5-1-2009

Campus emergency evacuation traffic management plan

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CAMPUS EMERGENCY EVACUATION TRAFFIC MANAGEMENT PLAN

By

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A Thesis
Submitted to the Faculty of
Mississippi State University
In Partial Fulfillment of the Requirements
For the Degree of Master of Science
In Transportation Engineering
In the Department of Civil and Environmental Engineering

Mississippi State, Mississippi

May 2009

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Pages in Thesis: 131

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This thesis was motivated to simulate the evacuation traffic of Mississippi Stated University (MSU) main campus using the Path-Following logic of TSIS/CORSIM and to evaluate a set of traffic management plans.

Three scenarios of traffic management plans were developed and tested. A NCT of 123 minutes was projected if evacuate without any plan. In comparison, under a pre-planned traffic management plan the NCT would decrease to 39 minutes. Further, if implement contra flow the NCT would reduce to 21 minutes. If even further adjust the signal timing plans at the university exits a NCT of 20 minutes would be achieved.

The sensitivity analysis found that the NCT was sensitive to the CORSIM parameters of free flow speed, time to react to sudden deceleration of lead vehicle and the configuration of driver type, while the effects of discharge headway and start up lost time were not found to be significant.

Key words: emergency evacuation, traffic management, route plan, CORSIM, Path-Following, iteration

DEDICATION

To my parents, father ***Yanchang Wu*** and mother ***Yuzhen Xue***.

ACKNOWLEDGMENTS

First of all, I would like to express my gratefulness to God for giving me this opportunity of oversea graduate education. Second, I want to thank Mississippi State University and the Department of Civil and Environmental Engineering. The third, I want to thank my committee professors, Dr. Li Zhang, Dr. Dennis D. Truax, and Dr. Mingzhou Jin for their guidance, especially my major advisor, Dr. Li Zhang.

I also want to thank the institutions I have worked for which gave me experience in transportation engineering and planning: The 2^{nd} Surveying and Designing Institute of Railway Department of P. R. China, Shenzhen Urban Transportation Planning Center, and Mississippi Department of Transportation. I appreciate the encouragement and support from the Assistant State Planning Engineer Al Brantley and my supervisor Jeffery C. Altman.

Last but not least, I would like to give thanks to Dr. David K Hale, Trung Trinh and Sammy D. Holcomb who helped me in CORSIM model developing and thesis writing.

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GLOSSARY

EEP ---- emergency evacuation plan

CEEP ---campus emergency evacuation plan

ETMP ---evacuation traffic management plan

ERP ---evacuation route plan

EZ --- evacuation effective zoon

OD --- -origin and destination

NCT --- network clearance time

MOE --- measure of effectiveness

TRSDLV --- time to react to sudden deceleration of lead vehicle

FFS – free flow speed

DCH – discharge headway

SULT --- startup lost time

CHAPTER I

INTRODUCTION

This project was designed to apply the Path-Following logic modeling approach of TSIS/CORSIM to evaluate a set of evacuation route plans (ERP) for Mississippi State University (MSU) main campus. It is felt that this approach might be helpful in preparation of a campus emergency evacuation plan (CEEP). The objective was to generate evacuation route plans under various traffic management strategies and evaluate their effectiveness. Sensitivity analyses were conducted on some key CORSIM parameters to compensate for not being able to perform model calibration and validation due to a shortage of field data. The entire thesis was based on the assumption of the worst-case traffic scenario.

1.1 MOTIVATION

An EEP is an indispensable preparedness package for hazard risk areas. For example, many universities and colleges have CEEPs which include a set of ERPs. No such a plan has yet been completed for MSU. Located at about 250 miles north of the Gulf of Mexico, MSU is affected by natural disasters such as hurricanes and tornados. Hence, developing a CEEP for MSU is not only important, it is imperative.

The evacuation traffic management plan (ETMP) is a major component of a CEEP. The ETMP should define scenarios of executive management strategies. An evacuation route plan (ERP) for each scenario should be generated. In the literature, many traffic simulation platforms are reportedly used in simulating ERPs. Among these, the Traffic Software Integrated System - Corridor Simulation (TSIS/CORSIM) model is one.

Familiar to CORSIM users, traffic volumes are inputted to CORSIM through entry nodes and distributed under random assignment according to turning percentages at the intersections. However, under the CORSIM Path-Following logic, vehicles will follow the pre-determined route paths in a path file once the path file and vehicle file are provided in the project folder. The Path-Following algorithm was developed initially to test dynamic traffic assignment for research purposes [(1)]. However in theory the path-based vehicle models are more plausible for generating evacuation traffic route plans than randomly controlled vehicle models. This is because during evacuation situations vehicles are more likely to be directed by traffic controls such as signals, message signs and arrow boards than being allowed to find their way out of an area randomly. Hence, in simulation, the vehicles are better off guided by a pre-planned route plan.

In the literature only one case of applying CORSIM Path-Following was found. It was used as a reference simulator to compare the major simulator of TRANSIMS [(2)]. This thesis was motivated to simulate the evacuation traffic using Path-Following logic of CORSIM to simulate a set of traffic route plans for MSU and evaluate the effectiveness of the traffic management strategies.

1.2 OBJECTIVES

The objective of this thesis was to generate a set of ERPs for MSU main campus under various traffic management scenarios and evaluate the effectiveness of traffic management strategies through simulation. In this thesis a framework was developed for MSU evacuation traffic including modules of evacuation traffic management scenario identification, ERP generation, ERP simulation and measure of effectiveness (MOE) analysis. For each scenario, the major questions to be answered are:

- What is the network clearance time (NCT)?
- What is the evacuation route for each parking lot under the plan producing the best improved NCT?
- What are the bottlenecks and how to eliminate them in order to improve the ERP?

Calibration parameters should have been calibrated according to data collected from actual evacuation. Since no evacuation data was available for this thesis, sensitivity analysis of these CORSIM parameters was conducted.

1.3 ASSUMPTION

This thesis was proposed to develop ERPs for MSU emergency evacuation for a school weekday. The worse case traffic situation was assumed in order to derive a conservative NCT. To define the worse case situation three assumptions were taken into consideration:

- The evacuation happens during rush hour;

- The number of vehicles to be evacuated equals the parking lot service capacity; and
- In order to simplify the modeling process, no mass transit options were considered.

CHAPTER II

LITERATURE REVIEW

In order to understand how EEP, CEEP and ETMP had been conducted, a literature review was performed. The review found that EEP had been intensively studied and implemented in which contra flow operation was a hot topic. CEEPs have been developed at many universities and colleges. However, most of them concentrated on personnel responsibilities. ETMP generation is a combination of planning, simulation and optimization for which dynamic origin and destination (OD) estimation and dynamic traffic assignment (DTA) had been increasingly studied and tested.

2.1 EMERGENCY EVACUATION PLAN

The emergency evacuation plan (EEP) is a preparedness package for guiding evacuation operations--dissipating evacuees from the risk area, named evacuation effective zone (EZ)--with the goal of reducing the loss of life and property [(3)]. Natural disasters that call for evacuations include hurricane, earthquake, volcanic eruption, tsunami, tornado, flood, wildfire and landslide. Man-made disasters that require evacuation include dam failure, terrorist attack, chemical, biological spill and nuclear blast and so forth.

Under the ultimate goal of minimizing loss, the evacuation objectives, strategies and procedures vary with many factors such as the type of disaster, the magnitude of population threatened, the characteristics of geography, and the situation of transportation infrastructure. Federal Emergency Management Agency (FEMA), a division of the Department of Homeland Security, is the agency which is "responding to, planning for, recovering from and mitigating against disasters" [(4)]. FEMA requires all states to develop a comprehensive emergency operation plan for all types of disasters. At the state level and local level, the emergency response management structures differ by state according to local conditions. In administrative operation, the government authority has the right to announce an evacuation [(4)].

Among all types of emergency evacuation, hurricane evacuation received most research interest because of its significant damage, the massive evacuation caused, and the large scale of traffic problems encountered [(3)]. Among other topics, contra flow (lane reversal) traffic operation is noticeably implemented and studied.

Ever since the first recognized freeway contra flow operation on I-16 in Georgia for Hurricane Floyd in 1999, in hurricane risk areas in Atlantic and Gulf Coast states, contra flow operation was implemented on major evacuation roads such as I-40 in North Carolina, I-26 in South Carolina, I-10 in Louisiana, I-16 in Alabama, I-45 in Texas, and I-55, I-59 in Mississippi. The inland terminations of the contra flow traffic were designed either by dispersing normal and contra flow traffic to different ramps at the freeway interchanges (I-64 Richmond, Virginia) or by merging contra flow lanes back to normal lanes through median crossover (I-55, I-59, Mississippi). The time-of-day for contra flow operation varies by states. When applicable, emergency shoulder lanes were used by allowing traffic on shoulders and adjacent lanes [5].

Traffic simulation was used to evaluate contra flow plans. In 2000 the Texas Transportation Institute in conjunction with Texas Department of Transportation used CORSIM on a 90 miles contra flow segment on I-37 for the Corpus Christi coastal region and identified five top contra flow lane configurations among 13 alternatives[6]. In 2004 Louisiana State University (LSU) Hurricane Center modeled the I-10 lane reversal plan with CORSIM and resulted in a 53% increase of capacity of contra flow plan over the normal lane use plan. This study also predicted significant queues upstream from the contra flow initiation point. This prediction was verified during Hurricane Ivan later in 2004. Contra flow termination design was studied using CORSIM by Erick Lim and Brian Wolshon in 2005[7]. This study concluded that merge designs are less favorable than split designs. This conclusion was based on the goal of maximum the throughput of the termination points and would not be applicable for occasions when throughput is not the dominant consideration. For example ,in the study sponsored by NCDOT in 2003, Billy M. Williams et al. modeled I-40 contra flow with CORSIM in order to improve the original evacuation plan, and found the merge termination was the best option in consideration of limiting contra flow from vicinity roadways[8].

It can be concluded that contra flow research is still on preliminary stage. Due to the common absence of field data of contra flow traffic, model calibration and validation are often difficult to conduct and the characteristics of evacuation contra flow traffic stream are still unclear [9].

2.2 CAMPUS EMERGENCY EVACUATION PLAN

Aside from natural disaster threatened areas, emergency preparedness is also indispensible for densely populated areas such as universities. For the purpose of smoothing the evacuation traffic and minimizing chaos, campus emergency evacuation plans (CEEP) are developed for universities and colleges providing guidance and procedural information. Though CEEPs focus on personnel responsibility, they also address traffic management plans for evacuation. Some provide traffic evacuation routes, either in the formed guidelines or maps (10-13).

For example, San Diego State University's CEEP (10) demonstrated regular evacuation drills and staff designation. Considering the factors of immediate impact including the timing and the availability of police officers, several traffic evacuation route plans were generated to cope with different scenarios of evacuation. Key intersections and vehicle evacuation routes were identified. In the cases of emergency evacuation, staffs of the Department of Public Safety and those who are currently on call are to be appointed as "site controllers" to direct traffic in the congested points on campus and to report the real-time situation (10).

No microscopic simulation for preparing CEEP was found in literature through Google, National Transportation Library or Engineering Index database search. Therefore it was suspected that those ERPs were of conceptual plans or at macroscopic analysis level. However, in reality many universities and colleges already experience traffic congestions on normal days. Further, in the event of an emergency evacuation, when students and staffs are under the threat of life and property, more aggressive driving behavior is to be expected. In further conjunction with the less familiar evacuation route of the evacuation plans, emergency traffic might produce worse congestions and even accidents. In order to cope with the highly dynamic and uncertain characteristics of evacuation traffic, more sophisticated traffic management frameworks for CEEP are needed.

2.3 EVACUATION TRAFFIC MANAGEMENT PLAN

The evacuation traffic management plan (ETMP) is a crucial component of the EEP and the CEEP. Most of the practices in disaster response preparedness plans reported in the literature were in qualitative approaches and these studies generally used macroscopic or mesoscopic modeling up to around 2005[(14)]. The process of modeling approach includes collecting input data, building the model, developing and testing traffic management scenarios and evaluating the results with measure of effectiveness (MOE) analysis [(15)].

2.3.1 Evacuation Demand

In evacuation planning since the objective is to dissipate evacuees from the evacuation effective zoon (EZ), the EZ is treated as the origin end of the OD pair. The destinations of the evacuation traffic vary by disaster type. For catastrophes such as earthquake, hurricane, and flood, the destinations are designed as out of the influenced area marked with threshold milestones on the evacuation highways. For hazards like chemical and biological releases, the destination is out of the EZ which could be a circular area centered by the incident point with a safe radii. [(16)].

The ultimate objective of evacuation demand estimation is to obtain the number of evacuating vehicles. (17) In the literature, the demand analysis can be classified into two approaches: static empirical OD estimation which produces time-independent OD for all time intervals and dynamic OD estimation which produces time-dependent OD matrixes.

Empirical evacuation demand estimation is similar to the trip generation of the traditional four-step-planning. It generally assumes that travelers evacuate from fixed location such as their homes. This assumption is grounded for evacuation from disasters with long warning time such as hurricane which allow the evacuees go back home and pick things they need and then start evacuating from their homes. This type of estimation begins with identifying the range of EZ and obtaining and examining the demographic data such as population distribution, the number of evacuating vehicles per residential household, and the numbers of public transit and special vehicles. Mathematical models used in this stage are normally cross-classification and regression. Background data needed include socioeconomic data, transportation network, and pricing data of automobile operation and parking (18).

However when evacuation time sequence is considered for geographical, economical, or political reasons, dynamic OD estimation is employed.

In the case of the Phoenix flooding evacuation study by Hyunson Noh in 2008, a departure curve along time was produced based on stationary OD tables. The evacuees were classified to five contours according to their location to the river which stands for degree of emergency. Their evacuation was timed and loaded dynamically to the model by contour. This batch loading can relieve the network congestion which would happen if all the evacuees start to evacuate at the same time. However its base assumption might not be sound as stated by Hyunson, because if there is a flood coming, the residents would be panic and leave as soon as possible; they might not wait for their turn as planned [19].

Within the Intelligent Transportation System (ITS) context, dynamic OD has received increasing attention since it can cooperate with on-line traffic management systems [20]. The OD matrices of each time profiles are obtained from the previous OD and the current on-line link traffic counts. This type of OD cannot be accurate since there exist random error when deriving OD from previous OD and measurement error in traffic count. Continued endeavors have tried testing algorithms to diminish these errors. The Kalman filtering algorithm, Bayesian statistical approach, least squares and weighted least squares approaches have been intensively studied and tested [20]. Although the errors were reduced to some degrees in various improved algorithms, paced together with the development of computational algorithms, simulation interface and traffic count hardware, no recognized milestone of improvement in this domain has yet found established.

2.3.2 Evacuation Route Plan (ERP)

The objective of an ERP is to derive traffic route plans for evacuees to travel from their origins to destinations. The methodology of ERP generation experienced a graduate shift from static to dynamic, with increasing emphasis on dynamic assignment, while the simulation models used experienced a shift from macroscopic to microscopic.

Traditional traffic assignment in planning generally assume the system is in full operation, and assign the traffic basing on historical or forecast demand[(21)] . This static method can handle normal traffic conditions, but where there is an incident and the travelers already on the road need to change their routes, dynamic traffic assignment (DTA) is needed instead. DTA is challenged to model how the travelers will reroute upon unexpected traffic supply changes when they are already on the trip. Hence other than planned routs addressed in static assignment, real-time traffic and typical traveler decision roles need to be addressed [(21)]. Transportation professionals increasingly found that DTA was relatively underdeveloped. Challenges exist widely in domains of application and fundamental theories on tractability and realism [(22)].

The computational models used in traditional traffic assignment are commonly macroscopic models such as Tranplan, EMME/2, and TransCAD. Evacuation traffic is largely oversaturated and highly congested. Individual vehicle behavior can heavily affect the network traffic performance; evacuation traffic is characteristically dynamic. Therefore macroscopic models are not appropriate for evacuation planning [(23)] and microscopic models are becoming increasingly more widely used by contemporary analysts. For DTA, mesoscopic models such as Dynamic Network Assignment-Simulation Model for Advanced Roadway Telematics (Planning version) (DYNASMART-P) and microscopic models such as Paramics are used.

In the 1980s, the first macroscopic evacuation modeling package of Hurricane Evacuation Studies (HES) was initiated by FEMA and the transportation analysis module evaluated the capacity of transportation infrastructure and identified the bottleneck within the relative roadway network[3]. More recently, a macroscopic model derived from CORFLO was developed in Oak Ridge Evacuation Modeling System (OREMS 1995) [3] and research is under development to integrate real-time traffic from remote sensing system, and the feasibility of intelligent consequence management [24].

An example of evacuation DTA framework is the model reference adaptive control (MRAC) which was developed by Henry Liu, et al. and tested in the city of Logan. This framework was a short-term preserve-predict-control system based on real-time traffic. Real time traffic observed by the monitoring system was sent to online OD estimation module, and dynamic OD was then generated and inputted to the prescriptive reference model where control strategies were generated and sent to the controller. A microscopic simulation model, PARAllel Microscopic Simulation ParamicsV5, was used for testing and evaluation [25].

The unique study which used Path-Following logic of CORSIM was Gu Y‘s thesis of evacuation study on Virginia Tech Blacksburg campus [1]. In Gu’s evacuation framework, the micro-scale transportation planning model TRANSIMS, composed with a Planner Module and a Traffic Simulation Module was used. CORSIM was used as an alternative simulation tool. The conversion utilities TranNet2Corsim and getCorsimPathVeh were used to interact TRANSIMS with CORSIM. The objective function of the traffic assignment was to choose the nearest boundary outgoing location for each evacuee, which was measured with direct distance between the origin and the destination. Several loops improvement between the planning module and the simulation module were conducted until the evacuation traffic stabilized. Gu's thesis gives the detail of the research framework [(2)].

2.3.3 Measure of Effectiveness (MOE) Analysis

Measure of effectiveness (MOE) analysis is a component of ERP iteration. MOE analysis is used to evaluate the traffic performance of the ERPs in order to compare them and identify the best ERP for a specific scenario. Due to the complicity of evacuation traffic, many factors need to be considered in MOE analysis. In the literature, evacuation MOE analysis has covered a wide range of traffic measurements, such as NCT, average speed, density, total and individual travel time, exposure time, number of congested links, individual and total delay. Furthermore, social economy and political factors such as the costs of evacuees not being evacuated and fairness have also been considered in MOE analysis [(26)].

Although MOE analysis is case specific, for disasters that have long warning time such as hurricanes, to minimize NCT is always on the list of priorities [(27)]. In this case, the vehicles on the minor roads crossing the major evacuation routes might not be favorable because evacuating these vehicles is less contributive to decreasing NCT. Hence the traffic signal will give the major evacuation road a very long green time and the vehicles on those minor streets need to wait for a long time to release. This signal timing plan therefore lacks fairness to the vehicles on the minor roads. In this case, how much shorter of a release time is appropriate and acceptable is a question to be addressed.

MOE setting is a trade off among different objectives and their degrees. For some disasters with little warning time such as chemical release incident and earthquake, evacuation is somewhat an escape from the aftermath of the disaster, and the focus of MOE analysis might shift somehow to controlling the chaos and to operate evacuation in order. Hence the fairness to all the evacuees might be given more weight (28).

Conventionally, the assignment with the best MOE is to be chosen as the final assignment. However, in evacuation planning, especially in dynamic traffic assignment, the feasibility of the improved plan is considered to be more important. Due to the high dynamic and the uncertainty of evacuation traffic, the assignments with the best MOE of consecutive simulation time steps, for example, within a few seconds, might differ abruptly. But the vehicles in the real world cannot change their route so often or so much. To cope with this problem the ERP with the smallest difference was chosen as the chosen EPR in the next time profile in the framework of MITSIMLab (29).

CHAPTER III

OBJECTIVE, SCOPE AND APPROACH

The objective of this thesis is to develop a set of ERPs for MSU main campus under different traffic management strategies and evaluate their effectiveness. The thesis scope is limited to MSU Starkville main campus within the eight university exits/gates. The approach is iterations of ERP generation, simulation, MOE analysis within a framework. Sensitivity analysis was conducted to test the sensitivity of some key CORSIM parameters to NCT instead of model calibration and validation due to absence of filed data.

3.1 OBJECTIVE AND SCENARIO DEVELOPMENT

As stated before, the objective of this thesis is to develop a set of ERPs for MSU under different traffic management strategies and evaluate their effectiveness. The framework to be developed includes modules of evacuation traffic management scenario identification, ERP generation, ERP simulation and MOE analysis. For each scenario, the major questions to be answered are:

- What is the NCT?
- What is the evacuation route for each parking lot under the plan with the best improved NCT?

- What are the bottlenecks and how to eliminate them in order to improve the ERP?

In a CEEP, deferent evacuation management scenarios need to be addressed to cope with disasters with different nature and degree of damage. Since contra flow and signal control adjustment are the major approaches to improve managing traffic, in this thesis the following three traffic management strategies were identified based on different arrangement of contra flow and signal control:

- Strategy 1: no contra flow and no adjustment in signal control at university exits;
- Strategy 2: implement contra flow but no adjustment in signal control at university exits ;
- Strategy 3: implement both contra flow and signal control adjustment at university exits.

Accordingly, in the process of ERP, three scenarios were defined:

- Scenario 1: no contra flow, no change in gate signal timing plan;
- Scenario 2: contra flow, no change in gate signal timing plan;
- Scenario 3: contra flow, modify gate signal timing plan;

Through this thesis for each of the above scenarios, the followings are to be derived:

- ERP for each major parking lots;
- NCT along with the clearance time of each university exit;
- Signal timing plan adjustment at the university exits (for scenario 3 only).

3.2 SCOPE

The geographic scope of this thesis is within the range of MSU main campus. The examined road network includes roads within the university gates. Intersections at the gates are also considered, if signals are already installed.

3.3 APPROACH

As foretasted the approach of the generating, evaluating and stabilizing is a combination of planning, simulation and optimization. For the campus evacuation the origins are known as the on campus parking lots while the destinations are the nodes just out of the university exits/gates. The ERP generation defines both the destinations (the gate to evacuate through) of evacuation vehicles and the evacuate routes. Hence the OD and traffic assignment are combined in the step to ERP generation.

The framework of this thesis includes modules of evacuation traffic management identification, ERP generation, ERP simulation and MOE analysis. After the scope and scenarios were identified, four steps were processed to build the framework:

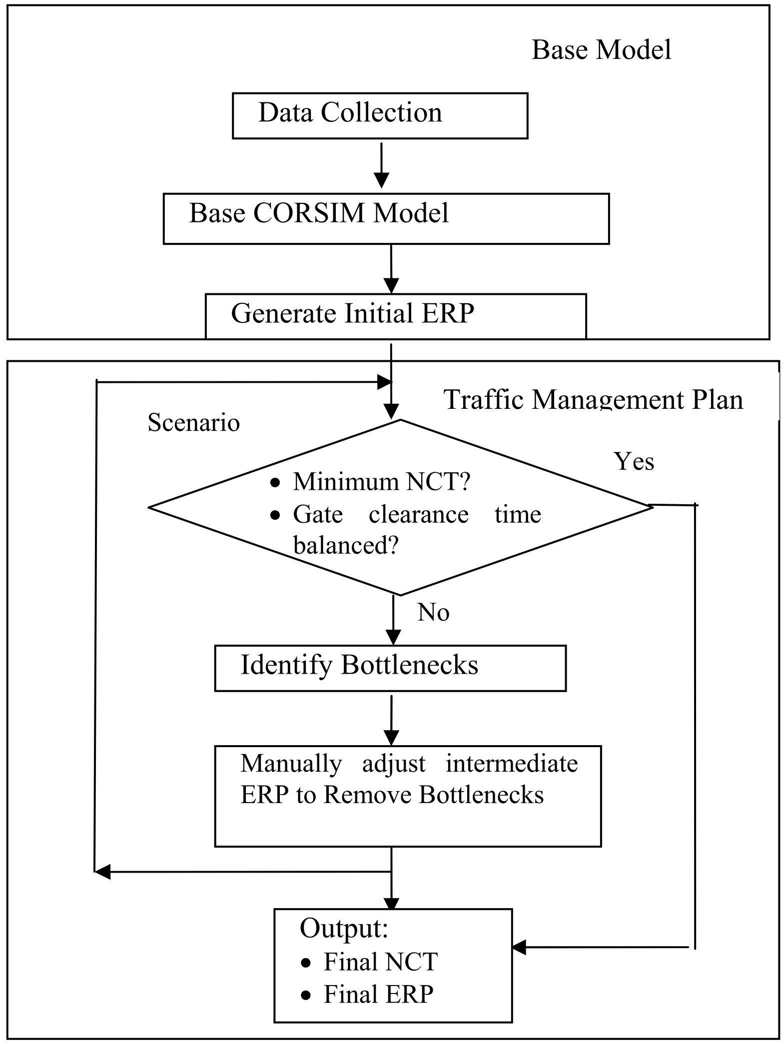

Figure 3.1 Flowchart of ERP Generation

- Collect data from field survey and previous MSU traffic studies [22]. The data needed include data for simulation model such as geometric data, traffic volume, turning percentage at intersections, driver type and vehicle type, signal timing plan, and evacuation demand data of service capacity of each parking lot;
- Develop the base model for MSU evacuation in TSIS/CORSIM. The calibration and validation of base model were skipped due to the shortage

of real evacuation field data. Instead, sensitivity study of key CORSIM parameters were conducted after the development of traffic management plan;

- Generate the initial evacuation route plan. The initial ERP follows the nearest gate principle which means the evacuation vehicles head to the geometrical nearest gates to their parking lots to evacuate through;
- Conduct iterations of ERP in each scenario targeting at improving MOE. Within this step the following were conducted:
  - ✓ Gather MOE data from CORSIM animation and check the MOE. The MOE of this thesis is defined as a dual objective on NCT. The major objective is to minimize NCT, and the secondary objective is to balance the clearance times at all the university gates. The stopping criterion is set as 30 iterations for each scenario;
  - ✓ Through observing the animation in CORSIM, identify traffic bottlenecks (most congested intersections or road segment);
  - ✓ Generate new ERPs manually to remove the bottlenecks and reduce the NCT;
  - ✓ Conduct ten multi-runs of the final ERP and average the gate clearance time to be the final results.

Figure 3.1 illustrates how this framework took form for this research effort. Calibration parameters such as start up delay, discharge headway, and driver behavior data should have been calibrated in CORSIM base model development according to real evacuation data from field data collection, and the base model should have been validated afterwards. However, no enough evacuation data was available for this thesis. To make up this deficiency, sensitivity analyses of key CORSIM parameters were conducted and their sensitivities to NCT were evaluated.

CHAPTER IV

BASE MODEL DEVELOPMENT

The base model is representative of the case specific evacuation traffic situation. Yet in this thesis in absence of field data of real evacuation, the base model was defined as a model in which all the vehicles from all the parking lots on campus head to the nearest university gate for evacuation.

4.1 DATA COLLECTION

To develop a base model which is representative, verifiable and reproducible for MSU EEP, background data was collected. In date collecting geometric data include network configuration, number of lanes, location and parking service capacity of all on campus parking lots. Traffic data include entry volumes of the entry nodes, turning percentages at intersections, and signal timing plans at signalized intersections. Driver type and vehicle type information was also collected. Calibration data of startup lost time (STLT), discharge headway (DCH), and driver behavior should have been collected also, since no evacuation was available for this thesis, sensitivity analyses were conducted instead.

Free flow speed (FFS) of each link is another data need to be collected. Normally, field traffic study is conducted to obtain the FFS. For each link at least 100 vehicles are to be observed. In order to simplify the data collection process, sensitivity study was conducted on FFS instead of data collection as well.

4.1.1 Geometric Data

The major geometric data for this project includes node location, link length, and number of lanes, lane channelization, parking lot location, and parking service capacity of each parking lot.

4.1.1.1 Node and Link

Based on field survey and Google map, a CSORIM network of MSU main campus was generated. The network is composed with 17 major roads. US Highway 182 and Blackjack Road are north and south boundary roads, respectively. Between them running from north to south are four east-west major streets.US Highway 25 and 12 is the west boundary. East Lee Boulevard is the east boundary. Between them are three north-south major roads. The data is shown in Table 4.1 and Figure 4.1.

Table 4.1 Major Roads of MSU Main Campus

Direction	Location	Street Name	Gate
East - West (North on top)	North Boundary	HW 182	1
	1st North	College View Dr. / Coliseum Blvd.	2
	2nd North	Barr Ave.	3
	3rd North	Russell St./Stone Blvd./Creelman St.	4
	4th North	Rogers St. / Bully Blvd. / Presidents Circle/ Morrill Rd.	5
	South Boundary	Blackjack Rd.	6,7
North - South (West on top)	West Boundary	HW 25 & 12	4
	1st West	College View St./B S Hood Dr. /Stone Blvd.	4
	2nd West	George Perry St.	1
	East Boundary	Hardy Rd. /East Lee Blvd.	7,8

Figure 4.1 Gates and Major Roads of MSU Main Campus

There are eight university exits, or "gates" to MSU main campus. They are shown as red dots in Figure 4.1 The relationship of the gates with the major roads are shown in Table 4.1. Except Gate 2 at College View Street and Gate 3 at Barr Avenue, six of them are signalized. Among the signalized gates, Gate 1, 4, 6 and 7 intersect with roads which are not belonging to MSU campus road while Gate 5 and Gate 8 intersect with campus roads. The outbound approach of the gates is one except Gate 1, and the number of the outbound lanes is totaled to nine as shown in Table 4.2.

Table 4.2 Signals and Outbound Lanes at MSU Main Campus Gates

Gate	Location	Signalized	Intersect with Non-campus Road	Number of Lanes of Outbound Road
Gate1	George Perry St @ Highway 182	Yes	Yes	2
Gate2	College view St @ Highway 12 ramp	No	No	1
Gate3	Barr Ave /University Dr	No	No	1
Gate4	Russell St @ Highway 182	Yes	Yes	1
Gate5	Bully Blvd /Roger St @ Robert L Dr	Yes	No	1
Gate6	Stone Blvd @ Blackjack Rd	Yes	Yes	1
Gate7	Hardy Rd @ Blackjack Rd	Yes	Yes	1
Gate8	East Lee Blvd @ Barr Ave	Yes	No	1
Total		6Yes	4Yes	9

On Blackjack Road between Gate 6 and Gate 7 there is a roundabout. CORSIM user's guide does not recommend users to code roundabouts with CORSIM, because the current version (CORSIM 6.0) cannot simulate roundabout satisfyingly [30]. Hence in this thesis the roundabout on Blackjack Road is coded as an un-signalized intersection.

4.1.1.2 Parking Lot

A study of parking lot count was conducted in April 2007 by the MSU Physical Plant. In this project 91 parking areas on campus were surveyed and the number of parking spaces was totaled to be 10,980. Of the 91 parking lots, some are located outside the campus gates. These are lots at the Center of Advanced Vehicular Systems (CAVS), POWE, Wise Center, and School of Veterinary Medicine. Meanwhile, some new parking lots have been constructed at the MSU Bookstore, Griffis Hall, Hilbun Hall, and along the south end of Hardy Road. Hence, the parking lot count for this project was adjusted to reflect these issues. In order to simplify the model, small parking lots whose parking services capacity was less than fifty were deleted from the model as being minor contributors. The final model included 48 parking lots with a total parking service of 8,939 as shown in Figure 4.2. The parking lot name, CORSIM ID and the name of the exit street name are listed in Appendix A.

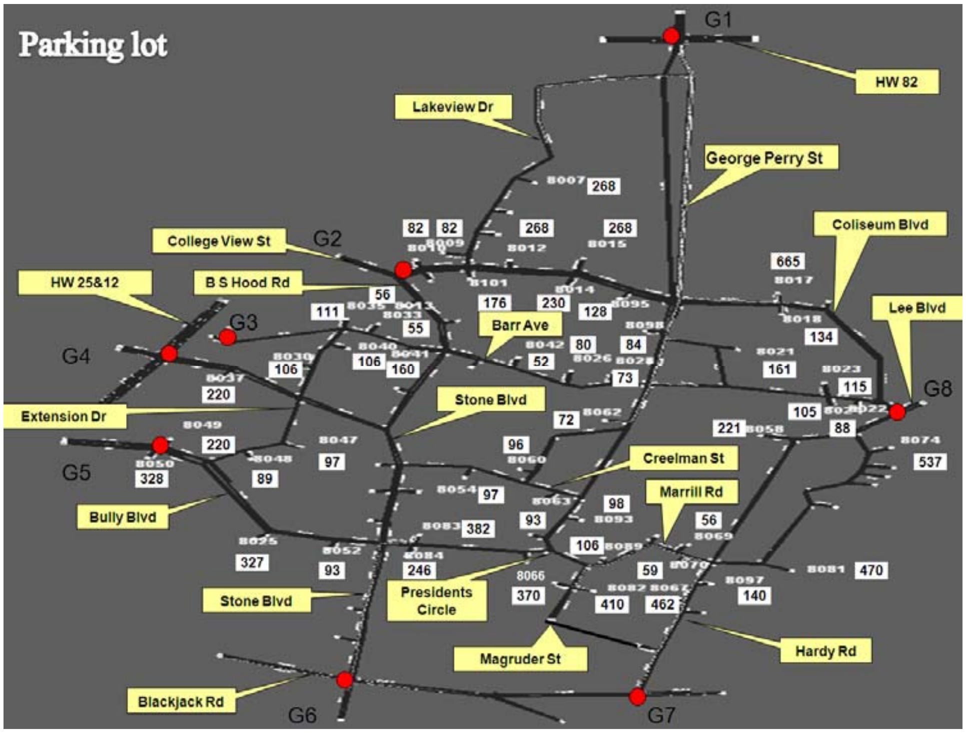

Figure 4.2 Major Parking Lots of MSU Main Campus

Note: 1. Number in white is CROSIM ID of the parking lot.
2. Number in black on white background is the parking service capacity of that parking lot.

4.1.2 Traffic Data

As a microscopic traffic simulator, CORSIM simulates the behavior of individual vehicles. Traffic volumes at entry nodes, turning percentage at each intersection, and the data of traffic control devices such as signal, stop sign, and yield sign were collected.

4.1.2.1 Entry Volume

As formerly stated, due to the assumption of rush hour for a conservative NCT, the traffic volumes of rush hour were collected. The entry nodes include parking lots and the nodes at the university gates. There are eight gates for MSU main campus. Among those six are signalized. The entry volumes were collected in Campus Traffic Studies of 2005 to 2008[31] in which the peak hour volumes of each gate were collected at AM, Noon and PM as shown in Table 4.3. Since the highest volume exist more frequently at Am, under the worse case assumption, Am peak hour volumes were selected as the entry volumes of the CORSIM base model.

Table 4.3 Rush Hour Volumes of Gate Entry Nodes

Gate #	**Location**	**Volume (veh /hour)**			
		Direction	AM	Noon	PM
Gate1	George Perry St. @ Highway 182 Barr Ave. /University Dr.	SB	33	119	119
		EB	703	562	562
		WB	648	512	512
Gate2	College view St. @ Highway 12 ramp	EB	185	185	185
Gate3	Bully Blvd. /Roger St. @ Robert L Dr.	EB	340	200	220
Gate4	Stone Blvd. @ Blackjack Rd.	EB	850	850	850
Gate5	Hardy Rd. @ Blackjack Rd.	EB	185	338	333
Gate6	East Lee Blvd .@ Barr Ave.	EB	727	761	868
Gate7	George Perry St. @ Highway 182	WB	416	236	280
Gate8	College view St .@ Highway 12 ramp	SB	385	305	510

4.1.2.2 Turning Percentage

Turning percentage is a percentile distribution on left turn, right turn, through movement, and/or left/right diagonal turnings for an approach at an intersection. In this thesis, the destination is defined as getting out of the university gates. The path in the path file needs to end with an entry node. If the gate intersection is connected to multiple inbound approaches, a path needs to be coded in the path file for each inbound approach. The turning percentages of the outbound traffic at the university gates were collected and used when distributing evacuating vehicles at the gates.

A survey was conducted on June 13, 2008 at the gates where multiple turning movements exist at the outbound gates and the relative turning percentage were calculated as shown in Table 4.4.

Table 4.4 Turning Percentages at the University Gates

Gate		**LT**	**TH**	**RT**	**Turning Ratio**
Gate 1	Vehicle Count	12	0	10	LT:RT = 1:1
	Entry ID	8103	8105	8104	
Gate 2	Vehicle Count	One Way			
	Entry ID	8034			
Gate 3	Vehicle Count	One Way			
	Entry ID	8044			
Gate 4	Vehicle Count	30	34	8	LT:TH:RT =4:4:1
	Entry ID	8106	8045	8107	
Gate 5	Vehicle Count	One Way			
	Entry ID	8057			
Gate 6	Vehicle Count	77	23	92	LT:TH:RT = 3:1:4
	Entry ID	8109	8110	8108	
Gate 7	Vehicle Count	80		160	LT:RT =1:2
	Entry ID	8111		8108	
Gate 8	Vehicle Count	One Way			
	Entry ID	8020			

Note: 1. The survey was conducted on June 13.2008.
2. The vehicle counts were 15 min.

4.1.2.3 Traffic Control

On MSU main campus, there are six traffic signals installed (five of them are at university gates and one is within campus). The rest of the on campus intersections are controlled by stop signs, yield signs, or no traffic control. The signal timing plans of signalized intersection were obtained from Campus Traffic Study of 2005 to 2008[31] and field data collection of this thesis.

4.2 CORSIM SETUP

In the process of CORSIM setup, parameters of network property and NETSIM setup such as simulation time period, vehicle type, and driver type were determined.

4.2.1 Simulation Time Period

Evacuation behaviors relating to time period are well studied in the literature. Three time periods were normally defined to cover the process of evacuation: warning time, preparation time, and evacuation time [32]. In this thesis, however, only the evacuation time mentioned in normal studies was discussed and the first two time periods are not within the topic. The NCT here is defined as the real evacuation time covering the time interval from the vehicles start moving to the last vehicle clearing out the university gate.

During evacuation vehicles running on the adjacent highways are not allowed to enter the university. Hence, for the university gates at intersections, Gate 1, 4, 6 and 7, the volumes of the entering traffic movements were adjusted to zero. For gates not at an intersection, Gate 2, 3, 5 and 8, entry volumes were adjusted to zero.

4.2.2 Driver Type

CORSIM allows defining ten types of drivers to make the model representative. For each driver type multiple parameters are adjustable for users, such as discharge headway, startup lost time, lane changing control, acceptable deceleration rate, acceptable gap in oncoming traffic when making turns, and etc.. For users' convenience, CORSIM set default values for all of these parameters [(1)].

By CORSIM default, driver type one is a typical conservative driver while driver type ten is a typical aggressive driver [(1)]. Considering during emergency evacuation, drivers would be presumed to be more aggressive than in normal situations. So the ratio of the total number of conservative drivers to aggressive drivers was set to 1:4. We set 20% of the drivers to be Type one and 80% to be Type ten. In the vehicle file, the driver type is defined as the repeating circles of 1, 10, 10, 10, 10 as shown Appendix C.

4.2.3 Vehicle Type

In order to determine the vehicle type distribution, a campus vehicle type survey was conducted. Among the vehicle count recorded, about 15% were pickup trucks and 85% were passenger cars as shown in Table 4.5. Among the passenger cars, about 10% were very old cars.

Table 4.5 Records of Campus Vehicle Survey

Location	Pick-up Truck	Passenger Car	Total
McCain Parking Lot	15	118	133
McKee Parking Lot	18	107	125
Eckie's Parking Lot	67	417	484
Sum	100	642	742
Percentage	15%	85%	100%

Note: 1. This survey was conducted on June 13, 2008 from 10:30~11:20 am

Accordingly, 15% of vehicles were set as type vehicle NETSIM 3 (a default CORSIM vehicle type representing pickup truck) (1), 10 % as NETSIM 5 (representing low performance cars), and 75% (representing high performance cars) as NETSIME 1. In the vehicle file, the vehicle type is defined as repeating circles of 1, 1, 3, 1, 1, 5, 1, 1, 1, 3, 1, 1, 1, 5, 1, 1, 1, 3, 1, 1 as shown in Appendix C.

4.3 INITIAL ERP

With the implementation of Path-Following, CORSIM included an interface for Path-Following through which each CORSIM simulation run will call the path file '.pat' and vehicle file '.veh'. The vehicles coded in the vehicle file will follow the defined path in the path file once the two files with the same name as the TRF file are included in the project folder.

4.3.1 Path File

Path file is a text file with an extension name of '.pat'. In the path file each line represents one route path starting with an entry node followed by the consecutive neighboring nodes along the path and ending with an entry node as shown in Figure 4.3. CORSIM allows up to 5,000 paths in one path file. The path ID is the sequence of the path in the path file [1]. For the gates with multiple turnings one path was generated for each turning movement as shown in Appendix B.

4.3.2 Vehicle File

Vehicle file is a text file with an extension name of '.veh'. In the vehicle file each line represents the movement of one vehicle with the following format: entry time (in second), entry node CORSIM ID, path ID, driver type, vehicle fleet, and vehicle type separated by a space. The relationship between the path file and vehicle file is displayed in Figure 4.3[2]. For the gates with multiple turnings vehicles were assigned with different paths according to the turning movement. The format of the vehicle file is shown in Appendix C.

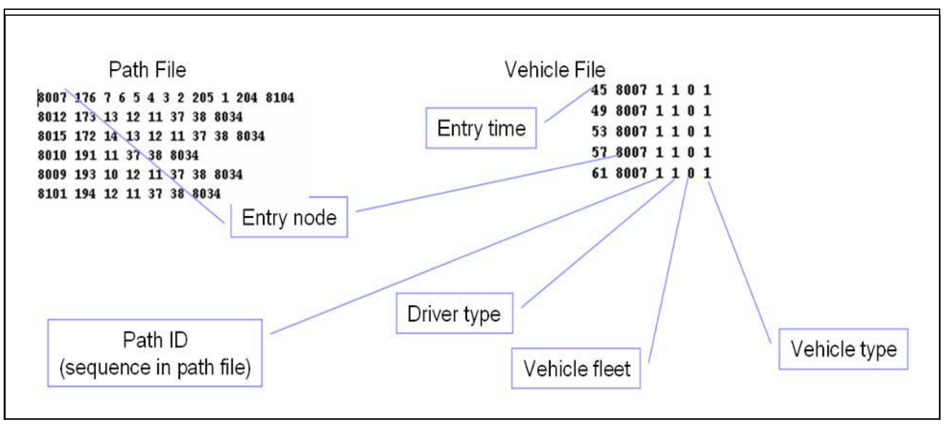

Figure 4.3 Path File and Vehicle File

4.3.3 Base Model Debug

Debugging is the process to correct errors in the model. The first step of debugging was to clear out the error messages and warning messages detected by CORSIM. Most of these errors were the coding errors of intersection properties and link property such as the un-understandable turning movement, violation of the turning pocket length limit, etc. The second step was to observe the animation for abnormal traffic and clear out errors in signal timing plan, detector setting, and lane channelization which cannot be detected by CORSIM error checking. The third step was to run CORSIM with path file and vehicle file and check out the errors in path ID and the miss-matching between path file and vehicle file.

4.3.4 Initial ERP

The initial ERP follows the 'nearest gate' rule. Evacuating vehicles head to the gate nearest (intuitively and geographically closest) to the parking lots where they are parked at the beginning of the evacuation. As shown in Figure 4.4, the vehicles will evacuate through the gates with the same color as the parking lots. The detailed traffic evacuation route for each parking lot is displayed in Appendix B.

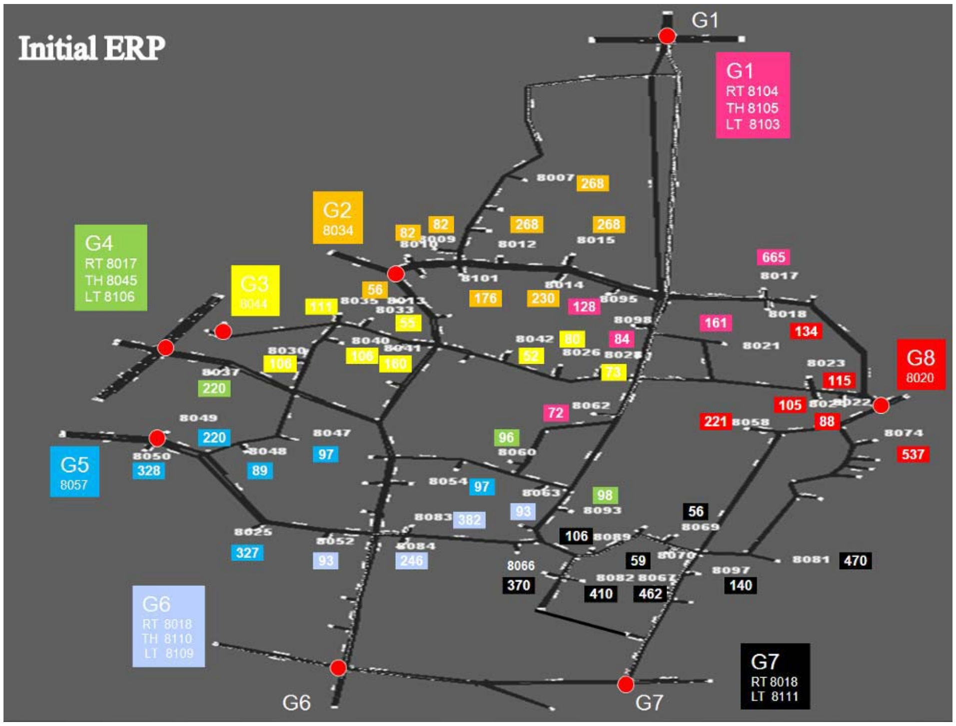

Figure 4.4 Initial ERP —Evacuating through the Nearest Gate

Through TRAFUD animation of TISIS/CORSIM, the clearance time of each gate was observed and recorded. Among the eight gates, Gate 4 and 5 had the shortest clearance time of about half an hour, and Gate 7 had the longest clearance time of about Two hours. The NCT of the whole network resulted to be 123 min as shown in Table 4.6.

Table 4.6 Evacuation Times of Initial ERP

Gate	Gate Location	Number of Vehicles Evacuated	Gate Clearance Time (min)
Gate 1	George Perry St. @ Highway 182	1110	60
Gate 2	College view St. @ Highway 12 ramp	1430	54
Gate 3	Barr Ave. /University Dr.	743	39
Gate 4	Russell St. @ Highway 182	690	30
Gate 5	Bully Blvd. /Roger St. @ Robert L Dr.	972	31
Gate 6	Stone Blvd. @ Blackjack Rd.	721	40
Gate 7	Hardy Rd. @ Blackjack Rd.	2073	123
Gate 8	East Lee Blvd. @ Barr Ave.	1200	54
	Network Clearance Time (NCT) : 123 min.		

A bottleneck existed in Gate 7 located at the intersection of Hardy Road and Blackjack Road. The area nearby has eight parking lots as shown in Figure 3.6. As stated before, a total of 8,939 evacuate vehicles are to be evacuated in this thesis, and the total number of outbound lanes is nine, so in average one outbound lane is expected to evacuate 1,000 vehicles. The number of outbound vehicles projected to leave through Gate 7 was 2,073 as shown in Table 4.6. Meanwhile, the intersection at Gate 7 is signalized and the capacity of the outbound approach is smaller than an un-signalized with on inbound traffic.

To remove the bottleneck of Gate 7 would be to maneuver a portion of the evacuating vehicles parked close to Gate 7 so that they would evacuate through other gates.

Table 4.7 Vehicles Evacuated through Gate 7 -- Initial ERP

	Parking Lot Name	**Parking Lot CORSIM ID**	**Parking Service Capacity**	**Street Name of Lot Exit**
1	Allen E Parking Lot	8089	106	Presidents Circle
2	Hand Lab Parking Lot	8069	56	Marrill Rd.
3	Morrill RD Parking Lot	8070	59	Marrill Rd.
4	Mccomas Parking Lot 2	8082	410	Hardy Rd **.**
5	GreenhouseP Parking Lot	8066	370	Magruder St.
6	Mccomas Parking Lot 1	8067	462	Hardy Rd.
7	Music Parking Lot	8097	140	Hardy Rd.
8	Eckie's Parking Lot	8081	470	Hardy Rd**.**
Total			2073	

CHAPTER V

EVACUATION TRAFFIC MANAGEMENT PLAN

Based on the base model and the initial ERP, traffic management plan development was conducted under the three traffic management scenarios defined in Chapter 3.1. Iterations of improved ERPs were conducted targeting at minimizing NCT and balancing the clearance times of all the university gates.

Once being guided by a pre-assigned route plan, the drivers would be inclined to disregard the stop signs and yield signs. Considering this situation, all stop signs and yield signs on campus were disabled in the TRAFED (platform of TSIS/CORSIM for editing). The only signal on campus located on Bully Boulevard at Stone Boulevard is currently arranged to be turned to flash yellow light mode during emergency situation in the field. In TRAFED the signal control of this intersection was coded as no control to approximate the flash mode for CORSIM has yet a satisfying algorithm for flash signals.

The step of disabling stop-signs and yield-signs are important because stop-signs and yield-signs were found in this thesis to have significant effect on NCT in CORSIM. Two comparison simulation runs were conducted on the ERPs before and after disabling stop signs and yield signs. Each case was tested on the same network but only with and without stop signs and yield signs. The NCT of ERP _S1 was 85 minutes with the stop signs and yield signs while it decreased 53% to 40 minutes after disabling the stop signs and yield signs. In the second case of ERP _S2, the NCT decreased 72% from 79 minutes to 22 minutes after deleting stop signs and yield signs as shown in Table 5.1.

Table 5.1 Comparison of NCTs of Networks with and without Stop Signs and Yield Signs

Gate	ERP_S1		ERP_S2	
	With Stop Sign and Yield Sign	Stop Sign and Yield Sign Disabled	With Stop Sign and Yield Sign	Stop Sign and Yield Sign Disabled
Gate 1	1:01:27	0:37:29	0:54:22	0:21:15
Gate 2	1:05:00	0:30:33	0:43:27	0:19:36
Gate 3	1:12:52	0:39:13	0:45:25	0:19:07
Gate 4	1:25:12	0:39:35	0:28:55	0:19:33
Gate 5	0:55:08	0:39:18	0:45:51	0:19:32
Gate 6	0:57:25	0:32:29	0:23:32	0:18:33
Gate 7	0:34:16	0:36:35	0:25:21	0:20:50
Gate 8	1:16:27	0:36:07	1:19:25	0:21:07
NCT(min)	85	40	79	22

This decreasing of NCT is understandable. In reality at each stop sign all the vehicles will decelerate, stop, check the acceptable gap, make the decision to move, and then accelerate. The process will take less time if the driver does not have to stop while he/she can make the judgment while driving. In CORSIM vehicles will be checked with algorithms of stop-sign and yield-sign when the intersection is coded with stop-sign and yield-sign. If no stop-sign or yield-sign coded, the vehicles will be discharged at the intersections if the gap requirements which are specified by the driver behavior parameters such as the acceptable gap of oncoming traffic are satisfied. The gap of the gate clearance time differs because where there are more stop signs in the path, the gap of with and without stop/yield sign will be bigger.

This thesis is not intended to exam how well the CORSIM stop-sign and yield-sign algorithms work as long as it demonstrates the beneficial aspect of having a pre-planned ERP. Furthermore, CORSIM developer will be noticed to exam their stop/yield sign models so that driver behavior would be more representative in emergency evacuations.

5.1 SCENARIO 1

Scenario 1 has neither contra flow operation nor adjustment in gate signal controls. Hence, this scenario evaluated the base condition which includes the bottlenecks identified in the base model. Evacuees from the parking lots near Gate 7 and Gate 1 were re-directed to the gates with the best improved NCTs. In determining what parking lots to re-assign, trial-and-error iterations were performed to determine what gate the vehicles to access and through what paths.

During the iterations of the trial-and-error and manual adjustment to approach the acceptable ERP, very often new problems emerged elsewhere in the network when old problems were solved. Among those, four typical problems were summarized as: wrong evacuation gate, traffic blocked between approaches, storage blocking and devious traffic, as displayed in Figure 5.1 through 5.4.

An example of the wrong evacuation gate problem was found at BS Hood Road where the evacuating vehicles of McArthur Parking Lot 1 backed up southbound toward

Gate 3 while the northbound toward Gate 2 was already cleared up as shown in Figure 3.3. The solution for this problem was to re-assign the vehicles of this parking lot to evacuate through Gate 2. In the path file, the code that controls the path for this lot was changed accordingly.

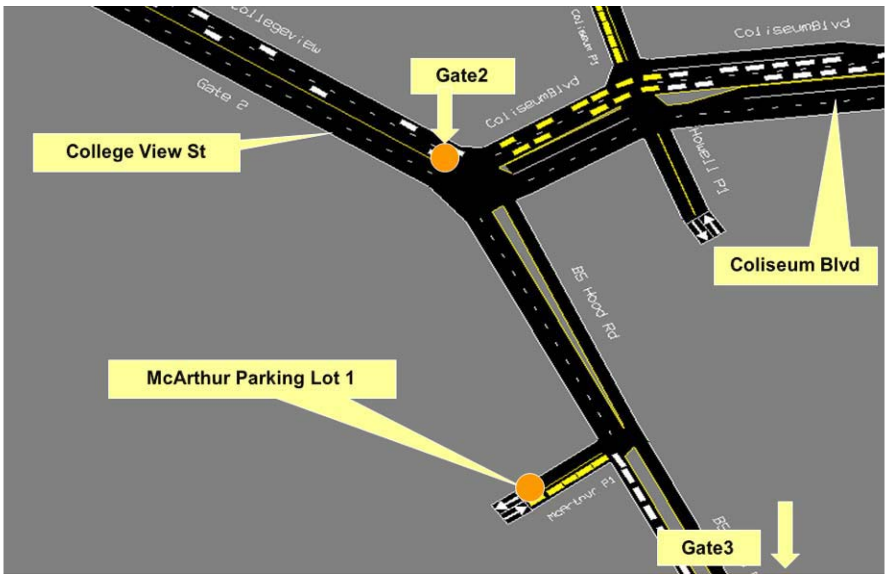

Figure 5.1 Problem Encountered in Iterations of ERP 1--Wrong Evacuation Gate

The example of the traffic blocked between approaches problem existed at the intersection of Stone Boulevard and Bully Boulevard. The south part of Stone Boulevard was not fully utilized because the vehicles coded to go through this path from Greenhouse parking lot to Gate 6 were blocked by the westbound vehicles on Bully Boulevard, and they could not exit the parking lot, as shown in Figure 5.2. The straight forward solution was to add one more westbound lane on Bully Boulevard east of Stone Boulevard, which can be achieved through contra flow operation. In Scenario 1, a circuitous -- to direct the vehicles from another parking lot (Thompson Parking lot) to use south Bully Boulevard -- was used to add more utilization to Stone Boulevard instead since no contra flow is allowed.

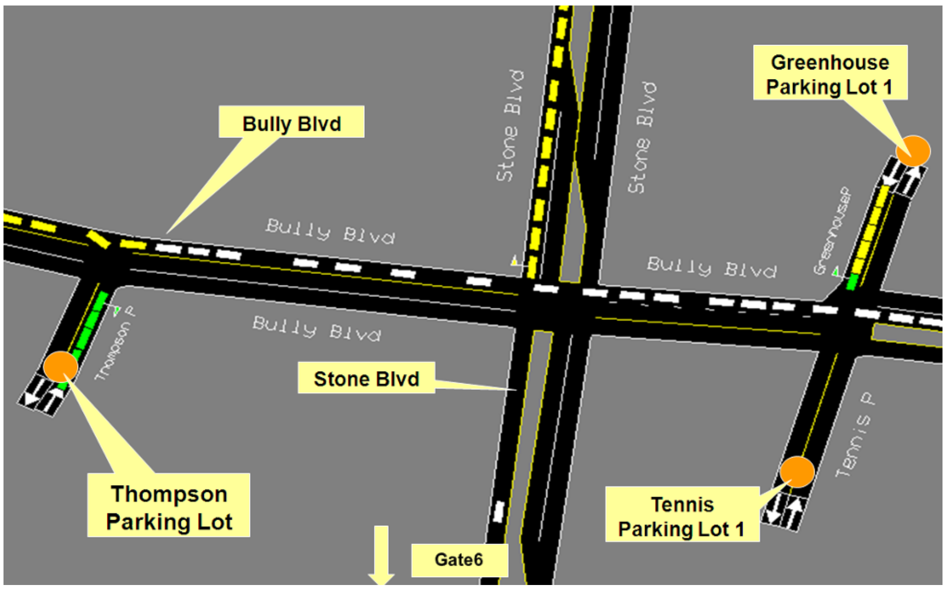

Figure 5.2 Problem Encountered in Iterations of ERP 2--Traffic Blocked Between Approaches

The problem of storage blocking happened at the Barr Avenue crossing BS Hood Road-- the through traffic was blocked by left turn traffic. The left turning vehicles on Barr Avenue were backed up from the south of B S Hood Road when the left turn storage bay was full of vehicles. The flagged green vehicle on Barr Avenue which was waiting to enter the left turn bay blocked the white vehicle behind it and the through traffic on Barr Avenue was stopped as shown in Figure 5.3. In this case, the solution could be either to add one more lane or to re-assign another path for any of the two traffic streams to avoid the conflict.

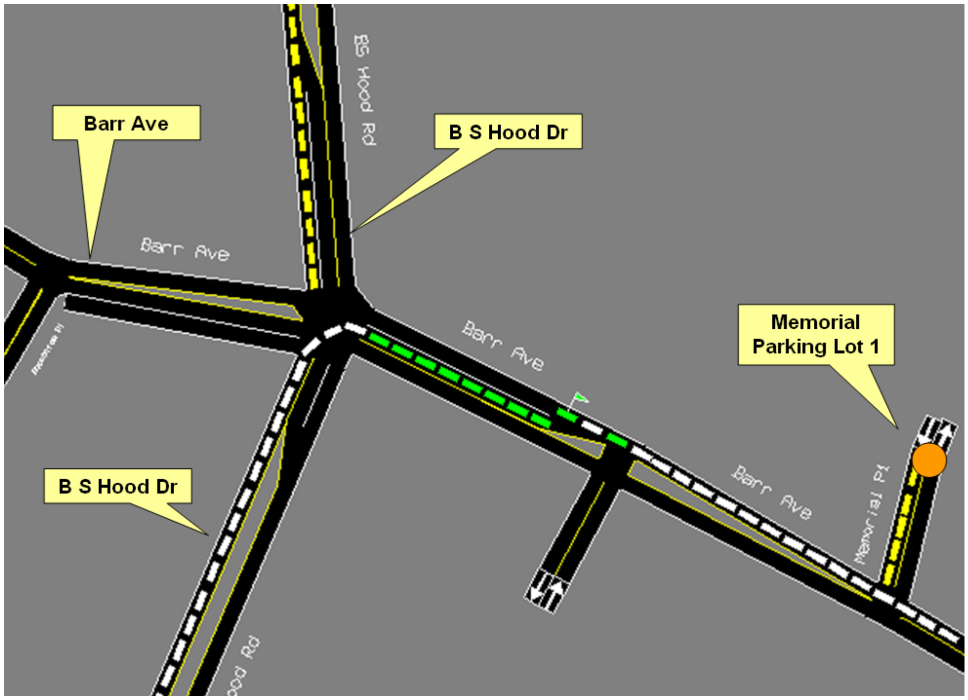

Figure 5.3 Problem Encountered in Iterations of ERP 3-- Storage Blocking

The devious traffic problem was identified at the intersection of Stone Boulevard and BS Hood Road where southbound vehicles intersected with northbound vehicles as shown in Figure 5.3. From the viewpoint of minimizing NCT, this is devious traffic. This kind of problem happened when trying to maneuver vehicles of a small parking lot to evacuate at a not-so-close gate in order to let vehicles from a big parking evacuate through the this gate. The potential assumption was that all the vehicles in the same parking lot would head to the same gate. If this maneuver is resulted to be not contributive to the NCT, it should be avoided. The solution was to redirect the southbound vehicle to go through a northern gate, while redirect the northbound vehicles to a southern gate.

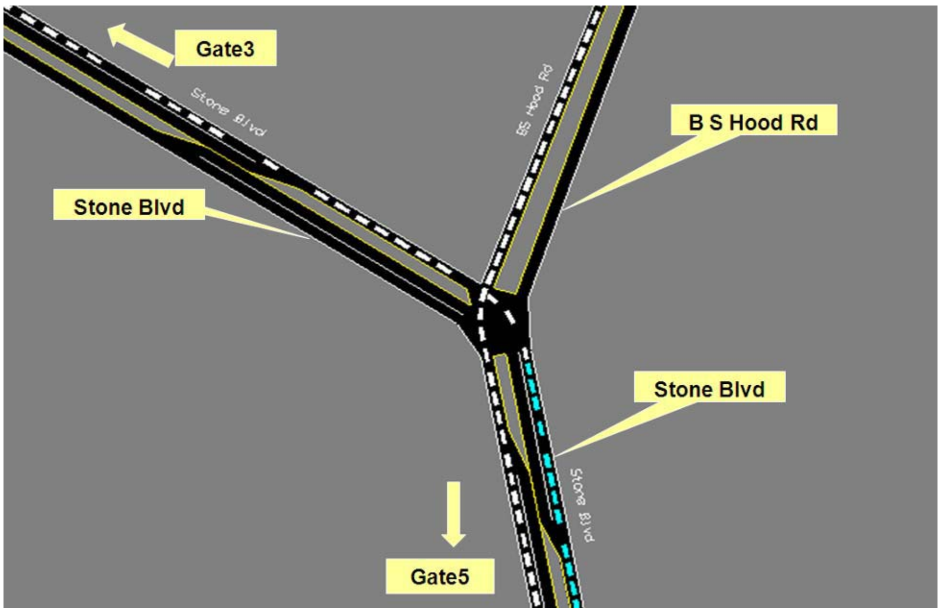

Figure 5.4 Problem Encountered in Iterations of ERP 4- -Devious Traffic

Through iterations of trial-and-error of combinations of parking lots, routes and gates, the final ERP of Scenario 1 with available shortest NCT was achieved. The signal of stopping criterion was completing 30 iterations.

The final ERP of Scenario 1 is shown in Figure 5.5. In comparison of the initial ERP, among the 8,939 evacuating vehicles of the 48 parking lots, 2,556 vehicles of 17 parking lots were re-directed. 831 vehicles were directed away from Gate 7. As a result, the bottleneck at Gate 7 was removed and the gate balance was improved. The detailed change of the ERPs of Scenario 1 from the initial ERP is shown in Table 5.2.

Through observing the TRAFVU animation of, the clearance time of each gate was observed, and the network NCT resulted to be 40 minutes. The evacuation time of each gate are recorded in Table 5.4. The evacuation routes of all the parking lots for Scenario 1 are listed in the path file in Appendix D.

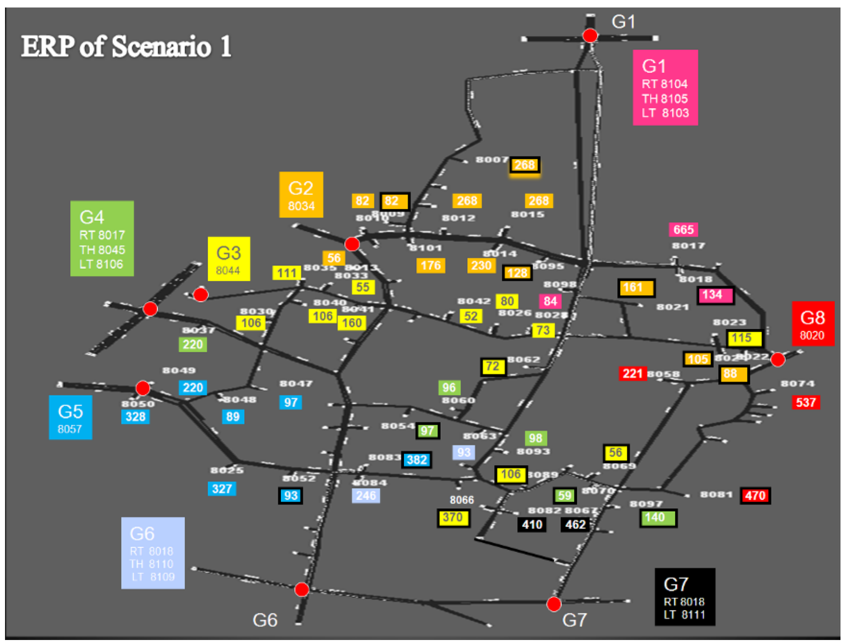

Figure 5.5 ERP of Scenario 1

Note: The parking lots with a white edge on the capacity rectangle were re-directed.

Table 5.2 Comparison of ERPs of Base Model and Scenario 1

Parking Lot CORSIM ID	Parking Service Capacity	Parking Lot Name	Street Name of Lot Exit	Initial ERP		Scenario 1	
				Evacuate Gate	Travel Distance (mile)	Evacuate Gate	Travel Distance to the Evacuation Gate (mile)
8021	161	Suttle Parking Lot	Barr Ave.	1	0.7	2	0.6
8062	72	Hull Parking Lot	George Perry St.	1	0.8	3	0.6
8095	128	Evans Parking Lot 1	Coliseum Blvd.	1	0.6	2	0.3
8054	97	Dorman Parking Lot	Creelman St.	5	0.5	4	0.5
8052	93	Thompson Parking Lot	Bully Blvd.	6	0.3	5	0.3
8083	382	Greenhouse Parking Lot 1	Bully Blvd.	6	0.3	5	0.4
8069	56	Hand Lab Parking Lot	Marrill Rd.	7	0.3	3	1
8070	59	Morrill RD. Parking Lot	Marrill Rd.	7	0.3	4	0.8
8081	470	Eckie's Parking Lot	Hardy Rd.	7	0.4	8	0.5
8089	106	Allen E Parking Lot	Presidents Circle	7	0.4	3	0.9
8097	140	Music Parking Lot	Hardy Rd.	7	0.2	4	0.9
8018	134	Ruby Parking Lot	Coliseum Blvd.	8	0.3	1	0.6
8022	88	Sessums Parking Lot	Barr Ave.	8	0.1	2	0.5
8023	115	Critz Parking Lot	Barr Ave.	8	0.1	3	0.6
8024	105	Hilbun Parking Lot	Barr Ave.	8	0.1	3	0.6
Total	2206						

Table 5.3 Evacuation Times of Scenario 1

Gate Number	Gate Location	Number of Vehicles Evacuated	Gate Clearance Time (min)
Gate 1	George Perry St. @ Highway 182	883	35
Gate 2	College view St. @ Highway 12 ramp	1807	31
Gate 3	Barr Ave. /University Dr.	1293	29
Gate 4	Russell St. @ Highway 182	707	37
Gate 5	Bully Blvd. /Roger S.t @ Robert L Dr.	1533	39
Gate 6	Stone Blvd. @ Blackjack Rd.	616	33
Gate 7	Hardy Rd. @ Blackjack Rd.	872	34
Gate 8	East Lee Blvd. @ Barr Ave.	1228	36
	Network Clearance Time: 39min.		

From Table 5.3, the bottleneck of the final ERP of Scenario 1 seems move to Gates 4 and 5, for they have the highest clearance time. This was a large number of vehicles parked around Gate 7 were redirected here. Further improvement would require more capacity of the key roads and gates, which can be achieved in Scenarios 2 and 3.

5.2 SCENARIO 2

As defined in Chapter 3.1.1, Scenario 2 is a contra flow operation without modifying the signal timing plans at the university gates. In the ERPs of Scenario 2 the following features were addressed:

- Add more lanes to outbound links to implement contra flow operation, the number of lanes added equal to the number of inbound lanes at the same segment;
- Keep signal controls at the university gates unchanged;

- The only signal on campus, which is located on Bully Boulevard at Stone Boulevard, is turned to flash operation, as currently arranged for emergency;
- Disable all the stop signs and yield signs on campus.

In contra flow operation, the gate clearance times decreased significantly in different degrees. Similar to the process in Scenario 1, iterations of ERPs were conducted to achieve best improved NCT and best balance of clearance time among the gates.

In the trial-and-error iterations, two aspects of lane reversal were found contributive to the decreasing of NCT. One is the increased capacity of lanes, and the other is the opportunity to direct traffic of different movements to use the fixed lanes separately which would avoid mutual-blocking.

An example is on Bully Boulevard east of Stone Boulevard where was identified to have a problem of traffic blocked between approaches in Scenario 1. In Scenario 2, contra flow design allowed one more lane on this section, upon which three different traffic streams can use their designated lanes. Evacuees form node 114 through node 94, 60 toward node 61 used the right most lanes, the vehicles from node 93 through 60 toward 61 used the middle lane, and the vehicles from node 115 through the same section used the left most lane as shown in Figure 3.7 and Table 3.7. In visualization the traffic moved obviously faster than in Scenario 1 and the blockage between each other in Scenario 1 was eliminated. Such this bottleneck in Scenario 1 was removed in a better way compared with redirecting the traffic to other routes which was the solution in Scenario 1.

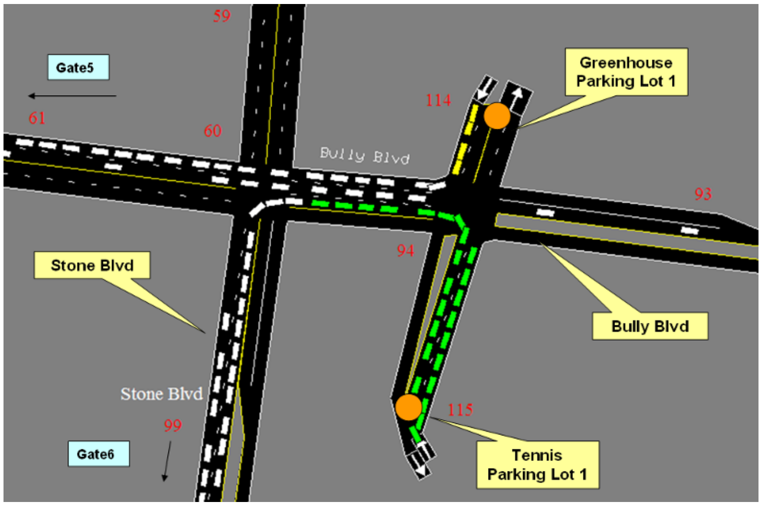

Figure 5.6 Contra flow Design on Bully Boulevard

In addition to adding reversal lanes, two locations of the network were modified in order to mimic the evacuation traffic. One of which is on the North Entrance Rd, and the other is on the Presidents Circle.

The George Perry Road is the immediate approach to Gate 1 at US Highway 182, and the lane configuration is a divided four lane road with two lanes on both directions. In contra flow design, the inbound two lanes used as outbound lanes, and the road should have been configured as two links with two lanes on both directions. However, in running CORSIM, Path-Following errors were identified, and cannot be solved even by McTrans (TSIS/CORSIM developer). In this case, the outbound four lanes in contra flow were designed as four individual outbound links as shown in Figure 5.6.

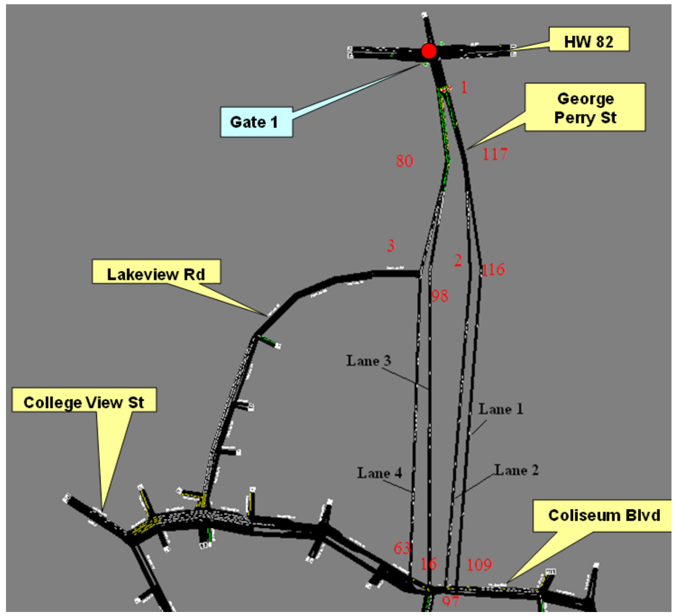

Figure 5.7   Contra flow Design of Gate 1

In order to represent the lane specification, another special design was used at the Presidents Circle between Bully Boulevard and Magruder Street. As shown in Figure 5.7, The traffic coming from node 74 and 102 toward node 71 were designed to use the right most lane while the traffic from node 102 toward node 93 were designed to use the left lane. Node 73 and 79 were actually one node in the real network, the split at this point was to diminish unwanted lane changes at the link to node 72. Only in this way the vehicles in CORSIM would run in their own lanes and move fast. The NCT can decrease around 5 minutes compared with the non-split design.

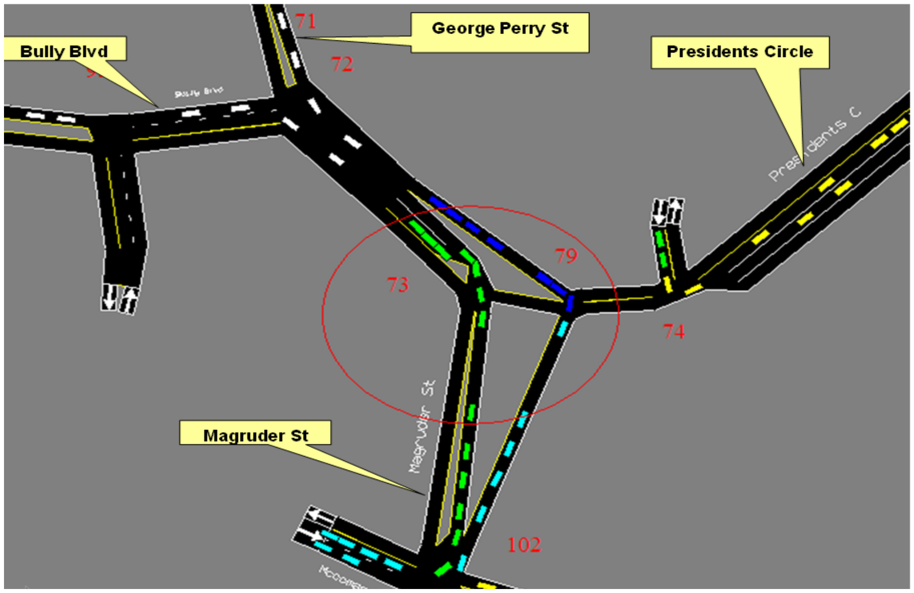

Figure 5.8 Contra flow Design on Presidents Circle

The stopping criterion for Scenario 2 was to complete 30 iterations. The final ERP of Scenario2 is shown in Figure 5.8. Among the 8,939 evacuating vehicles of 48 parking lots, 1,629 vehicles of 13 parking lots were re-directed. Under contra flow, the capacity of Gate 1 and Gate 8 were improved obviously. 321 vehicles were re-directed to Gate 1, and 477vehicles to Gate 8 as shown in Table 5.4. As a result, the bottleneck at Gate 4 and 5 were removed and the gate balance was improved.

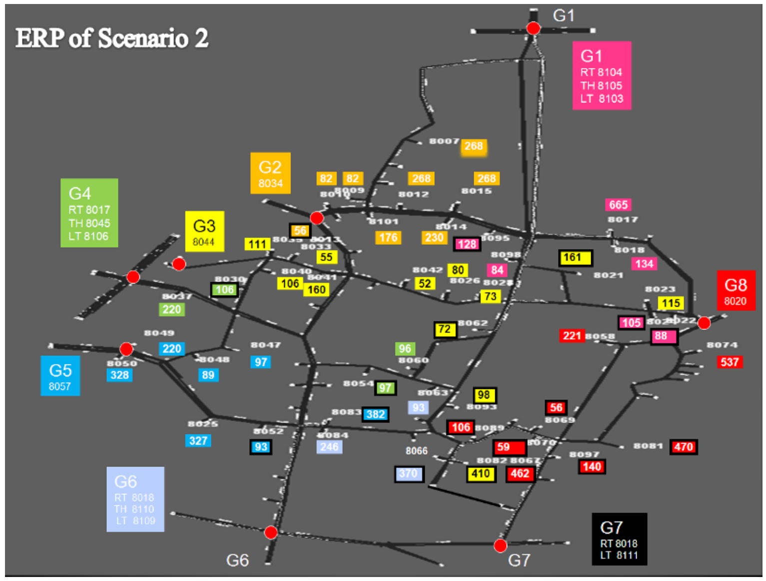

Figure 5.9 ERP of Scenario 2

Note: The parking lots with a white edge on the capacity rectangle were re-directed.

Table 5.4 Comparison of ERPs of Scenario 2 and Scenario 1

Parking Lot CORSIM ID	**Parking Service Capacity**	**Parking Lot Name**	**Street Name of Lot Exit**	**Scenario 1**		**Scenario 2**	
				Evacuate Gate	**Travel Distance (mile)**	**Evacuate Gate**	Travel Distance to the Evacuation Gate
8022	88	Sessums Parking Lot	Barr Ave.	2	0.5	1	0.7
8024	105	Hilbun Parking Lot	Barr Ave.	3	0.6	1	0.8
8095	128	Evans Parking Lot 1	Coliseum Blvd.	2	0.3	1	0.6
8013	56	McArthur Parking Lot 1	B S Hood Rd.	2	0.1	3	0.4
8021	161	Suttle Parking Lot	Barr Ave.	2	0.6	3	0.7
8082	410	Mccomas Parking Lot 2	Hardy Rd.	7	0.3	3	1
8093	98	Allen W Parking Lot	George Perry St.	4	0.6	3	0.8
8030	106	Bos Parking Lot t2	Extension Dr.	3	0.3	4	0.4
8069	56	Hand Lab Parking Lot	Marrill Rd.	3	1	8	0.4
8070	59	Morrill RD Parking Lot	Marrill Rd.	4	0.8	8	0.4
8089	106	Allen E Parking Lot	Presidents Circle	3	0.9	8	0.5
8097	140	Music Parking Lot	Hardy Rd.	4	0.9	8	0.4
8067	116 *	Mccomas Parking Lot 1	Hardy Rd.	7	0.2	7&8	0.5
Total	1629						

Note: * The total parking services is 462 among which 116 vehicles were directed to Gate 8 and the rest 346 vehicles were directed to Gate 7.

The final ERP of Scenario 2 was achieved with the satisfactory network NCT of 21 minutes, and the gaps of the clearance times between the gates are less than 4 minutes as shown in table 3.8. The evacuation routes of all the parking lots for Scenario 2 are listed in the path file in Appendix E.

Table 5.5 Evacuation Times of Scenario 2

Gate	Gate Location	Number of Vehicles Evacuated	Gate Clearance Time (min)
Gate 1	George Perry St. @ Highway 182	1204	21
Gate 2	College view St.@ Highway 12 ramp	1374	19
Gate 3	Barr Ave. /University Dr.	1549	19
Gate 4	Russell St. @ Highway 182	795	19
Gate 5	Bully Blvd. /Roger St @ Robert L Dr.	1350	19
Gate 6	Stone Blvd. @ Blackjack Rd.	616	19
Gate 7	Hardy Rd. @ Blackjack Rd.	346	20
Gate 8	East Lee Blvd @ Barr Ave.	1705	21
	Network Clearance Time: 21 min.		

Compared with Scenario 1 with the NCT of 39 minutes, Scenario 2 has a much smaller NCT of 21 minutes. This result shows that contra flow is contributive to declining the NCT.

5.3 SCENARIO 3

As aforementioned, Scenario 3 is defined as implementing contra flow and also adjusting the signal timing plans at the university gates. The network configuration of Scenario 3 was based on that of Scenario 2. The only difference on the two networks was the gate signal timing plans.

The signal adjustments in Scenario 3 are described as follows:

- Signals at Gate 1 and Gate 4 were adjusted to optimize evacuation capacity at the gates. In TRAFED in the entry of actuated controller properties in the node properties, the Max-Greens of the outbound phase were adjusted to 999 seconds as the top value allowed in CORSIM ;

- Signals at Gate 5 and Gate 8 were not adjusted for no conflict traffic against evacuation traffic that existed;
- The signal located on Bully Boulevard at Stone Boulevard was planned to operate in flashing yellow light mode. However, CORSIM is not able to simulate flash mode operation. In approximation, the signal at this intersection was disabled (code the control type to be 'none' in the intersection properties), and vehicles were controlled by driver behaviors such as turning gap acceptance along with their path assignment in ERP ;
- Signal coordination was performed at Gate 6 and Gate 7 in search of a maximum throughput of the evacuation traffic. The evacuation traffic of Gate 6 and Gate 7 blocked each other because the two intersections are closely located at Blackjack Road (1,700 feet in between.

Several traffic optimization software packages such as Passer, TRANSYT7F and SYNCRO are commonly used to optimize signal timing plans of coordinated intersections. However, none of these could be applicable to the evacuation optimization at the segment of Gate 6 and Gate 7 because their objective functions cannot match. The objectives of these software are limited to optimize progression on the road where both the coordinated signals located, the Blackjack Road in this case, while the objective in this case is to optimize the throughput of the streets intersecting Blackjack Road—Stone Boulevard and Hardy Street.

In this case, a manual method was used to improve the evacuation traffic at Gate 6 and Gate 7 --- to set pre-timed signal coordination and use trial-and-error method to approach the signal timing plan which can optimize the evacuation traffic.

The first step was to calculate the offset between the two intersections. According to the geometric locations, Gate 6 and Gate 7 are about 1700 feet apart. The offset time was calculated to be 39sec, as shown in the formula below:

$t = 1700*3600/5280/v = 39$ (sec)

Where:

t—offset time, second

v—speed, use 30mph.

The second step was to generate an ERP to be test on. The test ERP would be desirable if the volume was close to the final, for the volume would affect the gate clearance time. So the next-to-finish ERP that only signal coordination of Gate 6 and Gate 7 is yet to be done was used.

With the adjustment of the signal timing plan of Gate 1 and Gate 4, the gate clearance time of Gate 1 and 4 decreased to some degree compared with Scenario 2. Meanwhile, the signal control of Gate 6 and Gate 7 were adjusted to a pre-timed timing plan, and randomly selected 55 seconds to be the green time, and set 39 sec offset at Gate 6 as shown in Figure 3.10 and 3.11.

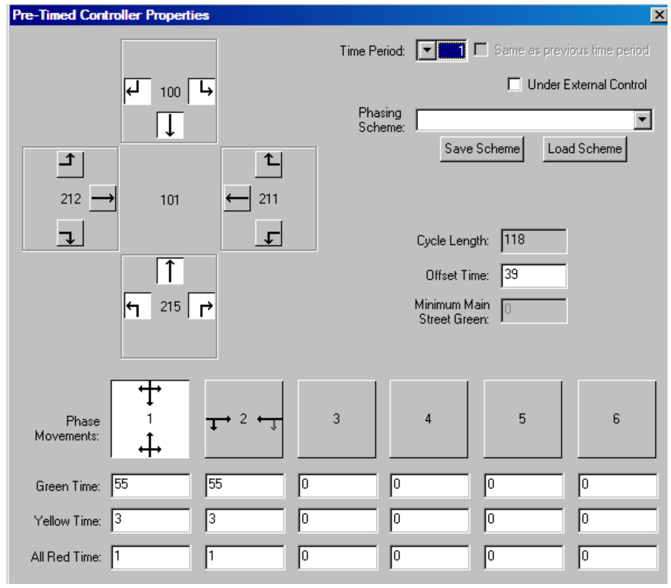

Figure 5.10 Signal Timing Plan of Gate 6 in Scenario 3

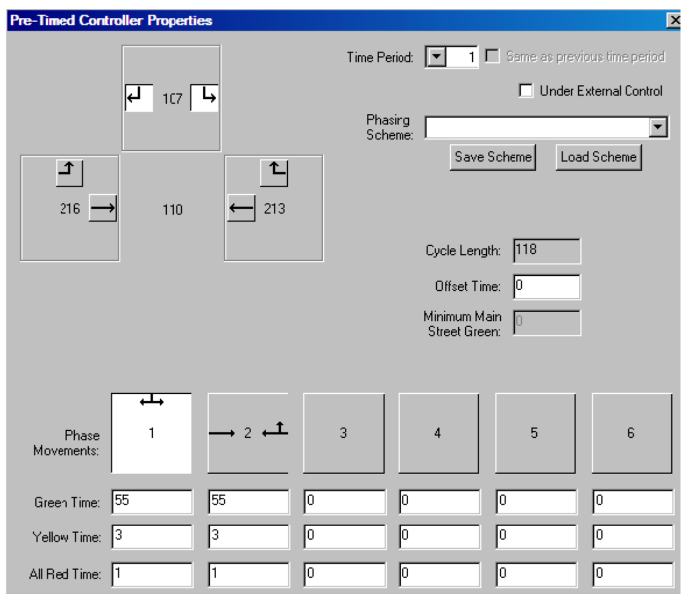

Figure 5.11 Signal Timing Plan of Gate 7 in Scenario 3

The third step was to determine the timing plan of Gate 6 and Gate 7. Combinations of different timing plans at Gate 6 and Gate 7 approaching the best improved NCT were tested on the test ERP. The result is recorded in table 3.9 which shows that test 6 gives the minimal clearance time on both Gate 6 and Gate 7. The signal timing plans of Gate 6 and Gate 7 are set accordingly.

Table 5.6 Trial-and-error Test Records of Green Time on Gate 6 and Gate 7

Sequence	Green Time of Gate 6			Green Time of Gate 7		
	Phase 1 (sec)	**Phase 2** (sec)	**NCT** (min :sec)	**Phase 1** (sec)	**Phase 2** (sec)	**NCT** (min :sec)
1	50	40	17:59	50	40	25:27
2	40	40	19:24	40	40	19:54
3	50	30	15:51	50	30	28:39
4	50	50	18:40	50	50	19:33
5	60	50	17:11	60	50	19:49
6	60	60	18:24	60	60	17:58
7	70	70	17:14	70	70	18:56
8	70	60	16:12	70	60	19:59
9	55	55	17:16	55	55	19:42
10	55	50	18:33	55	50	18:21
11	55	55	18:48	60	50	17:32

After fixing the signal at Gate 6 and 7, some adjustment of path files and vehicle files were conducted in order to balance the NCT of Gate 6 and Gate 7 with other gates. As a result, a test ERP of Scenario 3 was achieved.

Similar to the process in scenario 1and 2, iterations of ERP were performed then to achieve the best improved NCT and balance clearance times among the gates. The final ERP of Scenario3 is shown in Figure 3.11. Among the 8,939 evacuating vehicles, 839 vehicles of 4 parking lots were re-directed.

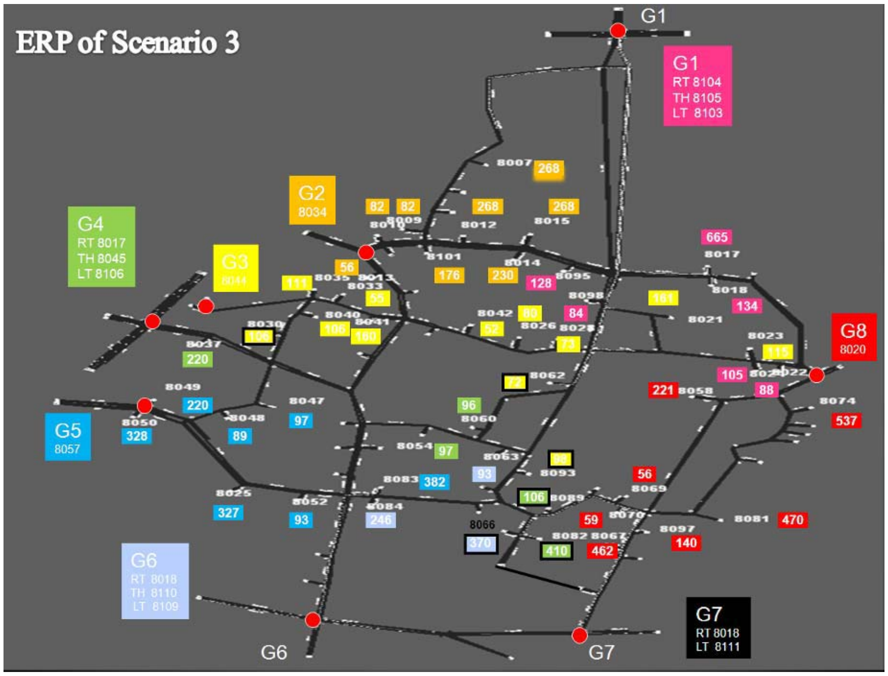

Figure 5.12 ERP of Scenario 3

Note: The parking lots with a white edge on the capacity rectangle were re-directed.

Table 5.7 Comparison of ERPs of Scenario 3 and Scenario 2

Parking Lot CORSIM ID	Parking Service Capacity	Parking Lot Name	Street Name of Lot Exit	Scenario 2		Scenario 3	
				Evacuate Gate	Travel Distance (mile)	Evacuate Gate	Travel Distance to the Evacuation Gate
8030	106	Bos Parking Lot t2	Extension Dr.	4	0.4	3	0.3
8066	271*	Greenhouse Parking Lot	Magruder St.	6	0.6	3&5	0.6
8082	410	McComas Parking Lot 2	Hardy Rd.	3	1	4	0.7
8089	106	Allen E Parking Lot	Presidents Circle	8	0.5	4	0.7
Total	893						

Note: * The total parking services is 370 among which 171 vehicles were directed to Gate 5 and 100 vehicles were directed to Gate 3 and the rest 100 vehicles were directed to Gate 6.

The final ERP of Scenario 3 with a NCT of 20 minutes was derived and the clearance time gaps between the gates are less than 2 minutes as shown in table 5.8. The detailed evacuation routes of all the parking lots for Scenario 3 are listed in the path file in Appendix F.

Table 5.8 Evacuation Times of Scenario 3

Gate	Gate Location	Number of Vehicles Evacuated	Gate Clearance Time (min)
Gate 1	George Perry St. @ Highway 182	1204	20
Gate 2	College view St. @ Highway 12 ramp	1374	19
Gate 3	Barr Ave. /University Dr	1345	18
Gate 4	Russell St. @ Highway 182	1205	19
Gate 5	Bully Blvd. /Roger St. @ Robert L Dr.	1520	19
Gate 6	Stone Blvd. @ Blackjack Rd.	346	19
Gate 7	Hardy Rd. @ Blackjack Rd.	346	19
Gate 8	East Lee Blvd. @ Barr Ave.	1599	20
	Network Clearance Time: 20 min.		

CHAPTER VI

SENSITIVITY ANALYSIS

Calibration and validation are necessary steps in constructing traffic simulation models to ensure the model to be representative. Field data are needed for model calibration and validation. However in this thesis, there was no real evacuation data available. To make up for this deficiency, sensitivity analyses of key CORSIM parameters were conducted and their sensitivities to NCT were evaluated.

In conducting the sensitivity analysis, key parameters were firstly identified, and input ERPs were generated with alternative testing values. The gate clearance times of each testing ERPs were gathered through visualization and analyzed with mathematical methods.

6.1 IDENTIFYING TESTING PARAMETERS

Hundreds of CORSIM parameters might be involved in calibration, and over 30 parameters might be used in calibrating a signalized intersection [(33)]. Through the study of the sensitivity of NETSIM parameters conducted by Li Zhang et al., free flow speed (FFS), discharge headway (DCH), startup lost time (SULT), and time to react to sudden deceleration of lead vehicle (TRSDLV) were identified as high sensitive parameters which had obvious impact on traffic operations [(33)]. These four parameters were selected for sensitivity analysis in this thesis. The definition of the parameters is listed in Table 6.1. In addition, the driver type was also tested in order to obtain a picture of how the different combination of driver types can affect the NCT.

6.2 SENSITIVITY ANALYSIS PROCEDURE

The sensitivity analysis was conducted under 4 steps as follows:

- Step 1 — determine the alternative values for testing parameters

  CORSIM sets values with the most likelihood as default values for all the calibration parameters. In the evacuation traffic management plan development of this thesis, the CORSIM default values were kept unchanged for the four testing parameters. The alternative values to be tested were set up around the CORSIM default values according to traffic experience along with the consideration of the tendency of change in emergency evacuation. For discharge headway, the value of 1.2 second was not tested although intended to because 1.4 second is the minimal acceptable value in CORSIM. The test values are shown in table 6.1.

Table 6.1 Parameters Tested in Sensitivity Analysis

	Parameter Name	Definition (39)	CORSIM Default Value	Base Model Value	Alternative Test Value
1	Time to React to Sudden Deceleration of Lead Vehicle	The amount of time required for a driver to begin to apply braking after his leader has begun a sudden deceleration.	1 sec	1 sec	0.3,0.5, 1.5 ,2.5 (sec)
2	Free Flow Speed	The desired, unimpeded mean speed.	30 mph	20 mph	10,30, 40,60 (mph)
3	Discharge Headway	The mean time gap (headway) between vehicles discharging from a standing queue	1.8 sec	1.8 sec	1.4, 1.6, 2.0, 2.2 (sec)
4	Mean Startup Delay	The delay experienced by the first vehicle in queue when responding to a phase change from red to green.	2.0 sec	2.0 sec	1.4, 1.6, 1.8, 2.2 (sec)
5	Driver Type			20% Type 1, 80% type 10	20% type 10, 80% type 1

- Step 2 — create the CORSIM input files

All the sensitivity tests were based on the same working model which is randomly chosen from one of the ERPs in Scenario 2. New CORSIM input files were generated from the working model through modifying the testing parameters in the TNO file, the TRF file or the vehicle file while other parameters were kept unchanged.

Editing the TNO file is to change the value of the testing parameter in TRAFED. Some parameters can be accessed through an entry in the global entries such as Network Properties or NETSIM Setup where one change can affect all the corresponding variables. For example, TRSDLV can be changed in the lane change entry of NETSIM setup. Otherwise, the values need to be changed link-by-link in link properties or node-by-node in node properties such as FFS, DCH, and SULT. In this case, editing the relative values in text form of the TRF file would be much time-efficient. In this thesis, the TRF files were revised manually. The modification of driver type was made on vehicle file in which the driver type code was revised to iterations of 10, 10, 10, 10, 1 for all consecutive vehicles.

- Step 3 — run CORSIM, and observe the animation for gate clearance time from TRAFED

Normally, the multi-run function in CORSIM is used in order to reduce the random error. In this thesis ten multi-runs were conducted for each testing value and the gate clearance time of each gate was observed in animation.

- Step 4 — data analysis

Three methods were applied to analyze the gate clearance data collected in setp3:

Time differences from the default value were calculated in order to illustrate the degree each gate clearance time changed. This step was used to give a numerical illustration of how the NCT changed with the testing parameters;

Between the two groups of gate clearance times with the testing value and the default value, paired two-tailed T-test was conducted in order to test whether the means of the two groups are statistically different. The null-hypothesis (H0) is that the two groups have statistically the same means at the confidence interval of 95%. It is rejected if the calculated P-value is smaller than alpha—0.05. The number of observation of each test is 80;

Graphs of gate clearance times against the values of the parameters were plotted in order to give a direct picture of the changes;

An evaluation or explanation was given for the sensitivity of each testing parameter according to the above analysis.

6.3 SENSITIVITY ANALYSIS RESULTS

6.3.1 Time to React to Sudden Deceleration of Lead Vehicle (TRSDLV)

From the data recorded in animation of the ERPs with the testing values of TRSDLV, the time difference of gate clearance time varies from 0 to 20.4 minutes when the TRSDLV changes from 0.1 sec to 1.5 sec. The average time differences vary from 1.6 to 11.1 minutes. The NCT of the models with TRSDLV less than 1 second are almost the same. But when TRSDLV increase to 1.5 second, the NCT increase 21% from 24 minutes to 29 minutes; and when TRSDLV increase to 2.5 second, the NCT increase 75% to 42 minutes. The t-test showed that none of the alternative groups has statistically the same means with the default value as shown in table 6.2.

Table 6.2 TRSDLV Table for Sensitivity Analysis

Gate	Gate Clearance Time (min) (mean) Time to React to Sudden Deceleration of Lead Veh (sec)				
	0.3	0.5	1*	1.5	2.5
Gate 1	22.15 (-1.1)	23.24 (0)	23.23	25.15 (1.9)	30.55 (7.3)
Gate 2	16.73 (-2.8)	17.37 (-2.2)	19.52	21.39 (1.9)	23.03 (3.5)
Gate 3	17.32 (-2.1)	17.94 (-1.5)	19.41	22.46 (3.1)	31.19 (11.8)
Gate 4	16.56 (-2.8)	17.51 (-1.9)	19.41	21.37 (2.0)	24.95 (5.5)
Gate 5	23.88 (1.2)	23.62 (0.9)	22.73	23.12 (0.4)	30.04 (7.3)
Gate 6	22.50 (-0.2)	22.08 (-0.7)	22.74	26.85 (4.1)	41.58 (18.8)
Gate 7	14.63 (-6.6)	16.00 (-5.2)	21.22	28.12 (6.9)	41.64 (20.4)
Gate 8	19.01 (-2.1)	18.76 (-2.4)	21.14	25.42 (4.3)	34.94 (13.8)
Average Difference(min)	-2.1	-1.6		3.1	11.1
P(T<=t) two-tail (95% confidence level)	1.31969E-11	1.07508E-09		4.04471E-21	7.40936E-27
H0: mean(T) = mean(T0)	Reject	Reject		Reject	Reject
Statistically different from default	Not Same	Not Same		Not Same	Not Same
NCT	24 (0)	24(0)	24	29(5)(+21%)	42(18)(75%)

Notes: * is default value.
(XX) = Time difference from default value.

From the X-Y scattered chart of TRSDLV against gate clearance times shown in figure 6.1, the gate clearance time increase obviously with TRSDLV. The detailed data are recorded in Appendix G.

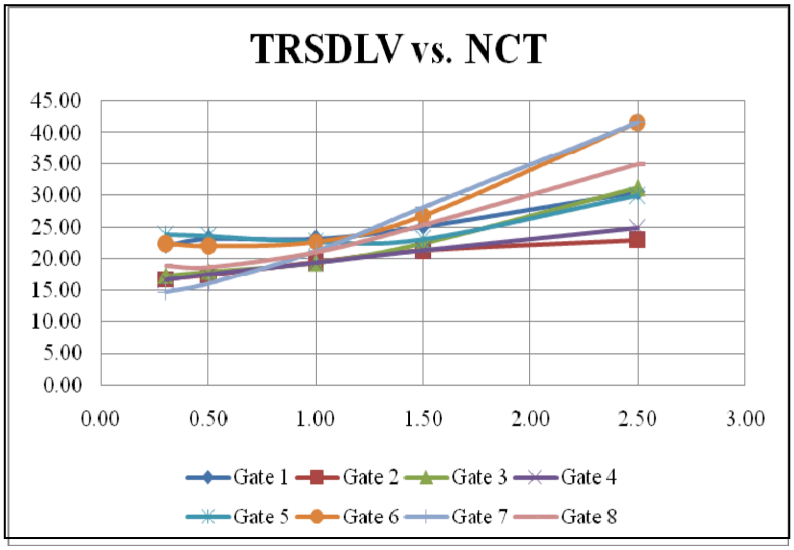

Figure 6.1 TRSDLV Graph for Sensitivity Analysis

Based on the analysis above, the gate clearance time is concluded to be positively relative to TRSDLV. It is understandable that TRSDLV is sensitive to NCT because in evacuation when the drivers are be more alert to the sudden change of the vehicles ahead, they can follow the leading vehicle more promptly and the entire evacuation can have a less NCT.

6.3.2 Free Flow Speed (FFS)

From the simulations of testing ERPs of various FFSs, the time difference of gate clearance time is found varying from 0 to 11.0 minutes. The average time differences vary from 0 to 5.9 minutes. The NCT of the models with FFS of 10 mph is 38% higher than the default and approach the default when FFS increases up to 30 mph. When FFS increases up to 60 mph the NCT will decrease slowly for 4%. The t-test showed that none of the alternative groups has statistically the same means with the default value at 95% confidence level when FFS increase from 10 mph to 60 mph as shown as listed in Table 6.3.

Table 6.3 FFFS Table for Sensitivity Analysis

Gate	Gate Clearance Time (min)				
	Free Flow Speed (mph)				
	10	20*	30	40	60
Gate 1	27.97(4.7)	23.23	23.20(0)	22.56(-0.7)	22.67(-0.6)
Gate 2	22.12(2.6)	19.52	19.46(-0.1)	19.22(-0.3)	19(-0.5)
Gate 3	28.02(8.6)	19.41	17.99(-0.1)	17.17(-2.2)	16.89(-2.5)
Gate 4	24.55(5.1)	19.41	18.43(-1.0)	18.34(-1.1)	18.02(-1.4)
Gate 5	26.82(4.1)	22.73	20.62(-2.1)	20.40(-2.3)	20.33(-2.4)
Gate 6	24.34(1.6)	22.74	21.72(-1.0)	22.65(-0.1)	21.27(-1.5)
Gate 7	32.22(11.0)	21.22	19.12(-0.5)	17.94(-3.3)	18.21(-3.0)
Gate 8	30.26(9.1)	21.14	20.60(-1.0)	20.42(-0.7)	20.27(-0.9)
Average Difference	5.86		-1.03	-1.34	-1.59
P(T<=t) two-tail(95% confidence level)	2.73968E-26		6.41546E-10	9.5005E-13	4.75774E-17
H0: mean(T) = mean(T0)	Reject		Reject	Reject	Reject
Statistically different from default	Not Same		Not Same	Not Same	Not Same
NCT	33 (9)(+38%)	24	24(0)	23(-1)(-4%)	23 (-1)(-4%)

Notes: *= default value.
(XX) = Time difference from default value.

From the X-Y scattered chart of FFS against gate clearance time, a clear negative relationship was displayed in Figure 6.2. The detailed data are recorded in Appendix H.

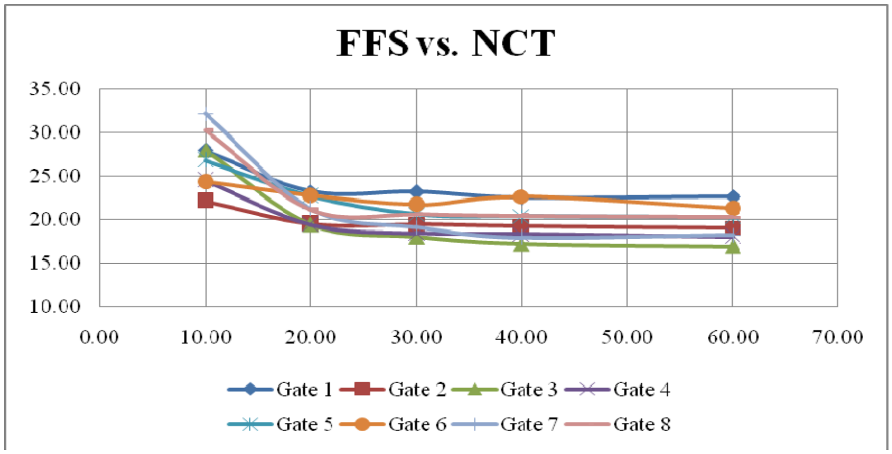

Figure 6.2 FFS Graph for Sensitivity Analysis

Based on the analysis above, it is concluded that FFS is negatively related to the gate clearance time. This founding is consistent with common sense—when vehicles can move faster the evacuation time can be shorter.

6.3.3 Discharge Headway (DCH)

From the sensitivity tests of DCH, the time difference of gate clearance time of the testing models varies from 0 to 1.7 minutes which is relatively narrow. The average time differences vary from 0.2 to 0.5 minutes. The NCT of all the testing value are close to each other with the difference up to 1 minute (4%). The t-tests show that the mean of gate clearance time of the testing value of 2.2 is statistically the same with the default value at 95% confidence level as described in table 6.4.

Table 6.4 Discharge Headway Table for Sensitivity Analysis

Gate	Gate Clearance Time (min) Discharge Headway (sec)				
	1.4	1.6	1.8	2*	2.2
Gate 1	22.86(-0.7)	23.22(-0.4)	23.23(-0.4)	23.59	23.55(0)
Gate 2	19.51(0)	19.39(-0.2)	19.52(0)	19.55	19.58(0)
Gate 3	18.92(-0.8)	18.95(-0.7)	19.41(-0.3)	19.68	20.23(0.6)
Gate 4	18.78(-1.1)	19.21(-0.7)	19.41(-0.5)	19.90	19.86(0)
Gate 5	21.56(-1.7)	21.85(-1.4)	22.73(-0.5)	23.25	24.03(0.8)
Gate 6	22.36(-1.2)	22.34(-1.2)	22.74(-0.8)	23.54	23.73(-0.2)
Gate 7	22.23(0.3)	21.58(0.7)	21.22(0.3)	20.93	20.75(0)
Gate 8	21.47(-0.4)	21.09(-0.5)	21.14(-0.3)	21.15	21.14(0.2)
Average Difference(min)	-0.5	-0.5	-0.3		0.2
P(T<=t) two-tail (95% confidence level)	0.001	0.00029	0.013		0.2225
H0: mean(T) = mean(T0)	Reject	Reject	Reject		Accept
Statistically different from default	Not Same	Not Same	Not Same		Same
NCT	23 (-1) (-4%)	23(-1) (-4%)	24(0)	24	25(1) (4%)

Notes: * = default value.
(XX) = Time difference from default value.

The X-Y scattered chart of DCH against gate clearance time shows five of the gates clearance time increase with the DCH while the other three decreases as shown in Figure 6.3. All the three methods show that the change of gate clearance time with the DCT is unobvious. The NCT of all the testing value are close to each other with up to 1 minute (4%) difference. Therefore it was concluded that DCH is not sensitive to NCT. The detailed data are recorded in Appendix I.

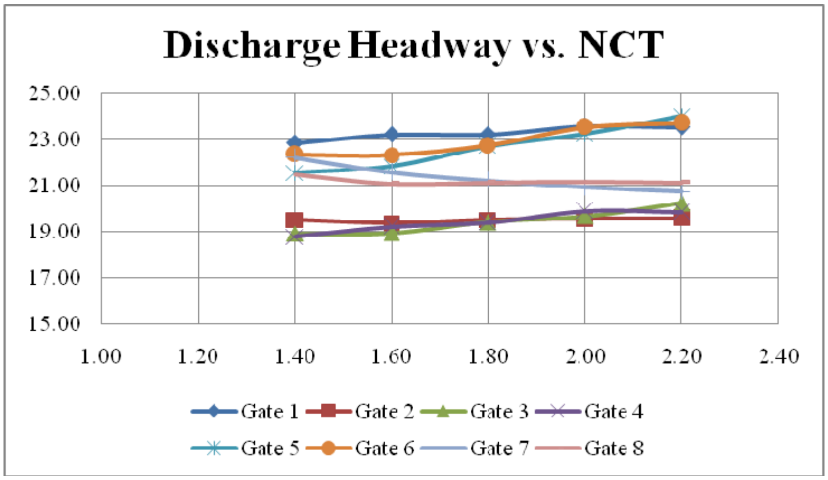

Figure 6.3 DCH Graph for Sensitivity Analysis

From the visualization of the ERPs, the evacuation traffic is running smoothly and the leading vehicles of the streams normally do not stop at the on campus intersections. This explained why the NCT is not sensitive to DCH– the DCH cannot have enough opportunity to control the vehicles because the vehicles do not stop so often as in normal conditions.

6.3.4 Startup Lost Time (SULT)

From the sensitivity tests of SULT, the time difference of gate clearance time varies from 0 to 2.0 minutes when the value of startup delay varies from 1.4 sec to 2.2 sec. The average time differences vary from 0 to 0.4 minutes. The t-tests show that two testing groups have the same means of the default model at 95% confidence level as described in table 6.5.

Table 6.5 SULT Table for Sensitivity Analysis

Gate	Gate Clearance Time (min) (mean)				
	Start Up Lost Time (sec)				
	1.40	1.60	1.80	2.00*	2.20
Gate 1	23.82(0.6)	24.88(1.6)	24.12(0.9)	23.23	24.10
Gate 2	18.23(-1.3)	18.28(-1.2)	17.57(-2.0)	19.52	19.50(0.9)
Gate 3	19.43(0)	19.33(-0.1)	19.22(-0.2)	19.41	19.58(0.2)
Gate 4	18.83(-0.6)	19.21(-0.2)	19.22(-0.2)	19.41	20.00(0.6)
Gate 5	20.93(-1.8)	21.61(-1.1)	21.45(-1.3)	22.73	21.24(-1.5)
Gate 6	22.34(-0.4)	22.69(0)	22.40(-0.3)	22.74	22.74(0)
Gate 7	21.27(0.1)	21.48(0.3)	21.38(0.2)	21.22	21.38(0)
Gate 8	21.10(0)	21.21(0.1)	21.34(0.2)	21.14	21.15(0)
Average Difference (min)	-0.4	-0.1	-0.3		0.0
P(T<=t) two-tail (95% confidence level)	0.00087	0.52	0.027		0.74
H0: mean(T) = mean(T0)	Reject	Accept	Reject		Accept
Statistically different from default	Not Same	Same	Not Same		Same
NCT	24(0)	25(1) (4%)	25(1) (4%)	24	23(-1) (-4%)

Notes: * = Default value.
(XX) = Difference from default value.

No obvious changing trend can be observed in the X-Y scattered chart of SULT against gate clearance time as shown in Figure 6.4.

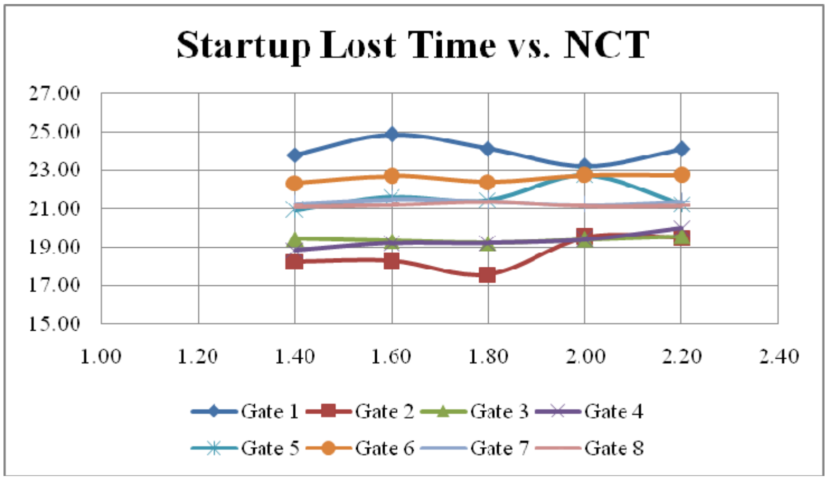

Figure 6.4 SULT Graph for Sensitivity Analysis

Therefore, it can be concluded that SULT is not sensitive to NCT. This founding is also consistent to common sense in which the leading vehicles seldom stop, so the SULT is not controlling the clearance time. The detailed data are recorded in Appendix J.

6.3.5 Driver Type

From the sensitivity tests of Driver Type, the time difference of gate clearance time varies from 3.9 to 17.4 minutes. The average time difference is 9.1 minutes. The t-tests show that two testing groups have different means of the default model at 95% confidence level as described in table 6.6.

Table 6.6 Driver Type Table for Sensitivity Analysis

Gate	Gate Clearance Time (min) (mean)	
	Low Aggressiveness	High Aggressiveness
Gate 1	30.18 (6.94)	23.23
Gate 2	23.47(3.95)	19.52
Gate 3	29.39(9.98)	19.41
Gate 4	28.05(8.64)	19.41
Gate 5	29.47(6.75)	22.73
Gate 6	40.13(17.39)	22.74
Gate 7	27.56(6.34)	21.22
Gate 8	33.74(12.61)	21.14
Average Difference	9.10	
P(T<=t) two-tail	2.66983E-32	
H0: mean(T) = mean(T0)	Reject	
Statistically different from default (95% confidence level)	Not the same	
NCT	41 (+71%)	24.00

The X-Y scattered chart of driver type against gate clearance time presents the obvious gaps of the gate clearance times with different configurations of driver type as shown in Figure 6.5. All the analyses show that the gate clearance time change obviously with the change of driver type. Therefore it is concluded that the driver type is sensitive to NCT. The detailed data are recorded in Appendix J.

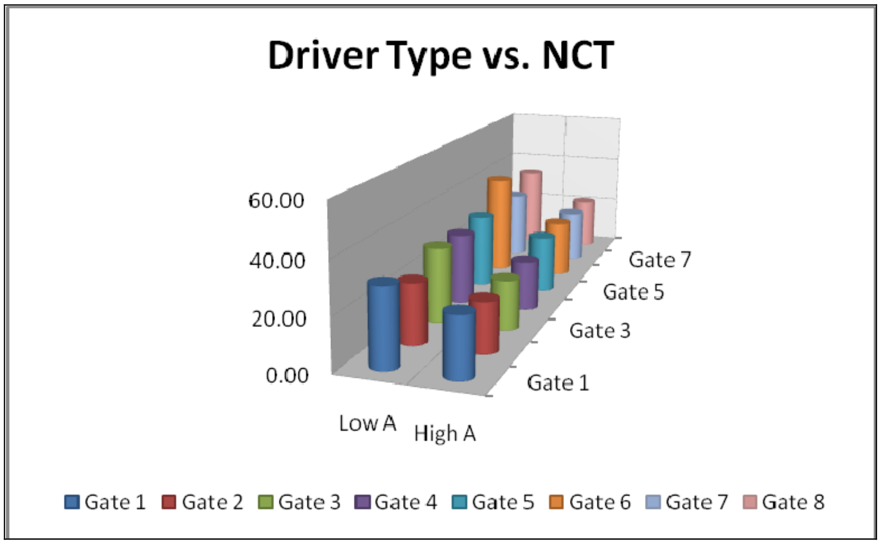

Figure 6.5 Driver Type Graph for Sensitivity Analysis

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

This thesis studied the evacuation traffic management plan for MSU Starkville main campus. Three scenarios representing three levels of traffic management strategies were examined. For each scenario an evacuation route plan (ERP) was developed and improved.

The microscopic traffic simulation platform TSIS/CORSIM was used to evaluate the ERPs and the Path-Following algorithm was applied. The measures of effectiveness (MOE) include network clearance time (NCT) and the degree of balancing the clearance times among all the university gates. Iterations of ERPs were conducted to improve route plans. The trail-and-error method was used to remove the bottlenecks. The improved ERPs were adjusted manually. The stopping criterion of the iterations was set as 30 iterations for each scenario.

For parameters such as startup lost time (SULT), discharge headway (DCH) and driver behavior data should have been calibrated according to actual evacuation data. In the case no evacuation data was available for this thesis, sensitivity analyses were conducted instead of calibration and validation.

In sensitivity analyses, free flow speed (FFS), discharge headway (DCH), startup lost time (SULT), and time to react to sudden deceleration of lead vehicle (TRAFED) were tested. The testing input files were generated manually, and methods of time differences of NCT, t- test, and X-Y scattered graph were used in data analyzing.

7.1 CONCLUSIONS

7.1.1 Base Model Development

The base model development experienced data collection, CORSIM setup and initial ERP generation. The data used in this thesis came from filed data collection and former traffic surveys and studies. Data collected include geometric data such as information of nodes, links and parking lots, traffic data such as campus adjacent road entry volumes and signal timing plans, and CROSM setup data such as those of driver type and vehicle type. Calibration data such as TRSDLV, DCH, SULT and FFS which should have been collected in the field were not available and sensitivity analysis was conducted instead.

Based on the worse-case traffic assumption, the evacuation origin was assumed as the sum of the capacities of all on campus parking lots. A total of 8939 vehicles on 48 parking lots were coded in the model. The destinations were defined as the nodes just outside the university exits/gates. The exact destinations were obtained in the process of generating the ERP in which traffic assignment was also completed.

In CORSIM setup, aside from the normal process of network generation and model debug, the path files and vehicle files were generated in order to implement Path-Following algorithm. The number of lines of the path file normally equals the number of paths and the number of lines of the vehicle file equals the total number of the evacuating vehicles.

The initial ERP employed the principle of evacuating through the nearest gate. The simulation showed that 123 minutes of NCT was needed and Gate 7 at Hardy Road and Blackjack Road is obviously more congested than other gates.

7.1.2 Evacuation Traffic Management Plan

Traffic management plan development examined the situations under traffic three traffic management strategies to test how well they can improve the evacuation. Three scenarios of different traffic management strategies were identified according to the arrangement of contra flow and gate signal timing plans:

- Scenario 1: no contra flow, no change in gate signal timing plan;
- Scenario 2: contra flow, no change in gate signal timing plan;
- Scenario 3: contra flow, modify gate signal timing plan;

Iterations of ERPs were conducted in each scenario targeting at improving measure of effectiveness (MOE). The major objective was to minimize NCT, and the secondary objective was to balance the clearance times at all the university gates. Through observing the animation of TSIS/CORSIM, traffic bottlenecks (most congested intersections or road segment) were identified and new ERPS to remove the bottlenecks were generated manually. The stopping criterion was set as 30 iterations for each scenario and ten multi-runs were conducted for the final ERPs.

The evacuation route plans of the three scenarios are shown in Figure 7.1 through 7.3 (vehicles in the parking lots evacuate through the university gates with the same color). The comparisons of the ERPs of the 3 scenarios are listed in Appendix A. The detailed evacuation routes of each parking lot are listed in appendix D, E and F.

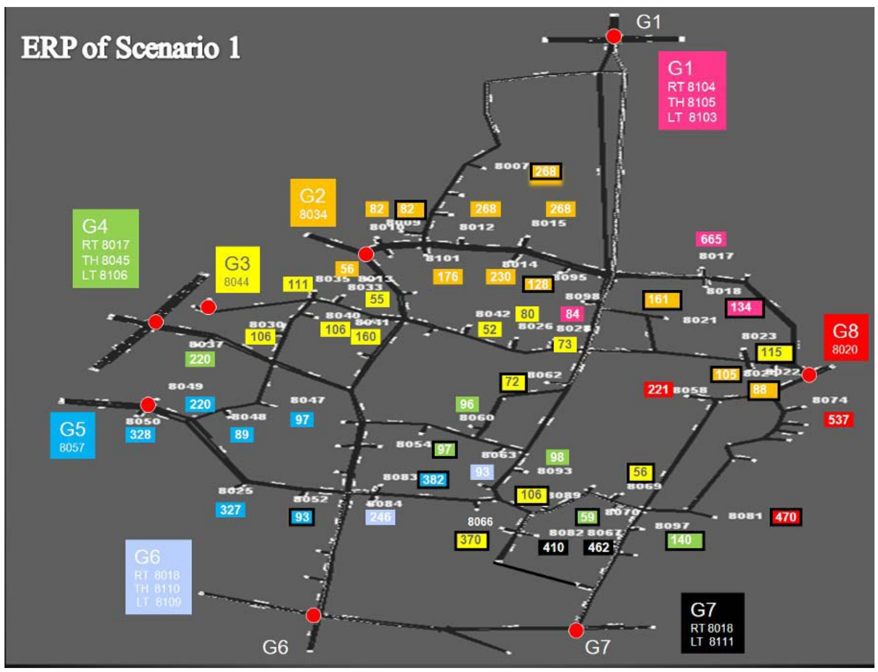

Figure 7.1 ERP of Scenario 1

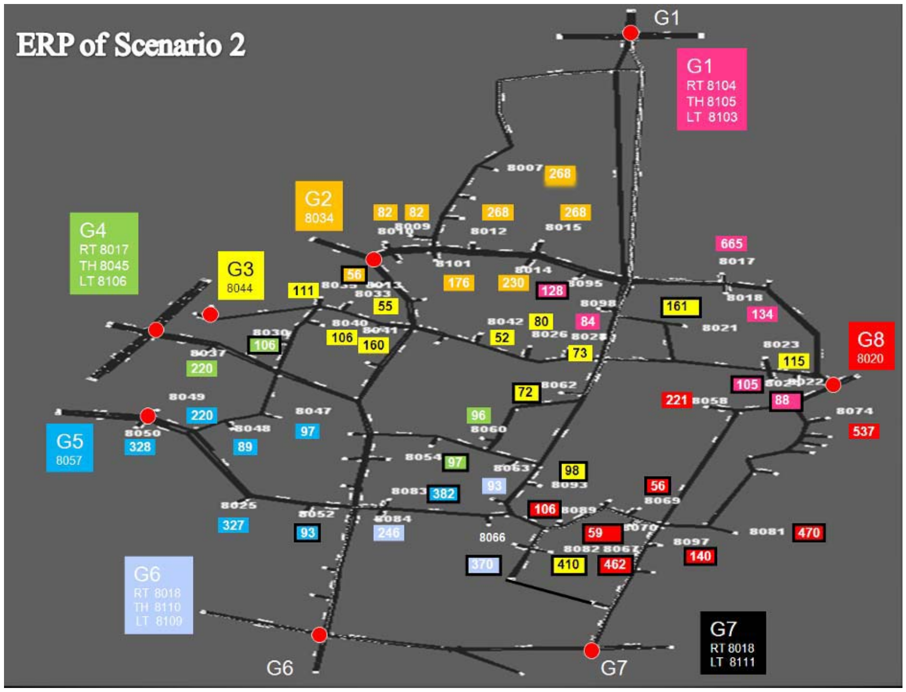

Figure 7.2   ERP of Scenario 2

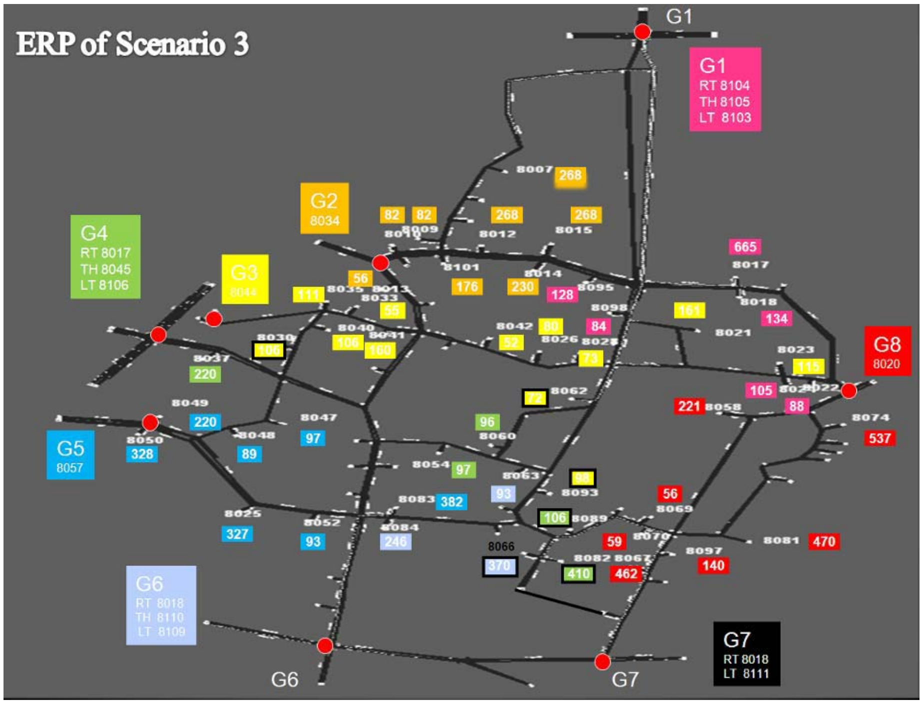

Figure 7.3 ERP of Scenario 3

The results show that the evacuation of MSU would have NCT of 39 min for Scenario 1, 21 min for Scenario 2, and 20 min for Scenario 3 as shown in Table 7.1.

Table 7.1 Network Clearance Times of All Scenarios

Scenario		Network Clearance Time (NCT)
Name	Description	
Base Model	No evacuation route plan, all vehicles evacuate through nearest gates.	123 min
Scenario 1	Use route plan; no contra flow; no gate signal adjustment	39 min
Scenario 2	Use route plan; contra flow; no gate signal adjustment	21 min
Scenario 3	Use route plan; contra flow; gate signal adjusted	20 min

In Table 7.1, the NCT of Scenario 1 is about 1/3 of that of base model, and the NCT of Scenario 2 is about 1/2 of Scenario 1, but is very close to the NCT of Scenario 3. Based on the results, it was concluded that using a pre-planned ERP to guide the evacuating traffic can reduce the NCT significantly; contra flow operation can substantially reduce the NCT; the overall improvement of optimizing signal timing plan is not obvious.

7.1.3 Sensitivity Analysis

In absence of evacuation field data, sensitivity analyses of key CORSIM parameters were conducted and their sensitivities to network clearance time (NCT) were evaluated.

Through sensitivity analysis, it was found that the NCT was sensitive to the CORSIM parameters of TRSDLV (time to react to sudden deceleration of lead vehicle), FFS (free flow speed) and driver type while the sensitivities of DCH (discharge headway) and SULT (start up lost time) to NCT were not found significant.

In evacuation if the drivers are be more alert to the sudden changes of the vehicles ahead, they can follow the leading vehicles more promptly and the entire evacuation can have a less NCT. The tests found if decrease the TRSDLV from 1.0 second to 0.5 second, the NCT might decrease 1.6 minutes, and for a TRSDLV of 0.3 second the NCT might decrease 3.0 minutes.

When vehicles can move faster the evacuation time can be smaller. The NCT would decrease about 1 minute if the FFS increase from 20 mph to 30 mph, and the NCT would decrease slower and decrease 1.6 minutes less when FFS reach 60 mph.

In the case of improved ERP, the evacuation traffic is running smoothly and the leading vehicles of the streams normally do not stop at the on campus intersections. Hence the NCT would not change much along DCH and SULT. It is considered reasonable that DCH and SULT were not found sensitive to NCT.

If more drivers are aggressive, the entire model will have a smaller TRSDLD which is positively related to NCT. Hence, the high aggressive configuration of driver type yields a smaller NCT. The sensitivity analysis showed that driver type is sensitive to NCT.

7.2 RECOMMENDATIONS

For generating real evacuation plans of MSU, the conclusions of this thesis can be used as a reference. The strategy of Scenario 2--implementing contra flow while no adjustment for gate signals-- is recommended and its final ERP can be used as a reference to the base model. Meanwhile, the following additional issues need to be addressed:

- To include the minor parking lots and the road curb parking services;
- To include partial evacuation, consider the necessity of prioritizing evacuates;
- To conduct broad driver type and vehicle survey to make the model more case-specific;

- To include the neighboring freeway traffic of the campus; and
- To include exogenous factors such as weather condition.

From the traffic engineering viewpoint simulation is a methodology of traffic analysis to support decision making [46]. The more representative the model to the real traffic, the more reliable the analysis is appreciated. Hence in theory calibration and validation are important steps in developing a model for a temporal project. On the other hand, the calibration data are sometimes difficult or expensive to obtain. From professional experiences, if the major objective changes within 5%, the calibration of the causing parameter can be skipped; if the change of the major objective is more than 10%, the calibration is regarded as necessary; if the change is between 5% and 10%, then the model developer can have optional choice. Hence, based on the sensitivity analysis, the following recommendations were given:

- Calibrations on discharge headway (DCH) and start up lost time (SULT) are not recommended because they are not sensitive to NCT ;
- Although FFS and TRSDLV are tested sensitive to NCT, but the NCT will change insignificantly in reasonable range in evacuation (the FFS of major campus roads are mostly more than 20 mph, and TRSDLV is expected to be less than 1 second), so calibration on FFS and TRSDLV are recommended to be decided by the model developer.

For future improvement of the model the thesis can be improved on the following aspects:

- To program a script tools to automatically adjust the path file and vehicle file in order to speed up the process of ERP improvement;
- To include various unforeseen events such as incident, path brake down, and traffic entering the wrong direction in contra flow;
- To conduct intensive study of the evacuation traffic stream characteristics to make the model more representative;
- To generate real time evacuation traffic management system.

As to the research of generation a CEEP, some questions popped up during the process of the thesis might be helpful such as: What is the maximum acceptable discrepancy in calibration and validation? What are the reasonable stopping criteria for ERP? How good is a fixed ERP compared with route diversion under the guidance of variable message signs (VMS)?

This thesis tried to gain a better understanding of the campus evacuation traffic, and hopefully it can function as the first step in the continuous endeavor to approaching a satisfactory evacuation traffic management plan for MSU.

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APPENDIX A

MSU MAIN CAMPUS MAJOR PACKING LOTS

	CORSIM IID	Parking Service Capacity	Parking Lot Name	Street Name of Lot Exit	Evacuate Gate			
					Initial RRP	S 1	S 2	S 3
1	8007	268	Sanderson Parking Lot 1	Lakeview Rd	1	2	2	2
2	8009	82	Coliseum Parking Lot 2	Lakeview Rd	1	2	2	2
3	8010	82	Coliseum Parking Lot 1	Lakeview Rd	2	2	2	2
4	8012	268	Sanderson Parking Lot 2	Coliseum Blvd	2	2	2	2
5	8013	56	McArthur Parking Lot 1	B S Hood Rd	2	2	3	3
6	8014	230	Memorial Parking Lot 2	Coliseum Blvd	2	2	2	2
7	8015	268	Sanderson Parking Lot 3	Coliseum Blvd	2	2	2	2
8	8017	665	Griffis Parking Lot 1	Coliseum Blvd	1	1	1	1
9	8018	134	Ruby Parking Lot	Coliseum Blvd	8	1	1	1
10	8021	161	Suttle Parking Lot	Barr Ave	1	2	3	3
11	8022	88	Sessums Parking Lot	Barr Ave	8	2	1	1
12	8023	115	Critz Parking Lot	Barr Ave	8	3	3	3
13	8024	105	Hilbun Parking Lot	Barr Ave	8	3	1	1
14	8025	327	Robert L J Parking Lot 2	Bully Blvd	5	5	5	5
15	8026	80	Garner Parking Lot	Barr Ave	3	3	3	3
16	8028	73	Butler Parking Lot	Barr Ave	3	3	3	3
17	8030	106	Bos Parking Lot t2	Extension Dr	3	3	4	3
18	8033	55	McArthur Parking Lot 2	Barr Ave	3	3	3	3
19	8035	111	Soccer Parking Lot	Barr Ave	3	3	3	3
20	8037	220	CQ sheely Parking Lot 1	Stone Blvd	4	4	4	4
21	8040	106	Bost Parking Lot 1	Barr Ave	3	3	3	3
22	8041	160	Book stroe Parking Lot 1	B S Hood Rd	3	3	3	3
23	8042	52	Memorial Parking Lot 1	Barr Ave	3	3	3	3
24	8047	94	Newwell Parking Lot	Extension Dr	4	5	4	4
25	8048	89	Poultry Parking Lot	Extension Dr	4	5	4	4
26	8049	220	CQ sheely Parking Lot 2	Extension Dr	5	5	5	5
27	8050	328	Robert L J Parking Lot 1	Bully Blvd	5	5	5	5
28	8052	93	Thompson Parking Lot	Bully Blvd	6	5	5	5
29	8054	97	Dorman Parking Lot	Creelman St	5	4	4	4
30	8058	221	McCain Parking Lot	Lee Blvd	8	8	8	8
31	8060	96	Lloyd Parking Lot	Creelman St	4	3	4	4
32	8062	72	Hull Parking Lot	George Perry St	1	3	3	3
33	8063	93	McCarthy Parking Lot	Creelman St	4	4	4	4
34	8066	370	GreenhouseP Parking Lot	Magruder St	7	6	6	5&6
35	8067	462	Mccomas Parking Lot 1	Hardy Rd	7	7	7&8	7&8
36	8069	56	Hand Lab Parking Lot	Marrill Rd	7	3	8	8
37	8070	59	Morrill RD Parking Lot	Marrill Rd	7	4	8	8
38	8074	537	Mckee Parking Lot	Lee Blvd	8	8	8	8
39	8081	470	Eckie's Parking Lot	Hardy Rd	7	8	3	8
40	8082	410	Mccomas Parking Lot 2	Hardy Rd	7	7	3	4
41	8083	382	Greenhouse Parking Lot 1	Bully Blvd	6	5	5	5
42	8084	246	Tennis Parking Lot	Bully Blvd	6	6	6	6
43	8089	106	Allen E Parking Lot	Presidents Circle	7	3	8	4
44	8093	98	Allen W Parking Lot	George Perry St	4	4	3	3
45	8095	128	Evans Parking Lot 1	Coliseum Blvd	1	2	1	1
46	8097	140	Music Parking Lot	Hardy Rd	7	4	8	8
47	8098	84	Evans Parking Lot 2	George Perry St	1	1	1	1
48	8101	176	Howell Parking Lot	Coliseum Blvd	2	2	2	2
Sum		8939						

APPENDIX B

PATH FILE OF BASE MODEL

8007 176 7 6 5 4 3 2 205 1 204 8104
8012 173 13 12 11 37 38 8034
8015 172 14 13 12 11 37 38 8034
8010 191 11 37 38 8034
8009 193 10 9 8 7 6 5 4 3 2 205 1 204 8104
8101 194 12 11 37 38 8034
8013 152 36 35 34 39 40 41 51 50 8044
8033 144 40 41 51 50 8044
8035 145 41 51 50 8044
8040 146 42 41 51 50 8044
8030 148 44 43 42 41 51 50 8044
8037 149 48 49 208 8107
8049 199 52 111 8057
8050 200 52 111 8057
8025 134 62 53 52 111 8057
8048 135 54 55 56 47 48 49 208 8107
8047 136 56 47 48 49 208 8107
8052 198 61 60 99 100 101 212 8108
8041 143 39 40 41 51 50 8044
8042 154 32 33 34 39 40 41 51 50 8044
8014 171 14 13 12 11 37 38 8034
8095 170 15 16 2 205 1 204 8104
8098 161 28 16 2 205 1 204 8104
8026 155 31 32 33 34 39 40 41 51 50 8044
8028 157 29 30 31 32 33 34 39 40 41 51 50 8044
8062 159 96 25 27 28 16 2 205 1 204 8104
8060 139 65 66 67 57 46 47 48 49 208 8107
8063 141 68 66 67 57 46 47 48 49 208 8107
8054 138 58 59 60 61 62 53 52 111 8057
8083 114 94 60 99 100 101 212 8108
8084 115 94 60 99 100 101 212 8108
8017 169 17 16 2 205 1 204 8104
8018 167 17 18 19 20 21 206 8020
8023 163 23 22 20 21 206 8020
8022 165 22 20 21 206 8020
8024 164 23 22 20 21 206 8020
8021 162 26 27 28 16 2 205 1 204 8104
8058 82 81 83 84 21 206 8020
8093 121 70 69 68 66 67 57 46 47 48 49 208 8107
8089 118 74 75 76 77 78 104 105 106 107 110 216 211 101 212 8108
8069 123 76 77 78 104 105 106 107 110 216 211 101 212 8108
8070 124 77 78 104 105 106 107 110 216 211 101 212 8108
8067 126 105 106 107 110 216 211 101 212 8108
8082 113 102 103 107 110 216 211 101 212 8108
8097 125 104 105 106 107 110 216 211 101 212 8108
8074 186 85 84 21 206 8020
8081 92 91 78 104 105 106 107 110 216 211 101 212 8108
8007 176 7 6 5 4 3 2 205 1 203 8103
8009 193 10 9 8 7 6 5 4 3 2 205 1 203 8103
8037 149 48 49 207 8045
8037 149 48 49 209 8106
8048 135 54 55 56 47 48 49 207 8045
8048 135 54 55 56 47 48 49 209 8106
8047 136 56 47 48 49 207 8045
8047 136 56 47 48 49 209 8106
8052 198 61 60 99 100 101 211 216 214 8109
8052 198 61 60 99 100 101 215 8110
8098 161 28 16 2 205 1 203 8103

8062 159 96 25 27 28 16 2 205 1 203 8103
8062 159 96 25 27 28 16 2 205 1 202 8105
8060 139 65 66 67 57 46 47 48 49 207 8045
8060 139 65 66 67 57 46 47 48 49 209 8106
8063 141 68 66 67 57 46 47 48 49 207 8045
8063 141 68 66 67 57 46 47 48 49 209 8106
8084 115 94 60 99 100 101 215 8110
8084 115 94 60 99 100 101 211 216 214 8109
8017 169 17 16 2 205 1 203 8103
8021 162 26 27 28 16 2 205 1 203 8103
8093 121 70 69 68 66 67 57 46 47 48 49 207 8045
8093 121 70 69 68 66 67 57 46 47 48 49 209 8106
8089 118 74 75 76 77 78 104 105 106 107 110 213 8111
8069 123 76 77 78 104 105 106 107 110 213 8111
8070 124 77 78 104 105 106 107 110 213 8111
8067 126 105 106 107 110 213 8111
8082 113 102 103 107 110 213 8111
8097 125 104 105 106 107 110 213 8111
8081 92 91 78 104 105 106 107 110 213 8111
8083 114 94 60 99 100 101 215 8110
8083 114 94 60 99 100 101 211 216 214 8109
8095 170 15 16 2 205 1 203 8103

APPENDIX C

VEHICLE FILE OF BASE MODEL

961 8007 1 10 0 1*
961 8007 1 1 0 1
961 8007 1 10 0 1
961 8007 1 10 0 1
961 8007 1 10 0 3
961 8007 1 1 0 1
961 8007 1 10 0 1
961 8007 1 10 0 5
961 8007 1 10 0 1
961 8007 1 1 0 1
961 8007 1 10 0 1
961 8007 1 10 0 3
961 8007 1 10 0 1
961 8007 1 1 0 1
961 8007 1 10 0 1
961 8007 1 10 0 5
961 8007 1 10 0 1
961 8007 1 1 0 1
961 8007 1 10 0 3
961 8007 1 10 0 1
961 8007 1 10 0 1
961 8007 1 1 0 1
961 8007 1 10 0 1
961 8007 1 10 0 1
961 8007 1 10 0 3
961 8007 1 1 0 1
961 8007 1 10 0 1
961 8007 1 10 0 5
961 8007 1 10 0 1
961 8007 1 1 0 1
961 8007 1 10 0 1
961 8007 1 10 0 3
961 8007 1 10 0 1
961 8007 1 1 0 1
961 8007 1 10 0 1
961 8007 1 10 0 5
961 8007 1 10 0 1
961 8007 1 1 0 1
961 8007 1 10 0 3
961 8007 1 10 0 1
961 8007 1 10 0 1
961 8007 1 1 0 1
961 8007 1 10 0 1
961 8007 1 10 0 1
961 8007 1 10 0 3

***: This is a sample of 55 vehicles in the parking lot of** Sanderson Parking Lot 1**. The entire vehicle file has 8939 lines.**

APPENDIX D

PATH FILE OF SCENARIO 1

8007 176 7 8 9 10 12 11 37 38 8034
8012 173 13 12 11 37 38 8034
8015 172 14 13 12 11 37 38 8034
8010 191 11 37 38 8034
8009 193 10 12 11 37 38 8034
8101 194 12 11 37 38 8034
8013 152 36 35 34 39 40 41 51 50 8044
8033 144 40 41 51 50 8044
8035 145 41 51 50 8044
8040 146 42 43 44 47 48 49 209 8106
8030 148 44 47 48 49 209 8106
8037 149 48 49 208 8107
8049 199 52 111 8057
8050 200 52 111 8057
8025 134 62 53 52 111 8057
8048 135 54 53 52 111 8057
8047 136 56 55 54 53 52 111 8057
8052 198 61 62 53 52 111 8057
8041 143 39 40 41 51 50 8044
8042 154 32 33 34 39 40 41 51 50 8044
8014 171 14 13 12 11 37 38 8034
8095 170 15 16 2 205 1 204 8104
8098 161 28 16 2 205 1 204 8104
8026 155 31 32 33 34 39 40 41 51 50 8044
8028 157 29 30 31 32 33 34 39 40 41 51 50 8044
8062 159 96 95 69 68 66 67 57 46 47 48 49 209 8106
8060 139 65 66 67 57 46 47 48 49 208 8107
8063 141 68 66 67 57 46 47 48 49 208 8107
8054 138 58 59 60 61 62 53 52 111 8057
8083 114 94 60 99 100 101 212 8108
8084 115 94 60 99 100 101 212 8108
8017 169 17 16 2 205 1 204 8104
8018 167 17 18 19 20 22 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8023 163 23 24 25 29 30 31 32 33 34 45 46 57 58 59 60 99 100 101 211 216 214 8109
8022 165 22 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8024 164 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8021 162 26 27 28 16 2 205 1 204 8104
8058 82 95 96 25 29 30 31 32 33 34 45 46 57 58 59 60 61 62 53 52 111 8057
8093 121 70 69 68 66 67 57 46 47 48 49 208 8107
8089 118 74 73 72 71 70 69 68 66 67 57 46 47 48 49 209 8106
8069 123 76 75 74 73 72 71 70 69 68 66 67 57 46 47 48 49 209 8106
8070 124 77 76 75 74 73 72 71 70 69 68 66 67 57 46 47 48 49 209 8106
8067 126 105 106 107 110 216 211 101 212 8108
8082 113 102 103 107 110 216 211 101 212 8108
8097 125 104 78 77 76 75 74 73 72 71 70 69 68 66 67 57 46 47 48 49 209 8106
8074 186 85 84 21 206 8020
8081 92 91 78 79 80 81 82 95 96 25 29 30 31 32 33 34 45 46 57 58 59 60 61 62 53 52 111 8057
8066 112 102 73 72 93 94 60 99 100 101 212 8108
8009 193 10 9 8 7 6 5 4 3 2 205 1 203 8103
8037 149 48 49 207 8045
8037 149 48 49 209 8106
8048 135 54 55 56 47 48 49 207 8045
8048 135 54 55 56 47 48 49 209 8106
8047 136 56 47 48 49 207 8045
8047 136 56 47 48 49 209 8106
8052 198 61 60 99 100 101 211 216 214 8109
8052 198 61 60 99 100 101 215 8110
8098 161 28 16 2 205 1 203 8103

8062 159 96 25 27 28 16 2 205 1 203 8103
8062 159 96 25 27 28 16 2 205 1 202 8105
8060 139 65 66 67 57 46 47 48 49 207 8045
8060 139 65 66 67 57 46 47 48 49 209 8106
8063 141 68 66 67 57 46 47 48 49 207 8045
8063 141 68 66 67 57 46 47 48 49 209 8106
8084 115 94 60 99 100 101 215 8110
8084 115 94 60 99 100 101 211 216 214 8109
8017 169 17 16 2 205 1 203 8103
8021 162 26 27 28 16 2 205 1 203 8103
8093 121 70 69 68 66 67 57 46 47 48 49 207 8045
8093 121 70 69 68 66 67 57 46 47 48 49 209 8106
8089 118 74 75 76 77 78 104 105 106 107 110 213 8111
8069 123 76 77 78 104 105 106 107 110 213 8111
8070 124 77 78 104 105 106 107 110 213 8111
8067 126 105 106 107 110 213 8111
8082 113 102 103 107 110 213 8111
8097 125 104 105 106 107 110 213 8111
8081 92 91 78 104 105 106 107 110 213 8111
8083 114 94 60 99 100 101 215 8110
8083 114 94 60 99 100 101 211 216 214 8109
8095 170 15 16 2 205 1 203 8103
8062 159 96 95 69 68 66 67 57 46 47 48 49 207 8045
8062 159 96 95 69 68 66 67 57 46 47 48 49 208 8107
8018 167 17 16 28 27 25 29 30 31 32 33 34 45 46 57 58 59 60 99 100 101 215 8110
8018 167 17 16 28 27 25 29 30 31 32 33 34 45 46 57 58 59 60 99 100 101 212 8108
8023 163 23 24 25 29 30 31 32 33 34 45 46 57 58 59 60 99 100 101 215 8110
8023 163 23 24 25 29 30 31 32 33 34 45 46 57 58 59 60 99 100 101 212 8108
8022 165 22 23 24 25 29 30 31 32 33 34 45 46 57 58 59 60 99 100 101 215 8110
8022 165 22 23 24 25 29 30 31 32 33 34 45 46 57 58 59 60 99 100 101 212 8108
8089 118 74 73 72 71 70 69 68 66 67 57 46 47 48 49 207 8045
8089 118 74 73 72 71 70 69 68 66 67 57 46 47 48 49 208 8107
8069 123 76 75 74 73 72 71 70 69 68 66 67 57 46 47 48 49 207 8045
8069 123 76 75 74 73 72 71 70 69 68 66 67 57 46 47 48 49 208 8107
8070 124 77 76 75 74 73 72 71 70 69 68 66 67 57 46 47 48 49 207 8045
8070 124 77 76 75 74 73 72 71 70 69 68 66 67 57 46 47 48 49 208 8107
8097 125 104 78 77 76 75 74 73 72 71 70 69 68 66 67 57 46 47 48 49 207 8045
8097 125 104 78 77 76 75 74 73 72 71 70 69 68 66 67 57 46 47 48 49 208 8107

APPENDIX E

PATH FILE OF SCENARIO 2

8007 176 7 8 9 10 12 11 37 38 8034
8012 173 13 12 11 37 38 8034
8015 172 14 13 12 11 37 38 8034
8010 191 11 37 38 8034
8009 193 10 12 11 37 38 8034
8101 194 12 11 37 38 8034
8013 152 36 35 34 39 40 41 51 50 8044
8033 144 40 41 51 50 8044
8035 145 41 51 50 8044
8040 146 42 41 51 50 8044
8030 148 44 47 48 49 209 8106
8037 149 48 49 208 8107
8049 199 52 111 8057
8050 200 52 111 8057
8025 134 62 53 52 111 8057
8048 135 54 55 56 47 48 49 209 8106
8047 136 56 47 48 49 208 8107
8052 198 61 62 53 52 111 8057
8041 143 39 40 41 51 50 8044
8042 154 32 33 34 39 40 41 51 50 8044
8014 171 14 13 12 11 37 38 8034
8095 170 15 63 3 80 1 204 8104
8098 161 28 16 98 80 1 204 8104
8026 155 31 32 33 34 39 40 41 51 50 8044
8028 157 29 30 31 32 33 34 39 40 41 51 50 8044
8062 159 96 25 29 30 31 32 33 34 39 40 41 51 50 8044
8060 139 65 66 67 57 46 47 48 49 208 8107
8063 141 68 66 67 57 46 47 48 49 208 8107
8054 138 58 57 46 47 48 49 209 8106
8083 114 94 60 61 62 53 52 111 8057
8084 115 94 60 99 100 101 212 8108
8017 169 17 109 116 117 1 204 8104
8018 167 17 109 97 16 63 3 80 1 203 8103
8023 163 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8022 165 22 23 24 25 27 28 16 98 80 1 204 8104
8024 164 23 24 25 27 28 16 98 80 1 204 8104
8021 162 26 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8058 82 81 83 84 21 206 8020
8093 121 70 69 95 96 25 29 30 31 32 33 34 39 40 41 51 50 8044
8089 118 74 75 76 77 78 81 83 84 21 206 8020
8069 123 76 77 78 81 83 84 21 206 8020
8070 124 77 78 81 83 84 21 206 8020
8067 126 105 106 107 110 216 211 101 212 8108
8082 113 102 79 72 71 70 69 95 96 25 29 30 31 32 33 34 39 40 41 51 50 8044
8097 125 104 78 81 83 84 21 206 8020
8074 186 85 84 21 206 8020
8081 92 91 78 81 83 84 21 206 8020
8066 112 102 73 72 93 94 60 99 100 101 212 8108
8037 149 48 49 207 8045
8037 149 48 49 209 8106
8095 170 15 63 3 80 1 203 8103
8098 161 28 16 98 80 1 203 8103
8062 159 96 25 27 28 16 98 80 1 203 8103
8060 139 65 66 67 57 46 47 48 49 209 8106
8060 139 65 66 67 57 46 47 48 49 207 8045
8063 141 68 66 67 57 46 47 48 49 207 8045
8063 141 68 66 67 57 46 47 48 49 209 8106
8083 114 94 60 61 62 53 52 111 8057

8083 114 94 60 61 62 53 52 111 8057
8084 115 94 60 99 100 101 212 8108
8084 115 94 60 99 100 101 211 216 214 8109
8017 169 17 109 97 2 117 1 203 8103
8023 163 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8021 162 26 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8093 121 70 69 95 96 25 29 30 31 32 33 34 39 40 41 51 50 8044
8067 126 105 106 107 110 213 8111
8082 113 102 79 72 71 70 69 95 96 25 29 30 31 32 33 34 39 40 41 51 50 8044
8017 169 17 109 97 16 98 80 1 204 8104
8066 112 102 73 72 93 94 60 99 100 101 211 216 214 8109
8096 127 106 107 110 213 8111
8019 168 18 17 109 97 16 98 80 1 204 8104
8017 169 17 109 97 16 63 3 80 1 203 8103
8098 161 28 16 63 3 80 1 204 8104
8098 161 28 16 63 3 80 1 203 8103
8062 159 96 25 27 28 16 63 3 80 1 204 8104
8062 159 96 25 27 28 16 63 3 80 1 203 8103
8023 163 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8023 163 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8022 165 22 23 24 25 27 28 16 63 3 80 1 203 8103
8024 164 23 24 25 27 28 16 63 3 80 1 203 8103
8054 138 58 57 46 47 48 49 208 8107
8019 168 18 17 109 97 16 63 3 80 1 203 8103
8018 167 17 109 97 16 98 80 1 204 8104
8017 169 17 109 97 16 63 3 80 1 203 8103
8017 169 17 109 97 16 98 80 1 204 8104
8066 112 102 73 72 93 94 60 61 62 53 52 111 8057
8067 126 105 104 78 81 83 84 21 206 8020
8030 148 44 47 48 49 208 8107
8030 148 44 47 48 49 207 8045
8048 135 54 55 56 47 48 49 208 8107
8048 135 54 55 56 47 48 49 207 8045
8047 136 56 47 48 49 208 8107
8047 136 56 47 48 49 207 8045
8054 138 58 57 46 47 48 49 207 8045

APPENDIX F

PATH FILE OF SCENARIO 3

8007 176 7 8 9 10 12 11 37 38 8034
8012 173 13 12 11 37 38 8034
8015 172 14 13 12 11 37 38 8034
8010 191 11 37 38 8034
8009 193 10 12 11 37 38 8034
8101 194 12 11 37 38 8034
8013 152 36 35 34 39 40 41 51 50 8044
8033 144 40 41 51 50 8044
8035 145 41 51 50 8044
8040 146 42 41 51 50 8044
8030 148 44 47 48 49 209 8106
8037 149 48 49 208 8107
8049 199 52 111 8057
8050 200 52 111 8057
8025 134 62 53 52 111 8057
8048 135 54 55 56 47 48 49 209 8106
8047 136 56 47 48 49 208 8107
8052 198 61 62 53 52 111 8057
8041 143 39 40 41 51 50 8044
8042 154 32 33 34 39 40 41 51 50 8044
8014 171 14 13 12 11 37 38 8034
8095 170 15 63 3 80 1 204 8104
8098 161 28 16 98 80 1 204 8104
8026 155 31 32 33 34 39 40 41 51 50 8044
8028 157 29 30 31 32 33 34 39 40 41 51 50 8044
8062 159 96 25 29 30 31 32 33 34 39 40 41 51 50 8044
8060 139 65 66 67 57 46 47 48 49 208 8107
8063 141 68 66 67 57 46 47 48 49 208 8107
8054 138 58 57 46 47 48 49 209 8106
8083 114 94 60 61 62 53 52 111 8057
8084 115 94 60 99 100 101 212 8108
8017 169 17 109 116 117 1 204 8104
8018 167 17 109 97 16 63 3 80 1 203 8103
8023 163 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8022 165 22 23 24 25 27 28 16 98 80 1 204 8104
8024 164 23 24 25 27 28 16 98 80 1 204 8104
8021 162 26 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8058 82 81 83 84 21 206 8020
8093 121 70 69 95 96 25 29 30 31 32 33 34 39 40 41 51 50 8044
8089 118 74 79 72 71 70 69 68 66 67 57 46 47 48 49 209 8106
8069 123 76 77 78 81 83 84 21 206 8020
8070 124 77 78 81 83 84 21 206 8020
8067 126 105 106 107 110 216 211 101 212 8108
8082 113 102 79 72 71 70 69 68 66 67 57 46 47 48 49 209 8106
8097 125 104 78 81 83 84 21 206 8020
8074 186 85 84 21 206 8020
8081 92 91 78 81 83 84 21 206 8020
8066 112 102 73 72 93 94 60 99 100 101 212 8108
8037 149 48 49 207 8045
8037 149 48 49 209 8106
8095 170 15 63 3 80 1 203 8103
8098 161 28 16 98 80 1 203 8103
8062 159 96 25 27 28 16 98 80 1 203 8103
8060 139 65 66 67 57 46 47 48 49 209 8106
8060 139 65 66 67 57 46 47 48 49 207 8045
8063 141 68 66 67 57 46 47 48 49 207 8045
8063 141 68 66 67 57 46 47 48 49 209 8106
8083 114 94 60 61 62 53 52 111 8057

8083 114 94 60 61 62 53 52 111 8057
8084 115 94 60 99 100 101 212 8108
8084 115 94 60 99 100 101 211 216 214 8109
8017 169 17 109 97 2 117 1 203 8103
8023 163 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8021 162 26 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8093 121 70 69 95 96 25 29 30 31 32 33 34 39 40 41 51 50 8044
8067 126 105 106 107 110 213 8111
8082 113 102 79 72 71 70 69 68 66 67 57 46 47 48 49 207 8045
8017 169 17 109 97 16 98 80 1 204 8104
8066 112 102 73 72 93 94 60 99 100 101 211 216 214 8109
8096 127 106 107 110 213 8111
8019 168 18 17 109 97 16 98 80 1 204 8104
8017 169 17 109 97 16 63 3 80 1 203 8103
8098 161 28 16 63 3 80 1 204 8104
8098 161 28 16 63 3 80 1 203 8103
8062 159 96 25 27 28 16 63 3 80 1 204 8104
8062 159 96 25 27 28 16 63 3 80 1 203 8103
8023 163 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8023 163 23 24 25 29 30 31 32 33 34 39 40 41 51 50 8044
8022 165 22 23 24 25 27 28 16 63 3 80 1 203 8103
8024 164 23 24 25 27 28 16 63 3 80 1 203 8103
8054 138 58 57 46 47 48 49 208 8107
8019 168 18 17 109 97 16 63 3 80 1 203 8103
8018 167 17 109 97 16 98 80 1 204 8104
8017 169 17 109 97 16 63 3 80 1 203 8103
8017 169 17 109 97 16 98 80 1 204 8104
8066 112 102 79 72 71 70 69 95 96 25 29 30 31 32 33 34 39 40 41 51 50 8044
8067 126 105 104 78 81 83 84 21 206 8020
8030 148 44 47 48 49 208 8107
8030 148 44 47 48 49 207 8045
8048 135 54 55 56 47 48 49 208 8107
8048 135 54 55 56 47 48 49 207 8045
8047 136 56 47 48 49 208 8107
8047 136 56 47 48 49 207 8045
8054 138 58 57 46 47 48 49 207 8045
8082 113 102 79 72 71 70 69 68 66 67 57 46 47 48 49 208 8107
8089 118 74 79 72 71 70 69 68 66 67 57 46 47 48 49 207 8045
8089 118 74 79 72 71 70 69 68 66 67 57 46 47 48 49 208 8107
8066 112 102 73 72 93 94 60 61 62 53 52 111 8057

APPENDIX G

SENSITIVITY DATA OF TRSDLV

TRSDLV		0.30	0.50	1*	1.50	2.50
Run 1#	Gate 1	23.38	23.67	23.47	24.77	30.00
	Gate 2	16.80	17.48	19.65	21.47	22.98
	Gate 3	17.77	17.52	19.58	22.80	31.33
	Gate 4	16.60	16.37	18.92	22.05	24.77
	Gate 5	24.48	23.68	23.13	22.28	29.18
	Gate 6	23.33	22.07	24.85	26.20	41.78
	Gate 7	14.37	17.28	23.33	26.70	41.55
	Gate 8	19.10	18.67	21.00	25.47	34.62
Run 2#	Gate 1	21.90	23.17	23.97	25.58	30.40
	Gate 2	16.70	17.53	19.37	21.50	23.12
	Gate 3	17.00	17.87	19.73	22.22	31.27
	Gate 4	16.33	18.03	18.48	20.63	24.33
	Gate 5	24.70	25.03	21.47	23.33	29.23
	Gate 6	23.17	24.55	21.77	26.70	42.83
	Gate 7	14.87	15.02	19.97	27.30	40.83
	Gate 8	18.95	18.68	21.08	25.40	34.57
Run 3#	Gate 1	22.90	22.82	24.10	25.10	30.40
	Gate 2	16.70	17.27	19.73	21.43	23.10
	Gate 3	17.00	17.75	19.33	22.42	30.87
	Gate 4	15.33	17.82	20.10	21.13	24.33
	Gate 5	23.70	23.07	23.08	23.22	29.33
	Gate 6	24.17	21.58	22.55	26.13	42.82
	Gate 7	15.87	15.72	23.20	27.80	40.83
	Gate 8	18.95	18.87	21.25	25.22	34.57
Run 4#	Gate 1	21.90	23.03	22.80	25.40	30.57
	Gate 2	16.77	17.50	19.52	21.38	22.98
	Gate 3	16.57	18.27	19.37	22.43	31.32
	Gate 4	16.57	18.18	20.30	20.50	24.92
	Gate 5	23.58	22.83	23.80	23.42	29.55
	Gate 6	22.40	21.27	22.97	26.52	44.08
	Gate 7	14.50	16.97	22.02	29.62	44.12
	Gate 8	19.30	19.07	21.20	25.18	34.20
Run 5#	Gate 1	22.07	23.37	23.23	24.90	29.87
	Gate 2	16.68	17.15	19.55	21.20	22.72
	Gate 3	17.18	18.23	19.33	22.57	30.85
	Gate 4	16.65	17.90	20.33	21.42	25.40
	Gate 5	23.78	26.10	22.67	22.32	30.12
	Gate 6	22.15	24.55	22.53	26.90	43.67
	Gate 7	14.60	15.17	19.72	28.60	41.85
	Gate 8	19.02	18.80	21.02	25.47	34.77
Run 6#	Gate 1	20.98	24.50	23.00	24.80	30.17
	Gate 2	16.88	17.53	19.47	21.80	23.18
	Gate 3	18.03	18.22	19.37	22.37	31.30

	Gate 4	17.77	16.42	18.78	22.08	24.55
	Gate 5	24.70	24.00	22.92	22.32	30.02
	Gate 6	20.82	23.68	21.90	26.38	30.85
	Gate 7	14.45	16.45	19.57	27.20	43.30
	Gate 8	18.92	18.72	21.18	25.48	38.57
Run 7#	Gate 1	22.82	24.07	22.20	25.30	34.25
	Gate 2	16.90	17.30	19.55	21.23	22.80
	Gate 3	17.87	17.63	19.18	22.52	31.10
	Gate 4	17.42	17.45	19.15	21.83	26.03
	Gate 5	22.42	22.33	23.20	23.60	31.47
	Gate 6	23.32	22.02	23.03	26.23	42.68
	Gate 7	14.83	18.07	20.92	28.37	41.40
	Gate 8	18.85	18.75	21.22	25.43	34.40
Run 8#	Gate 1	22.58	22.57	22.95	24.72	30.12
	Gate 2	16.55	17.28	19.62	21.42	23.10
	Gate 3	17.67	17.97	19.30	22.37	31.30
	Gate 4	15.88	17.45	18.47	20.43	23.92
	Gate 5	23.37	22.07	23.08	24.05	31.27
	Gate 6	21.47	20.10	22.78	26.60	43.95
	Gate 7	13.62	16.12	22.50	28.70	42.18
	Gate 8	19.15	18.70	21.07	25.48	34.43
Run 9#	Gate 1	21.70	22.37	23.25	25.37	30.02
	Gate 2	16.72	17.42	19.25	21.40	23.48
	Gate 3	16.98	17.98	19.52	22.32	31.18
	Gate 4	16.92	17.90	20.45	22.15	26.22
	Gate 5	24.52	23.40	21.52	22.45	29.98
	Gate 6	23.05	20.18	22.52	28.08	41.93
	Gate 7	14.65	14.75	19.05	28.67	36.28
	Gate 8	18.73	18.68	21.17	25.47	34.68
Run 10#	Gate 1	21.33	22.87	23.37	25.52	29.72
	Gate 2	16.62	17.18	19.48	21.10	22.87
	Gate 3	17.20	17.95	19.42	22.63	31.42
	Gate 4	16.17	17.62	19.12	21.50	25.07
	Gate 5	23.55	23.70	22.42	24.20	30.20
	Gate 6	21.15	20.88	22.50	28.75	41.23
	Gate 7	14.60	14.43	21.90	28.28	44.08
	Gate 8	19.10	18.68	21.18	25.57	34.62
Mean	Gate 1	22.16	23.24	23.23	25.15	30.55
	Gate 2	16.73	17.37	19.52	21.39	23.03
	Gate 3	17.33	17.94	19.41	22.46	31.19
	Gate 4	16.56	17.51	19.41	21.37	24.95
	Gate 5	23.88	23.62	22.73	23.12	30.04
	Gate 6	22.50	22.09	22.74	26.85	41.58
	Gate 7	14.64	16.00	21.22	28.12	41.64
	Gate 8	19.01	18.76	21.14	25.42	34.94

t-Test: Paired Two Sample for Means

	1	*0.3*
Mean	21.17458	19.10021
Variance	2.829297	10.36964
Observations	80	80
Pearson Correlation	0.710198	
Hypothesized Mean Difference	0	
df	79	
t Stat	7.90753	
P(T<=t) one-tail	6.6E-12	
t Critical one-tail	1.664371	
P(T<=t) two-tail	1.32E-11	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	1	*0.5*
Mean	21.17458	19.56583
Variance	2.829297	8.526258
Observations	80	80
Pearson Correlation	0.715505	
Hypothesized Mean Difference	0	
df	79	
t Stat	6.917296	
P(T<=t) one-tail	5.38E-10	
t Critical one-tail	1.664371	
P(T<=t) two-tail	1.08E-09	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	20.92551	23.95473
Variance	7.818792	12.28904
Observations	81	81
Pearson Correlation	0.795548	
Hypothesized Mean Difference	0	
df	80	
t Stat	-12.8356	
P(T<=t) one-tail	2.02E-21	
t Critical one-tail	1.664125	
P(T<=t) two-tail	4.04E-21	
t Critical two-tail	1.990063	

t-Test: Paired Two Sample for Means

	1	*2.5*
Mean	21.17458	32.24167
Variance	2.829297	44.56063
Observations	80	80
Pearson Correlation	0.451205	
Hypothesized Mean Difference	0	
df	79	
t Stat	-16.2171	
P(T<=t) one-tail	3.7E-27	
t Critical one-tail	1.664371	
P(T<=t) two-tail	7.41E-27	
t Critical two-tail	1.99045	

APPENDIX H

SENSITIVITY DATA OF FFS

FFS		10.00	20*	30.00	40.00	60.00
Run 1#	Gate 1	28.47	23.47	23.22	22.73	22.45
	Gate 2	22.12	19.65	19.52	19.48	18.82
	Gate 3	28.05	19.58	18.20	17.40	16.65
	Gate 4	25.25	18.92	18.62	18.20	18.18
	Gate 5	27.02	23.13	19.90	20.12	19.42
	Gate 6	25.10	24.85	20.42	22.53	20.02
	Gate 7	34.78	23.33	19.53	18.67	18.00
	Gate 8	31.00	21.00	20.67	20.38	20.23
Run 2#	Gate 1	27.93	23.97	22.97	22.97	22.37
	Gate 2	22.13	19.37	19.30	19.30	18.97
	Gate 3	28.10	19.73	18.22	16.22	16.37
	Gate 4	23.85	18.48	18.42	18.42	18.10
	Gate 5	26.87	21.47	22.28	22.28	20.88
	Gate 6	24.53	21.77	22.37	23.37	22.85
	Gate 7	32.78	19.97	18.57	17.57	18.38
	Gate 8	32.78	21.08	20.68	20.68	20.28
Run 3#	Gate 1	27.83	24.10	22.97	22.60	22.50
	Gate 2	22.00	19.73	19.43	19.27	18.83
	Gate 3	28.05	19.33	17.47	17.30	17.05
	Gate 4	24.23	20.10	17.87	19.00	17.73
	Gate 5	26.90	23.08	21.80	20.70	20.83
	Gate 6	26.55	22.55	21.93	23.35	20.62
	Gate 7	34.22	23.20	20.48	18.52	18.33
	Gate 8	29.18	21.25	20.85	20.43	20.33
Run 4#	Gate 1	27.95	22.80	22.97	22.50	23.57
	Gate 2	22.48	19.52	19.07	19.40	18.75
	Gate 3	28.20	19.37	18.02	17.28	16.28
	Gate 4	23.40	20.30	19.15	17.70	18.03
	Gate 5	26.52	23.80	19.02	18.83	19.73
	Gate 6	24.18	22.97	20.87	21.63	21.40
	Gate 7	29.65	22.02	20.32	18.37	18.67
	Gate 8	29.32	21.20	20.55	20.43	20.15
Run 5#	Gate 1	27.90	23.23	24.20	22.50	24.20
	Gate 2	21.92	19.55	19.52	19.42	19.52
	Gate 3	28.07	19.33	17.72	16.78	17.72
	Gate 4	23.87	20.33	18.23	18.00	18.23
	Gate 5	26.78	22.67	21.53	20.78	21.53
	Gate 6	23.67	22.53	21.57	22.08	21.57
	Gate 7	31.68	19.72	18.98	16.28	18.98
	Gate 8	29.45	21.02	20.58	20.28	20.58
Run 6#	Gate 1	27.78	23.00	23.32	22.33	22.12
	Gate 2	22.00	19.47	19.22	19.08	19.03
	Gate 3	28.05	19.37	17.87	16.73	16.87

	Gate 4	25.22	18.78	18.62	18.93	18.53
	Gate 5	26.75	22.92	19.43	21.10	20.73
	Gate 6	21.40	21.90	22.05	23.20	22.80
	Gate 7	32.05	19.57	19.05	17.30	17.93
	Gate 8	30.62	21.18	20.40	20.42	20.07
Run 7#	Gate 1	27.78	22.20	23.52	22.45	22.18
	Gate 2	22.00	19.55	19.70	18.80	19.08
	Gate 3	27.75	19.18	18.07	17.58	16.85
	Gate 4	24.65	19.15	18.77	19.20	18.07
	Gate 5	26.85	23.20	20.33	18.72	20.92
	Gate 6	25.75	23.03	19.88	22.67	21.95
	Gate 7	31.02	20.92	17.63	18.02	17.77
	Gate 8	29.30	21.22	20.48	20.33	20.17
Run 8#	Gate 1	28.20	22.95	23.02	22.28	22.50
	Gate 2	22.20	19.62	19.55	19.32	18.87
	Gate 3	27.87	19.30	18.22	17.62	17.15
	Gate 4	24.57	18.47	18.88	18.58	17.27
	Gate 5	27.17	23.08	21.98	19.68	19.50
	Gate 6	23.90	22.78	23.62	22.72	21.82
	Gate 7	31.57	22.50	17.48	18.88	18.57
	Gate 8	29.37	21.07	20.45	20.37	20.17
Run 9#	Gate 1	27.90	23.25	22.58	22.40	22.42
	Gate 2	22.33	19.25	19.65	18.85	18.93
	Gate 3	28.05	19.52	18.30	17.32	17.08
	Gate 4	25.07	20.45	17.70	17.93	18.20
	Gate 5	26.63	21.52	20.42	21.47	19.95
	Gate 6	23.20	22.52	22.23	22.55	19.63
	Gate 7	30.92	19.05	19.08	17.08	17.30
	Gate 8	29.38	21.17	20.60	20.40	20.22
Run 10#	Gate 1	27.95	23.37	23.23	22.83	22.43
	Gate 2	22.05	19.48	19.62	19.28	19.20
	Gate 3	27.98	19.42	17.85	17.43	16.90
	Gate 4	25.35	19.12	18.05	17.43	17.87
	Gate 5	26.73	22.42	19.42	20.33	19.82
	Gate 6	25.07	22.50	22.25	22.42	20.00
	Gate 7	33.50	21.90	20.02	18.72	18.12
	Gate 8	32.17	21.18	20.77	20.42	20.50
Mean	Gate 1	27.97	23.23	23.20	22.56	22.67
	Gate 2	22.12	19.52	19.46	19.22	19.00
	Gate 3	28.02	19.41	17.99	17.17	16.89
	Gate 4	24.55	19.41	18.43	18.34	18.02
	Gate 5	26.82	22.73	20.61	20.40	20.33
	Gate 6	24.34	22.74	21.72	22.65	21.27
	Gate 7	32.22	21.22	19.12	17.94	18.21
	Gate 8	30.26	21.14	20.60	20.42	20.27

t-Test: Paired Two Sample for Means

	20	*10*
Mean	21.17458	27.03563
Variance	2.829297	10.508
Observations	80	80
Pearson Correlation	0.222605	
Hypothesized Mean Difference	0	
df	79	
t Stat	-15.8713	
P(T<=t) one-tail	1.37E-26	
t Critical one-tail	1.664371	
P(T<=t) two-tail	2.74E-26	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	20	*30*
Mean	21.17458	20.14063
Variance	2.829297	3.179106
Observations	80	80
Pearson Correlation	0.713566	
Hypothesized Mean Difference	0	
df	79	
t Stat	7.034625	
P(T<=t) one-tail	3.21E-10	
t Critical one-tail	1.664371	
P(T<=t) two-tail	6.42E-10	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	20	*40*
Mean	21.17458	19.83688
Variance	2.829297	4.050342
Observations	80	80
Pearson Correlation	0.723018	
Hypothesized Mean Difference	0	
df	79	
t Stat	8.493374	
P(T<=t) one-tail	4.75E-13	
t Critical one-tail	1.664371	
P(T<=t) two-tail	9.5E-13	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	20	*60*
Mean	21.17458	19.58229
Variance	2.829297	3.538139
Observations	80	80
Pearson Correlation	0.726775	
Hypothesized Mean Difference	0	
df	79	
t Stat	10.70937	
P(T<=t) one-tail	2.38E-17	
t Critical one-tail	1.664371	
P(T<=t) two-tail	4.76E-17	
t Critical two-tail	1.99045	

APPENDIX I

SENSITIVITY DATA OF DCH

DCH		1.40	1.60	1.80	2*	2.20
Run 1#	Gate 1	23.28	22.78	23.47	23.68	24.15
	Gate 2	19.58	19.38	19.65	19.47	19.92
	Gate 3	18.82	18.78	19.58	19.68	20.48
	Gate 4	18.93	18.28	18.92	18.78	20.25
	Gate 5	21.18	20.68	23.13	23.63	23.37
	Gate 6	22.47	21.33	24.85	23.03	22.77
	Gate 7	21.77	22.45	23.33	20.52	21.85
	Gate 8	21.12	21.17	21.00	21.17	21.17
Run 2#	Gate 1	23.45	23.80	23.97	23.10	23.32
	Gate 2	19.30	19.33	19.37	19.62	19.35
	Gate 3	19.23	19.10	19.73	19.52	20.42
	Gate 4	18.42	19.25	18.48	20.15	19.30
	Gate 5	20.42	22.35	21.47	21.67	24.95
	Gate 6	21.83	22.13	21.77	22.48	25.25
	Gate 7	21.78	19.68	19.97	21.10	18.38
	Gate 8	21.12	21.12	21.08	21.08	21.18
Run 3#	Gate 1	22.68	23.48	24.10	24.52	23.58
	Gate 2	19.80	19.30	19.73	19.28	19.13
	Gate 3	19.03	18.97	19.33	19.80	20.38
	Gate 4	17.92	18.78	20.10	20.18	20.32
	Gate 5	22.55	22.12	23.08	23.25	23.88
	Gate 6	22.63	23.65	22.55	24.23	21.43
	Gate 7	22.57	24.05	23.20	21.32	21.27
	Gate 8	24.27	21.12	21.25	21.15	21.18
Run 4#	Gate 1	21.18	23.10	22.80	23.65	23.68
	Gate 2	19.62	19.30	19.52	19.58	19.62
	Gate 3	18.78	18.67	19.37	19.63	20.47
	Gate 4	19.68	19.90	20.30	20.02	19.52
	Gate 5	21.77	20.80	23.80	23.97	24.65
	Gate 6	22.58	20.25	22.97	23.18	23.12
	Gate 7	22.55	23.38	22.02	24.00	21.60
	Gate 8	21.12	21.17	21.20	21.30	21.27
Run 5#	Gate 1	23.45	24.10	23.23	23.72	24.33
	Gate 2	19.40	19.28	19.55	19.75	19.47
	Gate 3	18.85	19.02	19.33	19.60	20.43
	Gate 4	18.77	20.00	20.33	20.95	19.10
	Gate 5	23.02	22.80	22.67	23.10	25.03
	Gate 6	22.55	22.08	22.53	24.72	24.67
	Gate 7	21.28	19.77	19.72	19.72	18.55
	Gate 8	21.08	21.10	21.02	21.10	21.13
Run 6#	Gate 1	22.32	22.55	23.00	24.35	23.13
	Gate 2	19.93	19.40	19.47	19.35	19.80
	Gate 3	18.83	19.13	19.37	19.55	20.38

	Gate 4	18.58	19.23	18.78	20.45	20.55
	Gate 5	21.23	21.98	22.92	23.95	24.08
	Gate 6	22.53	21.98	21.90	23.83	25.35
	Gate 7	21.42	19.00	19.57	21.80	18.93
	Gate 8	21.10	20.90	21.18	21.12	21.13
Run 7#	Gate 1	23.32	22.75	22.20	22.70	23.60
	Gate 2	19.45	19.68	19.55	19.93	19.48
	Gate 3	18.93	18.93	19.18	19.47	19.93
	Gate 4	18.15	19.28	19.15	19.33	19.35
	Gate 5	20.08	20.73	23.20	23.43	22.57
	Gate 6	20.73	22.75	23.03	23.18	22.92
	Gate 7	23.20	20.17	20.92	19.77	23.17
	Gate 8	21.28	21.10	21.22	21.08	21.07
Run 8#	Gate 1	22.97	23.38	22.95	23.23	23.30
	Gate 2	19.15	19.55	19.62	19.68	19.83
	Gate 3	18.98	19.10	19.30	20.00	20.35
	Gate 4	18.43	19.08	18.47	19.93	20.97
	Gate 5	22.20	21.02	23.08	23.32	23.85
	Gate 6	21.78	22.40	22.78	24.57	23.03
	Gate 7	21.73	22.97	22.50	18.73	20.88
	Gate 8	21.23	21.07	21.07	21.02	21.05
Run 9#	Gate 1	22.73	22.92	23.25	23.85	22.95
	Gate 2	19.37	19.17	19.25	19.43	19.33
	Gate 3	18.67	18.83	19.52	19.70	19.30
	Gate 4	19.62	18.40	20.45	19.25	20.28
	Gate 5	20.88	22.97	21.52	23.63	23.73
	Gate 6	23.12	23.82	22.52	23.27	25.40
	Gate 7	21.07	20.70	19.05	20.17	21.80
	Gate 8	21.13	21.10	21.17	21.37	20.98
Run 10#	Gate 1	23.23	23.33	23.37	23.12	23.42
	Gate 2	19.53	19.47	19.48	19.42	19.87
	Gate 3	19.05	18.92	19.42	19.83	20.17
	Gate 4	19.28	19.87	19.12	19.92	18.97
	Gate 5	22.28	23.00	22.42	22.58	24.18
	Gate 6	23.37	23.02	22.50	22.85	23.35
	Gate 7	24.90	23.65	21.90	22.17	21.03
	Gate 8	21.22	21.10	21.18	21.10	21.22
Mean	Gate 1	22.86	23.22	23.23	23.59	23.55
	Gate 2	19.51	19.39	19.52	19.55	19.58
	Gate 3	18.92	18.95	19.41	19.68	20.23
	Gate 4	18.78	19.21	19.41	19.90	19.86
	Gate 5	21.56	21.85	22.73	23.25	24.03
	Gate 6	22.36	22.34	22.74	23.54	23.73
	Gate 7	22.23	21.58	21.22	20.93	20.75
	Gate 8	21.47	21.09	21.14	21.15	21.14

t-Test: Paired Two Sample for Means

	2	*1.4*
Mean	21.44792	20.96083
Variance	3.215193	2.91735
Observations	80	80
Pearson Correlation	0.718604	
Hypothesized Mean Difference	0	
df	79	
t Stat	3.311432	
P(T<=t) one-tail	0.000701	
t Critical one-tail	1.664371	
P(T<=t) two-tail	0.001401	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	2	*1.6*
Mean	21.44792	20.95271
Variance	3.215193	2.974166
Observations	80	80
Pearson Correlation	0.779895	
Hypothesized Mean Difference	0	
df	79	
t Stat	3.789763	
P(T<=t) one-tail	0.000147	
t Critical one-tail	1.664371	
P(T<=t) two-tail	0.000293	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	2	*1.8*
Mean	21.44792	21.17458
Variance	3.215193	2.829297
Observations	80	80
Pearson Correlation	0.8456	
Hypothesized Mean Difference	0	
df	79	
t Stat	2.516642	
P(T<=t) one-tail	0.006937	
t Critical one-tail	1.664371	
P(T<=t) two-tail	0.013873	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	2	*2.2*
Mean	21.44792	21.60771
Variance	3.215193	3.718846
Observations	80	80
Pearson Correlation	0.807221	
Hypothesized Mean Difference	0	
df	79	
t Stat	-1.22938	
P(T<=t) one-tail	0.111289	
t Critical one-tail	1.664371	
P(T<=t) two-tail	0.222577	
t Critical two-tail	1.99045	

APPENDIX J

SENSITIVITY DATA OF SULT

SULT		1.40	1.60	1.80	2*	2.20
Run 1#	Gate 1	23.07	25.83	24.60	23.47	24.88
	Gate 2	18.23	18.35	17.43	19.65	19.50
	Gate 3	19.43	19.47	19.48	19.58	19.80
	Gate 4	18.47	18.72	20.30	18.92	20.58
	Gate 5	19.42	22.10	20.92	23.13	21.83
	Gate 6	23.08	22.70	20.22	24.85	23.43
	Gate 7	22.18	21.17	23.43	23.33	22.83
	Gate 8	21.20	21.43	23.18	21.00	21.17
Run 2#	Gate 1	23.82	26.00	21.00	23.97	24.10
	Gate 2	18.18	18.42	17.67	19.37	19.07
	Gate 3	19.38	19.50	18.80	19.73	19.65
	Gate 4	19.53	18.43	19.53	18.48	19.68
	Gate 5	21.08	23.02	20.17	21.47	19.47
	Gate 6	22.70	21.75	22.13	21.77	22.67
	Gate 7	20.50	21.50	19.98	19.97	22.00
	Gate 8	21.05	21.32	21.12	21.08	21.10
Run 3#	Gate 1	24.35	26.28	24.65	24.10	23.38
	Gate 2	17.93	18.82	17.10	19.73	19.55
	Gate 3	19.18	19.37	19.65	19.33	19.32
	Gate 4	18.45	20.65	18.45	20.10	20.82
	Gate 5	20.62	22.83	20.65	23.08	21.45
	Gate 6	22.75	22.40	21.90	22.55	24.62
	Gate 7	22.12	23.50	23.88	23.20	22.43
	Gate 8	21.07	21.33	21.25	21.25	21.23
Run 4#	Gate 1	24.13	26.85	24.65	22.80	23.52
	Gate 2	18.40	18.38	17.82	19.52	19.40
	Gate 3	19.27	19.35	19.22	19.37	19.67
	Gate 4	18.57	19.58	19.35	20.30	19.90
	Gate 5	20.47	21.58	22.00	23.80	21.20
	Gate 6	22.38	22.98	22.73	22.97	22.25
	Gate 7	21.33	22.72	20.37	22.02	21.85
	Gate 8	21.08	21.38	21.03	21.20	21.38
Run 5#	Gate 1	23.35	23.47	23.55	23.23	24.07
	Gate 2	18.20	17.95	17.77	19.55	19.58
	Gate 3	19.72	19.22	19.18	19.33	19.57
	Gate 4	20.00	18.83	20.00	20.33	19.25
	Gate 5	21.15	22.70	23.95	22.67	21.22
	Gate 6	22.22	24.22	23.53	22.53	22.47
	Gate 7	21.53	19.37	19.68	19.72	19.67
	Gate 8	21.03	21.13	21.17	21.02	21.23
Run 6#	Gate 1	23.85	23.27	24.22	23.00	24.40
	Gate 2	18.25	18.28	17.75	19.47	19.53
	Gate 3	19.43	19.18	19.20	19.37	19.33

	Gate 4	18.73	18.95	18.57	18.78	19.30
	Gate 5	21.20	21.85	22.02	22.92	21.32
	Gate 6	20.90	21.88	22.80	21.90	22.25
	Gate 7	21.22	20.17	20.20	19.57	19.18
	Gate 8	21.20	21.00	21.22	21.18	21.08
Run 7#	Gate 1	23.57	24.45	24.53	22.20	24.28
	Gate 2	18.32	18.20	17.57	19.55	19.42
	Gate 3	19.72	19.28	18.82	19.18	19.87
	Gate 4	17.77	19.27	19.27	19.15	19.90
	Gate 5	21.42	19.95	19.83	23.20	22.15
	Gate 6	22.87	23.22	22.75	23.03	22.30
	Gate 7	22.57	22.68	22.10	20.92	21.03
	Gate 8	21.13	21.27	21.05	21.22	21.08
Run 8#	Gate 1	23.95	24.28	24.45	22.95	24.23
	Gate 2	18.13	18.27	17.32	19.62	19.72
	Gate 3	19.25	19.20	18.97	19.30	19.62
	Gate 4	18.62	18.68	18.48	18.47	19.63
	Gate 5	20.62	19.85	20.73	23.08	20.70
	Gate 6	21.40	22.03	22.73	22.78	21.93
	Gate 7	20.68	22.20	22.23	22.50	21.33
	Gate 8	20.95	21.07	21.17	21.07	21.00
Run 9#	Gate 1	24.63	24.77	24.78	23.25	24.32
	Gate 2	18.27	18.15	17.62	19.25	19.73
	Gate 3	19.38	19.43	19.55	19.52	19.77
	Gate 4	18.25	19.28	18.93	20.45	20.87
	Gate 5	22.23	20.60	22.03	21.52	21.95
	Gate 6	23.13	23.93	23.00	22.52	22.63
	Gate 7	19.82	20.37	21.15	19.05	20.25
	Gate 8	21.07	21.03	21.03	21.17	21.00
Run 10#	Gate 1	23.45	23.55	24.80	23.37	23.80
	Gate 2	18.40	17.95	17.63	19.48	19.48
	Gate 3	19.48	19.33	19.28	19.42	19.23
	Gate 4	19.92	19.67	19.33	19.12	19.95
	Gate 5	21.12	21.63	22.23	22.42	21.07
	Gate 6	21.98	21.82	22.15	22.50	22.87
	Gate 7	20.77	21.15	20.73	21.90	23.22
	Gate 8	21.18	21.13	21.17	21.18	21.25
Mean	Gate 1	23.82	24.88	24.12	23.23	24.10
	Gate 2	18.23	18.28	17.57	19.52	19.50
	Gate 3	19.43	19.33	19.22	19.41	19.58
	Gate 4	18.83	19.21	19.22	19.41	19.99
	Gate 5	20.93	21.61	21.45	22.73	21.24
	Gate 6	22.34	22.69	22.40	22.74	22.74
	Gate 7	21.27	21.48	21.38	21.22	21.38
	Gate 8	21.10	21.21	21.34	21.14	21.15

t-Test: Paired Two Sample for Means

	2	*1.4*
Mean	21.17458	20.74313
Variance	2.829297	3.357375
Observations	80	80
Pearson Correlation	0.802147	
Hypothesized Mean Difference	0	
df	79	
t Stat	3.462534	
P(T<=t) one-tail	0.000433	
t Critical one-tail	1.664371	
P(T<=t) two-tail	0.000867	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	2	*1.6*
Mean	21.17458	21.08604
Variance	2.829297	4.715692
Observations	80	80
Pearson Correlation	0.829992	
Hypothesized Mean Difference	0	
df	79	
t Stat	0.650621	
P(T<=t) one-tail	0.258589	
t Critical one-tail	1.664371	
P(T<=t) two-tail	0.517179	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	2	*1.8*
Mean	21.17458	20.83625
Variance	2.829297	4.579415
Observations	80	80
Pearson Correlation	0.777143	
Hypothesized Mean Difference	0	
df	79	
t Stat	2.246815	
P(T<=t) one-tail	0.013721	
t Critical one-tail	1.664371	
P(T<=t) two-tail	0.027443	
t Critical two-tail	1.99045	

t-Test: Paired Two Sample for Means

	2	*2.2*
Mean	21.17458	21.20958
Variance	2.829297	2.666356
Observations	80	80
Pearson Correlation	0.837026	
Hypothesized Mean Difference	0	
df	79	
t Stat	-0.33041	
P(T<=t) one-tail	0.370982	
t Critical one-tail	1.664371	
P(T<=t) two-tail	0.741964	
t Critical two-tail	1.99045	

APPENDIX K

SENSITIVITY DATA OF DRIVER TYPE

Driver Type		Low A	High A
Run 1#	Gate 1	30.00	23.47
	Gate 2	23.62	19.65
	Gate 3	29.08	19.58
	Gate 4	27.80	18.92
	Gate 5	29.75	23.13
	Gate 6	40.97	24.85
	Gate 7	25.95	23.33
	Gate 8	33.78	21.00
Run 2#	Gate 1	29.73	23.97
	Gate 2	23.37	19.37
	Gate 3	29.30	19.73
	Gate 4	28.48	18.48
	Gate 5	30.25	21.47
	Gate 6	41.37	21.77
	Gate 7	25.00	19.97
	Gate 8	33.75	21.08
Run 3#	Gate 1	30.67	24.10
	Gate 2	23.25	19.73
	Gate 3	28.98	19.33
	Gate 4	27.77	20.10
	Gate 5	29.53	23.08
	Gate 6	39.60	22.55
	Gate 7	29.13	23.20
	Gate 8	33.65	21.25
Run 4#	Gate 1	29.95	22.80
	Gate 2	23.33	19.52
	Gate 3	30.80	19.37
	Gate 4	29.03	20.30
	Gate 5	29.18	23.80
	Gate 6	39.77	22.97
	Gate 7	27.98	22.02
	Gate 8	33.80	21.20
Run 5#	Gate 1	30.15	23.23
	Gate 2	23.48	19.55
	Gate 3	29.35	19.33
	Gate 4	28.95	20.33
	Gate 5	30.22	22.67
	Gate 6	41.45	22.53
	Gate 7	28.68	19.72
	Gate 8	33.95	21.02

Run 6#	Gate 1	29.98	23.00
	Gate 2	23.82	19.47
	Gate 3	29.40	19.37
	Gate 4	26.78	18.78
	Gate 5	28.87	22.92
	Gate 6	39.53	21.90
	Gate 7	27.78	19.57
	Gate 8	33.55	21.18
Run 7#	Gate 1	30.13	22.20
	Gate 2	23.67	19.55
	Gate 3	29.22	19.18
	Gate 4	28.78	19.15
	Gate 5	28.68	23.20
	Gate 6	38.12	23.03
	Gate 7	28.90	20.92
	Gate 8	33.83	21.22
Run 8#	Gate 1	30.02	22.95
	Gate 2	23.67	19.62
	Gate 3	29.30	19.30
	Gate 4	27.07	18.47
	Gate 5	29.75	23.08
	Gate 6	40.35	22.78
	Gate 7	27.40	22.50
	Gate 8	33.58	21.07
Run 9#	Gate 1	30.73	23.25
	Gate 2	23.35	19.25
	Gate 3	29.33	19.52
	Gate 4	27.57	20.45
	Gate 5	29.43	21.52
	Gate 6	40.18	22.52
	Gate 7	25.92	19.05
	Gate 8	33.52	21.17
Run 10#	Gate 1	30.38	23.37
	Gate 2	23.12	19.48
	Gate 3	29.17	19.42
	Gate 4	28.22	19.12
	Gate 5	29.07	22.42
	Gate 6	39.92	22.50
	Gate 7	28.82	21.90
	Gate 8	34.00	21.18

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	30.24708	21.17458
Variance	21.92279	2.829297
Observations	80	80
Pearson Correlation	0.500197	
Hypothesized Mean Difference	0	
df	79	
t Stat	19.75476	
P(T<=t) one-tail	1.33E-32	
t Critical one-tail	1.664371	
P(T<=t) two-tail	2.67E-32	
t Critical two-tail	1.99045	