<tr>
<td>Total Distance Traveled</td>
<td>7897.665 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>700.9997 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>11.3394 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>637.295 (hr)</td>
</tr>
</tbody>
</table>

Notice here that the total travel time has decreased. This is because most of the traffic in this scenario was stopped as the result of blocking all the streets surrounding the area under attack thus discarding this lost time from the travel time. However the lost time in stopping is captured in the total network delay.

6.3.3. **Scenario 2 Regular evacuation plan (all buses used)**

The second scenario considered the use of all the buses that were assumed to be present at the bus depot during the incident. We assumed 500 persons were evacuated using 10 buses with two minutes headway between each two buses (difference in bus loading time) and the rest 1500 as pedestrians directly form the building to the west garage shown
in Figure 14. The scenario was run as two cases. Case (a) was do-nothing during the incident and case (b) involves rerouting to mitigate the negative impact of the incident.

Case 2a:
The first case evacuated people without rerouting any of the traffic in the surrounding streets. The vehicles at the intersection of Garland Avenue and Amelia Street intersection had to stop and wait till the end of the evacuation. The measures of effectiveness for this case were shown in Table 8. Figure 16 shows the snapshot of the pedestrians leaving the building during an evacuation operation. It can be observed that the vehicles were queued on Garland Avenue during evacuation and needs to be rerouted to reduce delay.

Figure 16: Snapshot of personnel evacuating from LYNX Depot to nearby garage
Table 8: Network Performance for scenario 1 without rerouting (case 2a)

<table>
<thead>
<tr>
<th>Number of vehicles</th>
<th>11453</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Distance Traveled</td>
<td>9263.519 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>992.292 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>9.335 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>593.313 (hr)</td>
</tr>
</tbody>
</table>

Case 2b:

The second case in the scenario simulated the rerouting of traffic as explained in section 6.2. Table 9 shows the network performance measures for this case. The number of buses and pedestrian evacuees were same as (case a) in scenario 1. The rerouted traffic was directed to clear out of the incident area in a manner to prevent queuing in another location.

Table 9: Network Performance for scenario 1 with rerouting (case 2b)

<table>
<thead>
<tr>
<th>Number of vehicles</th>
<th>11453</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Distance Traveled</td>
<td>9672.031 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>993.593 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>9.734 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>578.952 (hr)</td>
</tr>
</tbody>
</table>

6.3.4. Scenario 3 Regular evacuation plan with half buses used

The third scenario considered the use of half the buses that were assumed to be present at the bus depot during the incident. We assumed 250 persons were evacuated using 5 buses with two minutes headway between each two buses (difference in bus loading time) and the rest 1750 as pedestrians directly from the building to the west side garage shown in
Figure 14. The scenario was run as two cases. Case (a) was do-nothing during the incident and case (b) involves rerouting to mitigate the negative impact of the incident. This scenario mainly aimed to determine the impact of number of buses used in evacuation.

Case 3a:

This case is similar to case 1a but for number of buses used in evacuation and the pedestrian volume. The vehicles at the intersection of Garland Avenue and Amelia Street intersection will still have to stop and wait till the end of the evacuation. The measures of effectives for this scenario and case are as shown in Table 10.

Table 10: Network Performance for scenario 3 without rerouting (case 3a)

<table>
<thead>
<tr>
<th>Number of vehicles</th>
<th>11448</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Distance Traveled</td>
<td>9125.342 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>980.309 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>9.309 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>577.101 (hr)</td>
</tr>
</tbody>
</table>

Case 3b:

Also this case is similar to case 1b, which involves traffic rerouting. Table 11 lists the network performance measures for this scenario.
Table 11: Network Performance for scenario 3 with rerouting (case 3b)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vehicles</td>
<td>11448</td>
</tr>
<tr>
<td>Total Distance Traveled</td>
<td>9690.664 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>1006.970 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>9.624 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>576.024 (hr)</td>
</tr>
</tbody>
</table>

6.3.5. Scenario 4 Regular evacuation plan (no buses used)

The fourth scenario considered the use of no buses at all that were assumed to be present at the bus depot during the incident. We assumed no persons to be evacuated using buses to eliminate the bus loading time and the effect of the buses on the traffic network. All the 2000 evacuees were evacuated as pedestrians directly from the building to the west garage shown in Figure 14. The scenario will be run as two cases. Case (a) was do-nothing during the incident and case (b) involves rerouting to mitigate the negative impact of the incident.

Case 4a:

Table 12 lists the network performance measures for this case.

Table 12: Network Performance for scenario 4 without rerouting (case 4a)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vehicles</td>
<td>11443</td>
</tr>
<tr>
<td>Total Distance Traveled</td>
<td>9255,969 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>990.974 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>9.340 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>571.037 (hr)</td>
</tr>
</tbody>
</table>
Case 4b:

In this case, all the evacuees were evacuated as pedestrians and with traffic rerouting. Table 13 shows the network performance measures for this case.

<table>
<thead>
<tr>
<th>Number of vehicles</th>
<th>11443</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Distance Traveled</td>
<td>9717.561 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>1015.985 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>9.565 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>569.524 (hr)</td>
</tr>
</tbody>
</table>

Notice from Table 8 through Table 13 the total travel time in each scenario is higher in the rerouting case than the stop traffic case this is because when vehicles are stopped there stopping time is discarded from the network travel time. Also as the number of buses used in evacuation decreases the total travel time decreases because the network travel time is thrown off by the short travel time of the buses used in the evacuation process. In other words, as the number of these buses decrease they have less effect on the total travel time.

6.3.6. Scenario 5 alternative pedestrian destination (East garage)

An observation was made that the pedestrians’ evacuation route conflicts with the buses evacuation route forcing the buses to stop and wait till all the pedestrian evacuees clear. To resolve this situation an alternative evacuation destination was suggested. In this scenario 1500 pedestrian were directed to the East side garage across Orange Street plus
giving the buses priority in traffic signals meaning that the buses will not stop at traffic lights on their evacuation route. The network performance results are listed in Table 14.

Table 14: Network performance alternate pedestrian destination (East garage) Scenario 5

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vehicles</td>
<td>11453</td>
</tr>
<tr>
<td>Total Distance Traveled</td>
<td>9318.332 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>847.5995 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>11.029 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>623.2558 (hr)</td>
</tr>
</tbody>
</table>

6.3.7. **Scenario 6 alternative pedestrian destination (south garage)**

This scenario followed the pedestrian buses evacuation routes avoidance through directing the 1500 pedestrian to the garage south of the building on Livingston Street combined with giving the buses signal priority along their evacuation route. Network performance measures for this scenario are listed in Table 15.

Table 15: Network performance alternate pedestrian heading (south garage) Scenario 6

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vehicles</td>
<td>11453</td>
</tr>
<tr>
<td>Total Distance Traveled</td>
<td>8204.562 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>625.9194 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>13.1396 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>576.0934 (hr)</td>
</tr>
</tbody>
</table>

6.3.8. **Scenario 7 buses using the north exit**

Buses exiting the depot are not allowed to head east or make a left turn from the north exit because of regulatory double yellow solid lines placed at this intersection to manage
the access points on the Amelia arterial street. In case of an emergency that requires evacuation this regulatory access management rule can be over ridden to save on evacuation time. The Network performance measures for this scenario are listed in Table 16.

Table 16: Network performance buses using the north exit Scenario 7

<table>
<thead>
<tr>
<th>Number of vehicles</th>
<th>11453</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Distance Traveled</td>
<td>8660.756 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>827.8594 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>10.5306 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>564.7465 (hr)</td>
</tr>
</tbody>
</table>

6.3.9. Scenario 8 evacuation pedestrians split

In this scenario all the 2000 evacuees were evacuated as pedestrians but splitted in two groups, one group heading to the east side garage and the other half heading to the south side garage. Although achieving this evacuation manner in public transit station is not very easy thing however the expected decrease in evacuation time made this scenario a good alternative to examine. The Network performance results of this scenario are listed in Table 17.

Table 17: Network performance evacuation pedestrians split Scenario 8

<table>
<thead>
<tr>
<th>Number of vehicles</th>
<th>11443</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Distance Traveled</td>
<td>562.4125 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>10.7391 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>808.6956 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>8606.38 (hr)</td>
</tr>
</tbody>
</table>
In this scenario in addition to evacuation using 10 buses and 1500 pedestrian heading to the west side garage on Hugey Avenue, a traffic incident occurs on one of the major arterials surrounding the threatened zone blocking one lane for 15 minutes. Although this scenario is not very similar to the line of thinking of the other scenarios but it mainly aims to address the effect of the combined effect of evacuation and an incident occurring during the same time frame. The Network performance results are listed in Table 18.

<table>
<thead>
<tr>
<th></th>
<th>Traffic incident Scenario 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vehicles</td>
<td>11453</td>
</tr>
<tr>
<td>Total Distance Traveled</td>
<td>8491.532 (mile)</td>
</tr>
<tr>
<td>Total Travel Time</td>
<td>808.4649 (hr)</td>
</tr>
<tr>
<td>Average Network Speed</td>
<td>10.5721 (mph)</td>
</tr>
<tr>
<td>Total network Delay</td>
<td>614.2016 (hr)</td>
</tr>
</tbody>
</table>

The main goal of this comprehensive analysis and comparison was to determine the effect of the evacuation incident on the traffic network and compare between different scenarios to identify the better solution of the different alternatives. An ANOVA analysis was done on all scenarios to examine the significance of difference between the different scenarios. Summary of the ANOVA analysis is listed in Table 19 showing a significant difference between the network delay time of all scenarios with P-value= 0.38. This means that we reject the null hypothesis that there is no significant difference between the
different scenarios. Then we accept the alternate hypothesis that the results of the
scenarios are different from each other for degree of significance of 10% or even 5%.

Table 19: ANOVA analysis summary of network delay time for all scenarios

<table>
<thead>
<tr>
<th>Groups</th>
<th>Count</th>
<th>Sum</th>
<th>Average</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>10</td>
<td>5618.57</td>
<td>561.857</td>
<td>1818.372</td>
</tr>
<tr>
<td>Complete area blocking</td>
<td>10</td>
<td>6372.95</td>
<td>637.295</td>
<td>12756.62</td>
</tr>
<tr>
<td>East garage</td>
<td>10</td>
<td>6232.56</td>
<td>623.2558</td>
<td>5962.401</td>
</tr>
<tr>
<td>West garage without rerouting (all buses)</td>
<td>10</td>
<td>5933.13</td>
<td>593.313</td>
<td>4615.99</td>
</tr>
<tr>
<td>West garage with rerouting (all buses)</td>
<td>10</td>
<td>5789.52</td>
<td>578.952</td>
<td>1585.632</td>
</tr>
<tr>
<td>West garage without rerouting (half buses)</td>
<td>10</td>
<td>5771.01</td>
<td>577.101</td>
<td>1723.966</td>
</tr>
<tr>
<td>West garage with rerouting (half buses)</td>
<td>10</td>
<td>5760.24</td>
<td>576.024</td>
<td>690.5068</td>
</tr>
<tr>
<td>West garage without rerouting (no buses)</td>
<td>10</td>
<td>5710.37</td>
<td>571.037</td>
<td>4276.271</td>
</tr>
<tr>
<td>West garage with rerouting (no Buses)</td>
<td>10</td>
<td>5695.24</td>
<td>569.524</td>
<td>1542.654</td>
</tr>
<tr>
<td>South garage</td>
<td>10</td>
<td>5760.93</td>
<td>576.0934</td>
<td>6112.726</td>
</tr>
<tr>
<td>Alternative bus route (North exit)</td>
<td>10</td>
<td>5647.47</td>
<td>564.7465</td>
<td>9413.032</td>
</tr>
<tr>
<td>West and south Garage</td>
<td>10</td>
<td>5624.13</td>
<td>562.4125</td>
<td>10820.43</td>
</tr>
<tr>
<td>Traffic incident</td>
<td>10</td>
<td>6142.02</td>
<td>614.2016</td>
<td>11562.68</td>
</tr>
</tbody>
</table>

ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>72694</td>
<td>12</td>
<td>6057.84</td>
<td>1.08055</td>
<td>0.382778</td>
<td>1.835813</td>
</tr>
<tr>
<td>Within Groups</td>
<td>655932</td>
<td>117</td>
<td>5606.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>728626</td>
<td>129</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.4.1. Effect of the Evacuation process

The effect of the Evacuation decisions on the network can be noticed from comparing the different scenarios network performance measures specifically the total network delay in vehicle hours shown in Figure 17.

![Network performance comparison](image)

Figure 17: Network delay for different scenarios (vehicle hour)

The block all area scenario (scenario 1) which is the most likely scenario to happen in case of a major threat to the building the network delay increased from 561.857 vehicle
hours to 637.295 vehicle hours 13.4 % increase in total network delay this was the highest increase in delay and can be considered worst case scenario.

The alternative of using the East side garage (scenario 5) in which the pedestrians will have to cross the major arterial Orange Avenue caused the second worst increase in delay although in this case the buses were given signal priority and the conflict between the pedestrian and buses was eliminated but the effect of stopping an already congested arterial for pedestrian to cross increased the network delay from 561.857 vehicle hours to 623.256 vehicle hours. 10.9 % increase in total network delay.

The incident scenario in which a lane was blocked for 15 min as a result of a traffic incident other than the evacuation process (scenario 9) the total network delay time was 614.202 vehicle hours giving a 9.3% increase. Although in this scenario only one lane of the arterial street was blocked it had a high increase in delay if compared with scenario 5 in which the same arterial was completely blocked for the total duration of the evacuation time which had an increase of delay of 10.9%. This gives us an idea about what a minor incident associated with evacuation process can intensify the negative effect of threat that requires evacuation.

Table 20 lists the increase in delay that resulted from different scenarios compared to the initial condition of the network without evacuation showing a maximum increase in the network delay resulting from blocking all the traffic in the area (scenario 1) 13.4% increase to scenario number 8 where evacuees were evacuated as pedestrians only and
split on two evacuation headings (scenario 8) which resulted to only an increase of 0.1% of vehicle hours network delay.

Table 20: Different scenarios effect on the total network delay.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Scenario Number and case</th>
<th>Total Network Delay (vehicle hours)</th>
<th>Percent Increase in delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case scenario</td>
<td>Base case</td>
<td>561.857</td>
<td>-</td>
</tr>
<tr>
<td>Complete area blocking</td>
<td>Scenario 1</td>
<td>637.295</td>
<td>13.4%</td>
</tr>
<tr>
<td>East garage heading</td>
<td>Scenario 5</td>
<td>623.256</td>
<td>10.9%</td>
</tr>
<tr>
<td>Traffic incident</td>
<td>Scenario 9</td>
<td>614.202</td>
<td>9.3%</td>
</tr>
<tr>
<td>West garage without rerouting (all buses)</td>
<td>Scenario 2 case a</td>
<td>593.313</td>
<td>5.6%</td>
</tr>
<tr>
<td>West garage with rerouting (all buses)</td>
<td>Scenario 2 case b</td>
<td>578.952</td>
<td>3.0%</td>
</tr>
<tr>
<td>West garage without rerouting (half buses)</td>
<td>Scenario 3 case a</td>
<td>577.101</td>
<td>2.7%</td>
</tr>
<tr>
<td>West garage with rerouting (half buses)</td>
<td>Scenario 3 case b</td>
<td>576.024</td>
<td>2.5%</td>
</tr>
<tr>
<td>West garage without rerouting (no buses)</td>
<td>Scenario 4 case a</td>
<td>571.037</td>
<td>1.6%</td>
</tr>
<tr>
<td>West garage with rerouting (no buses)</td>
<td>Scenario 4 case b</td>
<td>569.524</td>
<td>1.4%</td>
</tr>
<tr>
<td>South garage</td>
<td>Scenario 6</td>
<td>576.093</td>
<td>2.5%</td>
</tr>
<tr>
<td>Alternative bus route</td>
<td>Scenario 7</td>
<td>564.747</td>
<td>0.5%</td>
</tr>
<tr>
<td>South and west garage</td>
<td>Scenario 8</td>
<td>562.413</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

Scenarios 2, 3 and 4 alternated the use of all the buses available at the bus depot during the proposed incident, using half the buses only and using no buses at all. Also each scenario was run under two cases rerouting versus No rerouting for the interrupted traffic. To measure the benefit of using buses and the rerouting the scenarios were compared to
each other. Figure 18 shows the effect of the evacuation under these scenarios conditions on the network performance as the total network delay varied from 561.857 vehicle hour to 593.331 vehicle hour in scenario (2), 576.024 vehicle hour in scenario (3) and 571.037 vehicle hour in scenario (4). Table 21 shows an increase in total network delay between 1.63% and 5.60%. This implied that the increase in number of buses had an adverse effect on the network wide performance. This might be due to the loading time of the passengers and the delay caused by waiting at the intersection.

![Figure 18: Network total delay without rerouting](image)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total network delay (hr)</th>
<th>Increase in delay (hr)</th>
<th>% increase in delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>2(a)</td>
<td>593.331</td>
<td>31.474</td>
<td>5.60%</td>
</tr>
<tr>
<td>3(a)</td>
<td>576.024</td>
<td>14.167</td>
<td>2.52%</td>
</tr>
<tr>
<td>4(a)</td>
<td>571.037</td>
<td>9.18</td>
<td>1.63%</td>
</tr>
</tbody>
</table>
Analysis was also done on the link-wide statistics. Garland Avenue was selected for analysis since this is the street closest to the incident and receives the largest impact. This approach had to be completely stopped during the pedestrian evacuation process and the vehicles at Amelia and Garland intersection had to wait till the end of the evacuation. Table 22 shows an increase of about 200% in the average delay time, 1255% in the maximum queue length.

Table 22: Measures of effect on the traffic on Garland Street

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Delay (sec)</th>
<th>% increase</th>
<th>Average Queue Length (ft)</th>
<th>% increase</th>
<th>Max Queue Length (ft)</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>105.9</td>
<td>-</td>
<td>26</td>
<td>-</td>
<td>122</td>
<td>-</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>a 344</td>
<td>224.8%</td>
<td>413</td>
<td>1488.5%</td>
<td>1663</td>
<td>1263.1%</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>a 327.1</td>
<td>208.9%</td>
<td>401</td>
<td>1442.3%</td>
<td>1656</td>
<td>1257.4%</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>a 312.4</td>
<td>195.0%</td>
<td>385</td>
<td>1380.8%</td>
<td>1655</td>
<td>1256.6%</td>
</tr>
</tbody>
</table>

6.4.2. **Rerouting benefits**

Table 23 shows the rerouting benefits for all the scenarios. Total travel time and total network delay was compared for cases (a) and (b) for the three scenarios. It can be seen that the route diversion scenarios showed reduction in overall delay of the network. But the travel time in the route diversion scenarios was increased because the rerouted vehicles took a longer route to reach its destination.
Table 23: Network performance measures for all scenarios and cases

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Number of Vehicles</th>
<th>Total Distance Traveled (mile)</th>
<th>Total Travel Time (hr)</th>
<th>Average Network Speed (mph)</th>
<th>Total Network Delay (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>11443</td>
<td>9243.641</td>
<td>971.86096</td>
<td>10.416874</td>
<td>561.857</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>a 11453</td>
<td>9263.519</td>
<td>992.292</td>
<td>9.335</td>
<td>593.313</td>
</tr>
<tr>
<td></td>
<td>b 11453</td>
<td>9672.031</td>
<td>993.593</td>
<td>9.734</td>
<td>578.952</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>a 11448</td>
<td>9125.3423</td>
<td>980.30862</td>
<td>9.308677</td>
<td>577.101</td>
</tr>
<tr>
<td></td>
<td>b 11448</td>
<td>9690.6641</td>
<td>1006.9697</td>
<td>9.6238134</td>
<td>576.024</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>a 11443</td>
<td>9255.9695</td>
<td>990.97366</td>
<td>9.3402646</td>
<td>571.037</td>
</tr>
<tr>
<td></td>
<td>b 11443</td>
<td>9717.5609</td>
<td>1015.985</td>
<td>9.5648764</td>
<td>569.524</td>
</tr>
</tbody>
</table>

The rerouting also reduced the travel time of the buses evacuating from LYNX Depot to TD Waterhouse Arena. Table 24 shows a decrease of 50% in the average trip time of the buses to reach their evacuation destination.

Table 24: Evacuation time of buses for different cases

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Bus Average Evacuation time (min)</th>
<th>% improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without Rerouting</td>
<td>With Rerouting</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>17.8</td>
<td>8.6</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>16.7</td>
<td>8.4</td>
</tr>
</tbody>
</table>
6.4.3. Evacuation time

Evacuation time is an important measure of effectiveness to evaluate different scenarios as saving a minute of evacuation time during a threat can save lives. The time of evacuation of pedestrians through all the scenarios was 20 minutes and did not change with the change of network management. On the other hand the evacuation time of buses changed for different scenarios. Table 25 compares between the bus evacuation time of each of the scenarios that used buses in the evacuation. The fastest scenario in evacuation was using the north exit of the bus depot and the worst was when pedestrians were directed towards the east garage although on this case buses were given signal priority.
Table 25: Bus evacuation time for Different scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Scenario number</th>
<th>Evacuation time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete area blocking</td>
<td>Scenario 1</td>
<td>12.8</td>
</tr>
<tr>
<td>East garage</td>
<td>Scenario 5</td>
<td>18.0</td>
</tr>
<tr>
<td>West garage without rerouting (all buses)</td>
<td>Scenario 2 case a</td>
<td>17.8</td>
</tr>
<tr>
<td>West garage with rerouting (all buses)</td>
<td>Scenario 2 case b</td>
<td>8.6</td>
</tr>
<tr>
<td>West garage without rerouting (half buses)</td>
<td>Scenario 3 case a</td>
<td>16.7</td>
</tr>
<tr>
<td>West garage with rerouting (half buses)</td>
<td>Scenario 3 case b</td>
<td>8.4</td>
</tr>
<tr>
<td>South garage</td>
<td>Scenario 6</td>
<td>10.5</td>
</tr>
<tr>
<td>Alternative bus route</td>
<td>Scenario 7</td>
<td>8.3</td>
</tr>
</tbody>
</table>

6.4.4. Traffic incident effect

Scenario 9 suggested the blocking of one lane of the arterial Orange Avenue for 15 minutes this can be assumed to be a traffic incident that occurred during the same time of the disaster. This scenario resulted in a total network delay of 614.201 vehicle hours 9.3% increase in total network delay making it the third worst in the effect on the network. The bus evacuation time for this scenario was 17.2 minutes which means that the evacuation
time was also one of the longest bus evacuation times. In fact his scenario is the same as scenario 2 case a but with an additional incident, than if we compare the percentage increase in the total network delay of the two scenarios we will find that scenario 9 caused 3.7% more increase in the delay. This might be because of the additional congestion that happens as a result of blocking a lane of a major busy arterial street like Orange Avenue. This means that a threat executer can delay the response by simply blocking one lane on an arterial street near the area desired to be attacked.
CHAPTER SEVEN:

CONCLUSIONS

Based on the analysis of the different scenarios it was noticed that an evacuation incident in the Orlando Downtown CBD area with complete area road blockage would have an impact on the performance of the network. Total delay to the overall network performance was affected by 13.4% increase of total network delay. Also roads in proximity to the evacuating traffic experienced blockage in case of no rerouting strategy. Maximum queue length at Garland Avenue increased from 122 ft in the case without incident to 1663 ft in the case using 10 buses for evacuation and an increase of nearly 200% in the average delay per vehicle.

The study found that the evacuation of personnel during peak hour was best done through a complete pedestrian evacuation. Using buses increased the evacuation time due to loading time needed for buses and the difficulty of operating large number of buses in a congested traffic situation. Simulation results showed a reduction from 593 vehicle hours to 571 vehicle hours in total network delay between the scenario of no buses and scenario of using 10 buses in evacuation (scenarios 2, 3 and 4). Buses should be used if large number of handicapped or senior citizens were needed to be evacuated or if the destination is too far to walk.

The use of vehicles rerouting is suggested to reduce the delay near the incident area. The rerouting process must be planned such that it solves the problem at the incident location
and also not create problems at other locations. And from a security point of view, redirecting vehicles away from the threat area is a good solution. The traffic lights on the rerouting path were coordinated so that the rerouted vehicles were given priority over the other vehicles. The rerouting strategy proved to reduce the delay in all the evacuation scenarios.

Giving signal priority for buses during evacuation decreases the time of evacuation for buses and allows the traffic to resume normal operation faster. However if not associated with careful planning for pedestrian evacuation, bus signal priority does not yield the desired improvement in the network performance. This was evident in scenario 5 where buses were given signal priority but because pedestrian evacuees were directed to the east garage across Orange Avenue the negative effect on the network performance was observed to be the second worst.

A traffic incident happening during the evacuation process can render all the management and mitigation efforts in vain in terms of saving lost time and delay as a result of the evacuation incident. Thus any incident that occurs during the evacuation time should be dealt with and the problem eliminated as soon as possible. This requires the local emergency authorities to be at full awareness of the traffic situation in the area surrounding the building under threat.

Managing all the evacuees as pedestrians had great advantage, particularly when more than one destination was used for evacuation. Scenario 8, where all the evacuees were
evacuated as pedestrians and were split in two groups, had the least negative effect on the network performance. Although this option executed in a public bus depot is not very practical, it can be applied at other buildings that contain only regular employees that can be pre-assigned to their evacuation destinations before the actual threat.

Each facility should have an evacuation plan and the possible evacuation destinations that would provide a safe shelter for the evacuees and also meet with the FTA evacuation guidelines to avoid major damage to properties or loss in lives.

Rerouting decreased the total network delay and thus reduced congestion. But at the same time the total traveled distance and the total traveled time for the network was increased. This was expected from rerouting because the traffic took longer route to its destination. On the other hand it would be safer if vehicles were redirected away from the incident area.

Local police and emergency personnel responders should be kept informed about the evacuation plans for different public facilities in their area of authority. This helps them respond to an emergency situation in a timely manner and execute the evacuation plan in orderly fashion. Also it is essential for them to estimate the number of emergency personnel required to contain the situation efficiently and safely.
APPENDIX:

SAMPLE OF VISSIM OUTPUT FILES
1. Traffic data collection points and traffic volume counts

Data Collection (Compiled Data)

Measurement 1: Data Collection Point(s) 5, 6, 7
Measurement 2: Data Collection Point(s) 8, 9, 10
Measurement 3: Data Collection Point(s) 11, 12
Measurement 4: Data Collection Point(s) 13, 14
Measurement 5: Data Collection Point(s) 15, 16, 17
Measurement 6: Data Collection Point(s) 18, 19
Measurement 7: Data Collection Point(s) 20, 21, 22
Measurement 8: Data Collection Point(s) 23
Measurement 9: Data Collection Point(s) 24, 25, 26
Measurement 10: Data Collection Point(s) 27, 28
Measurement 11: Data Collection Point(s) 29, 30, 31
Measurement 12: Data Collection Point(s) 32
Measurement 13: Data Collection Point(s) 33, 34, 35
Measurement 14: Data Collection Point(s) 36, 37
Measurement 15: Data Collection Point(s) 38, 39, 40
Measurement 16: Data Collection Point(s) 41
Measurement 17: Data Collection Point(s) 42, 43, 44
Measurement 18: Data Collection Point(s) 45, 46, 47
Measurement 19: Data Collection Point(s) 48, 49, 50
Measurement  20: Data Collection Point(s) 51, 52, 53
Measurement  21: Data Collection Point(s) 54, 55, 56
Measurement  22: Data Collection Point(s) 57, 58, 59
Measurement  23: Data Collection Point(s) 60, 61, 62, 63
Measurement  24: Data Collection Point(s) 64, 65, 66, 67
Measurement  25: Data Collection Point(s) 68, 69, 70, 71
Measurement  26: Data Collection Point(s) 72, 73, 74
Measurement  27: Data Collection Point(s) 75, 76, 77
Measurement  28: Data Collection Point(s) 78, 79
Measurement  29: Data Collection Point(s) 80, 81
Measurement  30: Data Collection Point(s) 82
Measurement  31: Data Collection Point(s) 83, 84
Measurement  32: Data Collection Point(s) 85, 86
Measurement  33: Data Collection Point(s) 87, 88
Measurement  34: Data Collection Point(s) 89, 90
Measurement  35: Data Collection Point(s) 91, 92
Measurement  36: Data Collection Point(s) 93, 94
Measurement  37: Data Collection Point(s) 95, 96
Measurement  38: Data Collection Point(s) 97
Measurement  39: Data Collection Point(s) 98, 99
Measurement  40: Data Collection Point(s) 100, 101
Measurement  41: Data Collection Point(s) 102, 103
Measurement  42: Data Collection Point(s) 104, 105
Measurement 43: Data Collection Point(s) 106
Measurement 44: Data Collection Point(s) 107, 108
Measurement 45: Data Collection Point(s) 109, 110
Measurement 46: Data Collection Point(s) 112
Measurement 47: Data Collection Point(s) 113
Measurement 48: Data Collection Point(s) 114
Measurement 49: Data Collection Point(s) 115
Measurement 50: Data Collection Point(s) 116
Measurement 51: Data Collection Point(s) 117, 118
Measurement 52: Data Collection Point(s) 119, 120
Measurement 53: Data Collection Point(s) 121, 122
Measurement 54: Data Collection Point(s) 123, 124
Measurement 55: Data Collection Point(s) 125, 126
Measurement 56: Data Collection Point(s) 127, 128
Measurement 57: Data Collection Point(s) 129
Measurement 58: Data Collection Point(s) 130
Measurement 59: Data Collection Point(s) 131, 132
Measurement 60: Data Collection Point(s) 133, 134
Measurement 61: Data Collection Point(s) 135, 136
Measurement 62: Data Collection Point(s) 137, 138
Measurement 63: Data Collection Point(s) 139, 140
Measurement 64: Data Collection Point(s) 141
Measurement 65: Data Collection Point(s) 142, 143
Measurement 66: Data Collection Point(s) 144, 145
Measurement 67: Data Collection Point(s) 146, 147
Measurement 68: Data Collection Point(s) 148, 149
Measurement 69: Data Collection Point(s) 150, 151
Measurement 70: Data Collection Point(s) 152, 153
Measurement 71: Data Collection Point(s) 154, 155
Measurement 72: Data Collection Point(s) 156, 157
Measurement 73: Data Collection Point(s) 158, 159
Measurement 74: Data Collection Point(s) 160, 161
Measurement 75: Data Collection Point(s) 162
Measurement 76: Data Collection Point(s) 163, 164
Measurement 77: Data Collection Point(s) 165, 166
Measurement 78: Data Collection Point(s) 167, 168
Measurement 79: Data Collection Point(s) 169, 170
Measurement 80: Data Collection Point(s) 171
Measurement 81: Data Collection Point(s) 172
Measurement 82: Data Collection Point(s) 173
Measurement 83: Data Collection Point(s) 174, 175
Measurement 84: Data Collection Point(s) 176, 177
Measurement 85: Data Collection Point(s) 178, 179
Measurement 86: Data Collection Point(s) 180, 181
Measurement 87: Data Collection Point(s) 182
Measurement 88: Data Collection Point(s) 183
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Data Collection Point(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>89</td>
<td>184</td>
</tr>
<tr>
<td>90</td>
<td>185</td>
</tr>
<tr>
<td>91</td>
<td>186</td>
</tr>
<tr>
<td>92</td>
<td>1, 2, 3, 4</td>
</tr>
</tbody>
</table>

**Measur.: Data Collection Number**

**from:** Start time of the Aggregation interval

**to:** End time of the Aggregation interval

**Number Veh:** Number of Vehicles

<table>
<thead>
<tr>
<th>Measur.;from;to;Number Veh</th>
</tr>
</thead>
<tbody>
<tr>
<td>; ; ;</td>
</tr>
<tr>
<td>; ; ; ;all veh. types</td>
</tr>
<tr>
<td>1;900;4500;549</td>
</tr>
<tr>
<td>2;900;4500;1813</td>
</tr>
<tr>
<td>3;900;4500;226</td>
</tr>
<tr>
<td>4;900;4500;323</td>
</tr>
<tr>
<td>5;900;4500;1822</td>
</tr>
<tr>
<td>6;900;4500;250</td>
</tr>
<tr>
<td>7;900;4500;585</td>
</tr>
<tr>
<td>8;900;4500;239</td>
</tr>
<tr>
<td>9;900;4500;1802</td>
</tr>
<tr>
<td>10;900;4500;231</td>
</tr>
</tbody>
</table>
11;900;4500;546
12;900;4500;114
13;900;4500;2202
14;900;4500;218
15;900;4500;500
16;900;4500;211
17;900;4500;1997
18;900;4500;774
19;900;4500;984
20;900;4500;1055
21;900;4500;1021
22;900;4500;904
23;900;4500;889
24;900;4500;1046
25;900;4500;927
26;900;4500;685
27;900;4500;683
28;900;4500;311
29;900;4500;183
30;900;4500;158
31;900;4500;169
32;900;4500;176
33;900;4500;117
57;900;4500;265
58;900;4500;0
59;900;4500;83
60;900;4500;178
61;900;4500;110
62;900;4500;151
63;900;4500;155
64;900;4500;134
65;900;4500;235
66;900;4500;282
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71;900;4500;698
72;900;4500;759
73;900;4500;679
74;900;4500;534
75;900;4500;281
76;900;4500;214
77;900;4500;236
78;900;4500;264
79;900;4500;246
2. Table of Travel Times

No.   1: from link   132 at   11.2 ft to link   137 at  553.1 ft, Distance 2549.0 ft
No.   2: from link   205 at    6.1 ft to link   209 at  417.3 ft, Distance 2532.0 ft
No.   3: from link   236 at    6.0 ft to link   228 at  588.0 ft, Distance 2606.9 ft
No.   4: from link   321 at    8.1 ft to link   317 at  530.6 ft, Distance 3264.3 ft

Time; Trav;#Veh; Trav;#Veh; Trav;#Veh; Trav;#Veh;
VehC; All;;       All;;       All;;       Bus;;
No.:;     1;   1;     2;   2;     3;   3;     4;   4;
2000; 115.5;  72; 278.5; 162;  96.7; 751;   0.0;   0;
4000; 554.8; 303; 625.1; 196; 105.0; 825;1169.9;   6;
5400; 112.6; 187; 572.1; 192;  91.2; 782;   0.0;   0;

3. Queue Length Record

Queue Counter    1: Link   137 At     544.301 ft

Avg.: average queue length [ft] within time interval
Max.: maximum queue length [ft] within time interval
Stop: number of stops within queue

Time; Avg.; max;Stop;
4. Network Performance

Wed Feb 22 15:13:21 2006

*****************************************

Number of Vehicles: 11453
Total Distance Traveled: 9263.519 mi
Total Travel Time: 992.292 h
Average Network Speed: 9.335 mph
Total Network Delay: 593.313 h

*****************************************
LIST OF REFERENCES


