Demand Based Signal Retiming

Contract #: BDK79-977-05

Final Report

March, 2014

Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Metric Conversion Table

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Technical Report Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Demand Based Signal Retiming	5. Report Date December 31st. , 2013
	6. Performing Organization Code

7. Author(s) Aleksandar Stevanovic, Soheil Sajjadi, Jaehyun So.	8. Performing Organization Report No.

9. Performing Organization Name and Address Florida Atlantic University 777 Glades Rd., Bldg. 36, Boca Raton, FL 33431.	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. BDK79-977-05

12. Sponsoring Agency Name and Address Florida Department of Transportation Research Center 605 Suwannee Street MS-30 Tallahassee, FL 32399-0450 USA	13. Type of Report and Period Covered Draft Final Report From April 2012 To December 2013
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The objective of this research was to develop a method that can be implemented by a signal maintaining agency in Florida to measure and report traffic demand in real-time and to predict demand by using methods calibrated through microsimulation models. This research defines demand thresholds that would indicate safety and mobility problems on an arterial network in Broward County equipped with an Advanced Transportation Management System (ATMS) comprising of Intelligent Transportation System (ITS) devices and data reporting software. High fidelity traffic simulation models were developed in the VISSIM microsimulation platform and used to model traffic demand as it would be measured from the available field data sources. An algorithm was developed to measure true traffic demand, by using second-by-second information about vehicular presence on links between signalized intersections. Results from this algorithm were used for benchmark testing of all other methods to estimate actual traffic demand. Multiple recurring and nonrecurring congestion scenarios were developed to reflect field traffic conditions. For each of those scenarios appropriate strategies were defined to alleviate the traffic congestion caused by those scenarios. The results show that various traffic scenarios have distinctive performance signatures which can help Traffic Management Center (TMC) operators to recognize those scenarios by observing traffic data from the field ATMS devices. The practical thresholds, strategies and potential benefits of the scenarios are included in the traffic operating guidelines, a document that is attached (as an appendix) to this report.

17. Key Word Demand; Mobility; Software; Traffic signal control systems; Traffic signal timing	18. Distribution Statement No restrictions.		
19. Security Classif. (of this report): Unclassified.	20. Security Classif. (of this page) Unclassified.	21. No. of Pages: 302	22. Price

Acknowledgements

Executive Summary

Traffic congestion represents a major problem in urban areas in the U.S. With a constant increase in the driving population, the roadway infrastructure is unable to keep its pace, and our highway networks are more frequently experiencing oversaturated traffic conditions. For these reasons, traffic oversaturation is manifested, more than ever before, both temporally and spatially.

One of the major requirements to successfully deal with oversaturated traffic conditions is the ability to measure traffic demand by detecting temporal and spatial boundaries of oversaturated conditions. Satisfying this requirement is usually an expensive task because it requires a comprehensive set of traffic sensors that cover the entire network under consideration. Once such an extensive set of sensors is installed, it can be used to monitor traffic demand and oversaturation in real-time and deploy a set of strategies to reduce the negative impact of traffic congestion. It should be noted here that traffic oversaturation cannot be fought with operational tools alone. For example, retiming traffic signals will have an effect only to a certain extent; therefore, other traffic demand management strategies should also be deployed, such as multi-modal transportation, congestion pricing, telecommuting, flexible work hours, and others. Although traffic operation tools and methods cannot prevent oversaturated traffic conditions, they can help to reduce the degree of spatial and temporal oversaturation.

The Florida Department of Transportation (FDOT) Transportation Systems Management and Operations (TSM&O) program's main objective is to improve safety and mobility by implementing real-time strategies by monitoring traffic conditions utilizing Intelligent Transportation Systems (ITS) infrastructure in the state of Florida A considerable amount of information is collected in the current ITS infrastructure, which provides agencies with large amounts of raw data;, however, a need exists for a robust and effective framework that would allow agencies to use this data in real-time to optimize transportation systems.

The TSM&O program will use several methods of traffic operations and management to provide better mobility and promote positive safety in Florida transportation system. The ITS infrastructure monitors different performance measures (speed, volume, and travel times). However, it is not possible to estimate traffic demand directly from the field data. Traffic demand should be considered when deploying certain strategies on arterial networks, optimizing traffic operations, or managing traffic.

The objective of this research is to develop a method that can be implemented by a signal-maintaining agency in Florida to measure and report demand in real-time and to predict demand using microsimulation models. The demand and other performance measures thresholds will be used to identify network traffic condition. Additionally, this research will use the developed thresholds as mobility indicators. The outcome of the research is a guideline, which helps traffic operators to manage and control different traffic scenarios effectively. In order to reach these objectives, the following tasks were defined:

- Build, calibrate, and validate a microsimulation model
- Identify types and formats of traffic data from the field sensors
- Identify performance measures for traffic demand
- Develop methods to derive traffic demand from available field data

- Identify traffic demand thresholds to activate strategies
- Develop strategies to improve traffic condition
- Identify and model a variety of traffic demand scenarios
- Evaluate impact of the selected strategies on the road network.
- Develop and evaluate TMC operating guidelines.

Two high fidelity microsimulation models were developed in this study as network and Broward Blvd. models. The network model encompasses major corridors in central Broward County. The major corridors modeled in this simulation model are Oakland Park Blvd., Sunrise Blvd., Broward Blvd., Davie Blvd., SR-7, and US-1. The area also represents the scope of the research project. Also, Broward Blvd. was separately modeled, calibrated, and validated. Broward Blvd. represents the heart of Fort Lauderdale and is lined with many businesses, entertainment, and attraction areas.

The review of literature in this study included a review of previous research efforts related to this study. The literature review tasks were subdivided into different project tasks.

This study has developed multiple procedures and tools to derive traffic demand from both simulation and field data. An algorithm was developed to estimate traffic demand in a microsimulation models. Also, several statistical models were generated to estimate traffic demand from its surrogates such as throughput, occupancy, spot speed, and travel time. Geometrical characteristics were also considered for demand modeling. The result of the demand modeling showed that assuming a linear relationship between traffic demand and traffic and geometrical parameters is reasonable.

Several recurring and nonrecurring scenarios were identified and modeled in the microsimulation model. The recurring scenarios included base, saturation, and oversaturation scenarios, and nonrecurring scenarios included freeway incidents, left-turn spillover, rail preemption, arterial incidents, and event traffic. Appropriate strategies to alleviate the congestion of each strategy were also developed and evaluated using the microsimulation models.

Based on the results of this study, it was concluded that methodologies and procedures developed in this research study can be utilized to derive traffic demand and other traffic parameters from the simulation model. Methods and procedures developed in this research will be used to derive traffic demand from the available field sensors. For example, Bluetooth detection devices can supply travel times whereas mid-block sensors can provide volume, speed, and occupancy data wherever such data are used in the developed procedures. The performance measures' thresholds can be used to identify different traffic conditions in the field. Furthermore, several strategies can be tested and evaluated in the simulation model to select the most effective strategy to mitigate the resulted congestion of traffic scenarios.

The results of the study revealed that some scenarios, such as rail preemption, oversaturation, arterial incident and event traffic, possess stronger signatures compared to the other scenarios. Left turn spillover and saturation scenarios are hard to identify as they do not possess strong signatures. Rail preemption, oversaturation, and arterial incident scenarios imposed the highest congestion on the transportation network. This assessment is justified by the fact that a left-turn

spillover at this location does not create severe traffic congestion on the arterial, when compared to the other scenarios (e.g. rail preemption or incidents). A potential change in the location of this scenario (e.g. a left-turn spillover at another intersection) could yield different results but this location was selected due to proximity to field devices (BlueToad and mid-block sensors) which can be used to capture such an impact of the left-turn spillover.

The implementation of the strategies had different impact on different scenarios. The results of the strategy analysis showed that freeway incident and oversaturation scenarios were significantly impacted by the recommended strategies. The travel time decreased by 42.9% and 34.1% in freeway incident and oversaturation scenarios, respectively. The strategy of left-turn spillover scenario was not significantly effective as the maximum improvement in the traffic parameters was around 2.0%.

The scenario thresholds, strategies, and other supporting information are presented as the "Traffic Operators Guideline" document, which is submitted as a separate project deliverable. The proposed guideline includes detail information about each scenario, such as location, scope, identification strategy, and respective traffic strategy. The guideline also includes a summary of expected benefits of the recommended strategies.

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List of Selected Acronyms and Abbreviations

AADT	Annual Average Daily Traffic
ANOVA	Analysis of Variance
ATCS	Adaptive Traffic Control System
ATIS	Advanced Traffic Information System
ATMS	Advanced Traffic Management System
AVI	Automatic Vehicle Identification
BCTED	Broward County Traffic Engineering Department
BlueTOAD	Bluetooth Travel Time Origination And Destination
CBD	Central Business District
CCTV	Closed Circuit TV
CFEM	Curve-Fitting Estimation Model
CMS	Changeable Message Signs
CTAC	Combined Traffic Assignment and Control
DBSR	Demand Based Signal Retiming
DMS	Dynamic Message Signs
DOS	Disk Operating System
DSS	Decision Support System
DTA	Dynamic Traffic Assignment
FAU	Florida Atlantic University
FDOT	Florida Department of Transportation
FEC	Florida East Coast
FEFM	Federated Evidence Fusion Model
FHWA	Federal Highway Administration
GA	Genetic Algorithm
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphic User Interface
ICM	Integrated Corridor Management
ITS	Intelligent Transportation System
LTSO	Left Turn Spillover
MAPE	Mean Absolute Percentage Error
MILS	Man-In-the-Loop Systems
MOE	Measure Of Effectiveness
MPO	Metropolitan Planning Organization
NBA	National Basketball Association
O-D	Origin-Destination
OIL	Operator in the Loop
PTV	Planung Transport Verkehr
RBC	Ring Barrier Controllers

RCP	Recursive Cell Processing
RT/IMPOST	Real-time Traffic Control Policy
RTOR	Right Turn on Red
SCATS	Sydney Coordinated Adaptive Traffic System
SCOOT	Split Cycle Offset Optimization Technique
SDOT	Seattle Department of Transportation
SIL	Software in the Loop
TDM	Travel Demand Models
TMC	Traffic Message Channel
TOD	Time of the Day
TRPS	Traffic Responsive Pattern Selection
TSM&O	Transportation Systems Management and Operations
UTDF	Universal Traffic Data Format
VB.NET	Visual Basic .NET
VDS	Video Detection Systems
VISGAOST	VISSIM Based Genetic Algorithm Optimization of the Signal Retiming
VMS	Variable Message Signs
VNP	Virtual Next Phase

1. Introduction

1.1. Background

Traffic congestion represents a major problem in urban areas in the U.S. With a constant increase in the driving population, the roadway infrastructure is unable to keep pace, and our highway networks more frequently experience oversaturated traffic conditions. For these reasons, traffic oversaturation is manifested, more than ever before, both temporally (congestion is present on the network for longer time) and spatially (congestion spreads over a larger portion of the network).

One of the major requirements to successfully deal with oversaturated traffic conditions is the ability to measure traffic demand by detecting temporal and spatial boundaries of oversaturated conditions. Satisfying this requirement is usually an expensive task because it requires a comprehensive set of traffic sensors covering the entire network under consideration. Once such an extensive set of sensors is installed, it can be used to monitor traffic demand and oversaturation in real-time and deploy a set of strategies to reduce the negative impact of traffic congestion. It should be noted that traffic oversaturation cannot be fought with operational tools alone (e.g., retiming traffic signals will have an effect only up to a certain extent); therefore, other traffic demand management strategies should also be deployed (e.g., multi-modal transportation, congestion pricing, telecommuting, flexible work hours, etc.). Although traffic operation tools and methods cannot prevent oversaturated traffic conditions, they can reduce the degree of spatial and temporal oversaturation.

Two general categories of actions can be taken to alleviate traffic congestion: traffic control and traffic management. Traffic control is generally exercised, at least in urban networks with high traffic volumes, through a set of signal timing plans that provide the best traveling experiences for prevailing traffic demand throughout the day. In contrast, a good representative of traffic management techniques is dynamic message signs (DMS) (or variable message signs), which are used (traditionally more on freeways than on arterial streets) to inform drivers of downstream road conditions and, to a certain extent, to influence their driving decisions. DMS represent a powerful tool to reroute traffic and utilize residual capacities of a road network in a more efficient manner. The full potential of DMS in traffic mobility applications is yet to be discovered. In the near future, new wireless communication technologies will provide applications that will solidify feedback from the drivers to traffic management centers. Until then, it will be difficult to evaluate the impact of DMS on driver behavior.

The Florida Department of Transportation (FDOT) Transportation Systems Management and Operations (TSM&O) program intends to improve safety and mobility by implementing real-time strategies by monitoring traffic conditions utilizing Intelligent Transportation System (ITS) infrastructure. A considerable amount of information is collected in the current ITS infrastructure, which provides agencies with large amounts of raw data;, however, a need exists for a robust and effective framework that would allow agencies to use this data in real-time to optimize transportation systems.

1.2. FDOT TSM&O Program

One of the specific projects of the TSM&O program is the deployment of an Advanced Traffic Management System (ATMS) in central Broward County along major arterials. This project will deploy ITS infrastructure (data collection devices and communications), which will improve the monitoring and management of traffic conditions in central Broward County. The overall goal of the project, in an area that frequently faces oversaturated traffic conditions, is to provide better mobility for travelers. The Federal Highway Administration (FHWA) defines TSM&O as "an integrated program to optimize the performance of existing multimodal infrastructure through implementation of systems, services, and projects to preserve capacity and improve the security, safety, and reliability of our transportation system."

The TSM&O program is based on measuring performance, actively managing the multimodal transportation network, and delivering positive safety and mobility outcomes to the travelling public in Florida. The TSM&O program application may potentially include areas such as work zone management, freight management, freeway and arterial management, and transit operations and management.

More specifically, the goal of the TSM&O program in District 4 is to provide a framework for the active management of its transportation network. The principals of the program are summarized as follows:

1. Define a network to be managed
2. Define performance indicators and targets
3. Deploy and operate IT-based systems to manage traffic in real-time
4. Report performance outcomes
5. Improve performance

The FDOT TSM&O program will be implemented in FDOT District 4 in both Palm Beach and Broward Counties. The installation of the ITS infrastructure is being implemented in three phases. The current participating municipalities in FDOT District 4 include:

1. FDOT
2. Broward Metropolitan Planning Organization
3. Broward County Traffic Engineering Department
4. Broward County Transit
5. Palm Beach County Traffic Engineering
6. PalmTrans
7. The City of Boca Raton
8. The City of Palm Beach
9. St. Lucie County

In summary, due to high variation in traffic demand in the state of Florida, it is necessary to equip the area using ITS infrastructure. The TSM&O program will use different levers of traffic operations and management to provide better mobility and positive safety in the Florida transportation system. The ITS infrastructure monitors different performance measures (speed, volume, and travel times). However, it is not possible to estimate traffic demand directly from

field data. Traffic demand should be considered when deploying certain strategies on arterial networks, optimizing traffic operations, or managing traffic.

FDOT is interested in a research program that identifies or develops methods that utilize ITS infrastructure (such as vehicle detection cameras or vehicle detection sensors) to measure, report and utilize traffic demands to optimize the arterial network traffic condition. In addition, strong interest lies in developing a Decision Support System (DSS) for the ad-hoc traffic operator's decision making. The guidelines should provide clear and effective instructions regarding how to implement certain traffic or incident management strategies such as DMS signing, road ranger deployment, signal retiming, and others.

1.3. Project Objectives

The objective of this research is to develop a method that can be implemented by a signal-maintaining agency in Florida for measuring and reporting demand measures in both real-time and predicted. The demand thresholds will be used to identify network traffic conditions. Additionally, other traffic parameters such as throughput, occupancy, speed, and travel time are considered and appropriate thresholds are identified to determine the traffic condition. Additionally this research will use identified thresholds as transportation network mobility indicators. The outcome of the research is a guideline, which helps traffic operators to manage and control different traffic scenarios effectively. In order to reach these objectives, the following tasks were defined:

1. Build, calibrate, and validate a microsimulation model
2. Identify types and formats of traffic data from the field sensors
3. Identify performance measures for traffic demand
4. Develop methods to derive traffic demand from available field data
5. Identify traffic demand thresholds to activate strategies
6. Develop strategies to improve traffic condition
7. Identify and model a variety of traffic demand scenarios
8. Evaluate impact of the selected strategies on the road network.
9. Develop and evaluate TMC operating guidelines.

1.4. Proposed Research Approach

In order to accomplish project goals, the FAU research team proposed three solutions in different time spans of long, medium, and short term.

1.4.1. Long-Term Solution - A Combined Traffic Control and Route Guidance System

The Florida Atlantic University (FAU) Research Team expects that in the long-term future, once real-time data protocols and formats are firmly established and emerging technologies are proven, the project objectives will be addressed by combined traffic control and route guidance systems. An example application of this system is the use of DMS to reroute traffic when an incident occurs on arterial streets. As a result, the other route would receive an extra inflow of cars, which cannot be accommodated by the existing capacity of the traffic signals. To increase traffic signal capacity, the signals are retimed based on real-time increased traffic demand. This particular approach is known in the scientific community as the Combined Traffic Assignment

and Control (CTAC) problem, and numerous papers have addressed the theory behind this approach. (Meneguzzer, 1997)

Farhan, et al. (2010) implemented the practical application of this approach in a microsimulation environment, and the results were encouraging. This approach has been studied in only academic exercises and journal papers; however, recently, its application was implemented in the field.

Historically, responsive and adaptive traffic control systems have been used for the purpose represented as the major research problem of this study – to measure traffic demand and develop signal timing plans "on the fly" to ultimately improve traffic performance. However, the deployment of an ATCS is not recommended in Broward County due to the following reasons:

1. A steep learning curve is needed to implement and operate ATCS
2. Uncertainty of the benefits and costs associated with ATCS deployment
3. A pre-installation study is needed to investigate which to select appropriate ATCS
4. Only few ATCSs can perform very efficiently in grid networks
5. There is a necessity to use special interfaces to measure benefits of ATCS.
6. Software and hardware requirements are different from existing infrastructure. (Stevanovic, 2010)

1.4.2. Medium-Term Solution - Automated Signal Retiming Process

While waiting for new emerging technologies such as CTAC to be proven and widely deployed, we propose that FDOT and Broward County make the process presented in this study semi-automatic. The primary idea is that once traffic demand reporting mechanisms and the threshold are established, a signal retiming process will be defined to run automatically in the background with repetitions every 15 or 60 minutes. A robust reporting mechanism with visualization of the measured data and estimated benefits could be used by Traffic Management Center (TMC) operators for near real-time decision-making. The following are the major components of this process:

1. Collect data from the field – identify the points for the field data collection that signals that the retiming process can be automatic
2. Populate signal retiming data using UTDF (Universal Traffic Data Format) or a similar data format
3. Feed data into the signal retiming software
4. Recalculate signal timings (specify various types of optimizations that should be performed); recalculate every 15 or 60 minutes depending on the time necessary to perform optimizations
5. Compare the performance of the resulting signal timings with existing timings running in the field (benefits could be recorded for the entire network and individual intersections – it would be beneficial for operators to observe if the signal retiming benefits are associated with the same intersection where oversaturation occurs)
6. Store signal timings in the database in a format compatible with field hardware and software (e.g., Naztec controllers and ATMS.now)
7. Visualize in real-time (e.g., dynamic chart in a spreadsheet) the benefits of signal retiming (e.g., level of throughput improvement)

8. Always keep two or three signal timing plans. For example, the best signal plan based on historic data or the best signal plan based on predictive models, which recognizes a pattern-matching algorithm to recognize one-hour patterns using 15-minute datasets. The datasets are available for an easy download to field controllers
9. Based on the estimated benefits and/or engineering judgment, a TMC operator decides whether he/she wants to implement a recommended signal timing plan

The proposed medium-term solution represents a type of semi-adaptive signal control. Data collection and signal retiming processes would be automatic; however, the implementation of signal timings would be manual. Similar processes are called the Man-In-the-Loop Systems (MILS) and have been implemented in environments that are known for a long history of facing problems with over-saturated traffic conditions. (Wuping et al., 2008)

One practical approach of the proposed system is a traffic signal operator who has the opportunity to make a judgment whether reported benefits of updating signal timing plans are sufficient to warrant changes in signal timings.

1.4.3. Short-Term Solution - Development of Signal Timing Plans Based on Demand

A short-term (or immediate) solution to the problem of demand-based signal retiming is the core of the FAU research team effort, which is the primary focus of this research program. The short-term solution is based on the following factors:
1. Types and formats of the existing and future real-time traffic data
2. Availability of software, hardware, and communication devices in the study area
3. Size and shape of the arterial network
4. Protocols, procedures, and practices of the staff from the stakeholder Traffic Management Center (TMC)

1.5. Study Scope

The study covers the Central Business District (CBD) of the city of Fort Lauderdale, which is located between SR -7 and US-1, from east to west, and between Davie Blvd. and Oakland Blvd., from south to north. The area also includes the Fort Lauderdale downtown area of Broward Blvd. and Sunrise Blvd. Six major corridors are present in the scope of the project as follows:

1. Oakland Park Blvd.
2. Sunrise Blvd.
3. Broward Blvd.
4. Davie Blvd.
5. SR-7
6. US-1

The study area will be equipped with ITS infrastructure through "ATMS Installation in Central Broward County Phase I (FM #427971-1)", which was awarded in January 2012. The project includes the design and deployment of ATMS infrastructure along portions of Broward Blvd., Sunrise Blvd., Oakland Park Blvd., US1/Federal Hwy, SR-7, and University Dr. The project

components include 10 dynamic message signs, 63 traffic-monitoring cameras, 33 travel time collection sites, 54 vehicle data collection devices, software to manage the devices, and approximately 18 miles of fiber optic cable and required conduit. A map of the study area is shown in Figure 1.
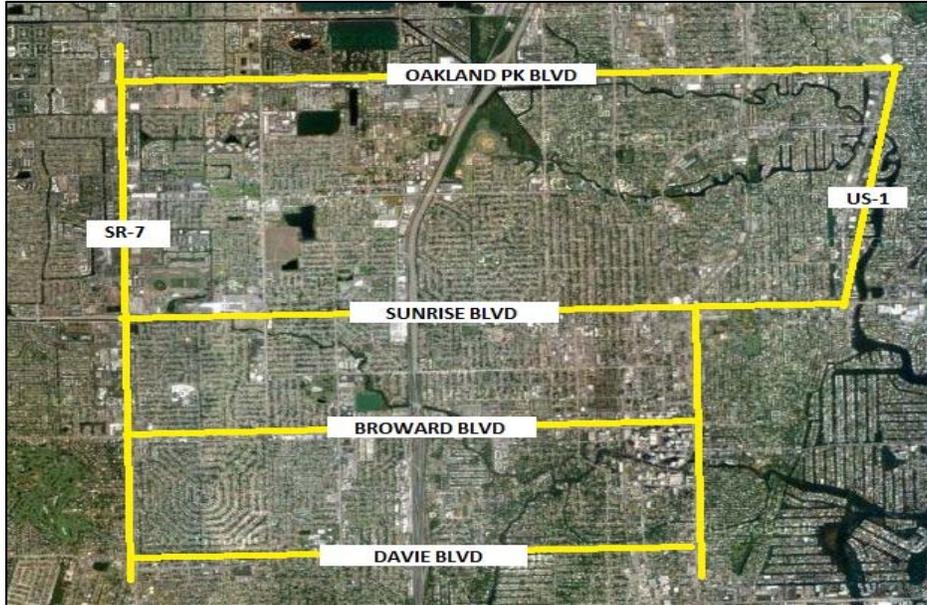
Figure 1- Map of the Study Area and Six Major Corridors under Study

It should be noted that there are two more ongoing ATMS installation projects covering southern Broward County (Phase II) and Three Major Corridors (Phase III). ATMS Installation in phase II of the project will cover sections of Hallandale Beach Blvd., Hollywood/Pines Blvd., Pembroke Rd., and US-1/Federal Hwy, SR-7, University Dr., while project phase III will cover sections of US 441/SR-7, University Dr., and Griffin Rd. Figure 2 depicts the TSM&O network in Broward County.
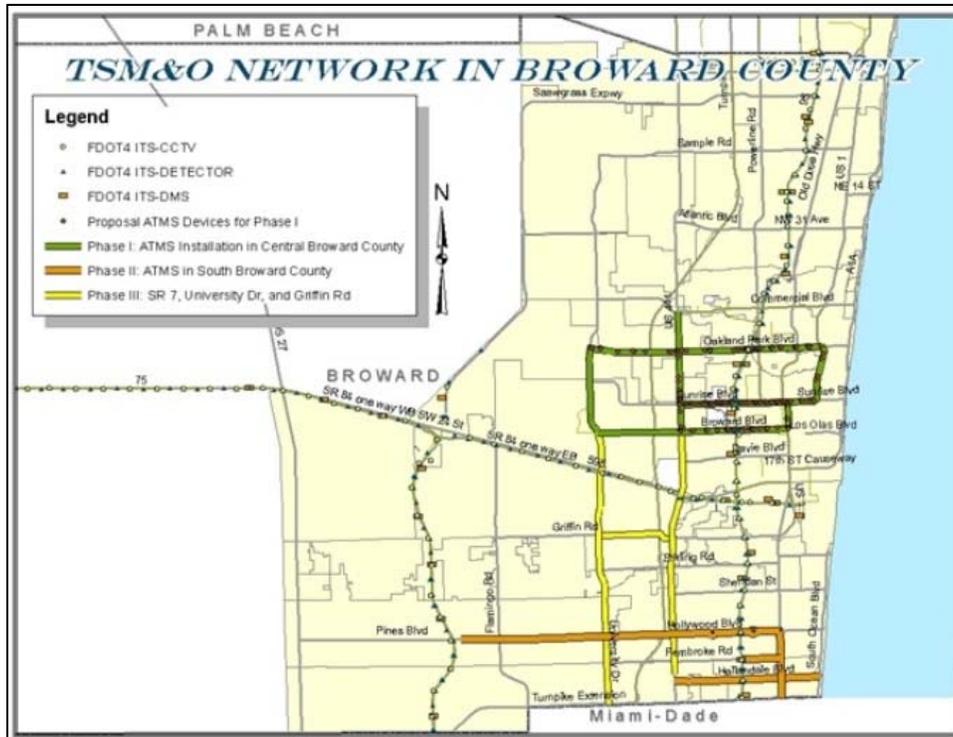
Figure 2- The TSM&O Network in Broward County (Source: FDOT)

Multiple ATMS infrastructure installation projects have been planned in Palm Beach County and are intended to start during summer 2014. These projects will cover sections of Southern Blvd., Northlake Blvd., and Okeechobee Blvd.

1.6. Overview of the Project Tasks

This section provides an overview of the project tasks that are addressed in this project. The following tasks were defined in this project to accomplish the research goals.

1.6.1. Task1: Build, Calibrate, and Validate a Microsimulation Model

High fidelity microsimulation models of the study area represent a core of the research approach by the FAU research team. The FAU research team used VISSIM microsimulation software to model the study area because VISSIM software offers a variety of options and programming flexibility that will ensure successful modeling outputs. A considerable amount of available resources of the FAU research team (staff time, data collection trips, meetings, etc.) was devoted to build two microsimulation models that closely resemble field conditions of the study area. Various data sources were utilized to accomplish this task. For example, Broward County Metropolitan Planning Organization (MPO) data was used for roadway classification, initial speeds, volumes, and others. The data were also supplemented by the Geographical Information System (GIS) centerline files, high-resolution aerial imagery, video streams, traffic volumes, signal timing data, and others. Figure 3 shows a centerline file for the study area depicting the transportation network of the study area.
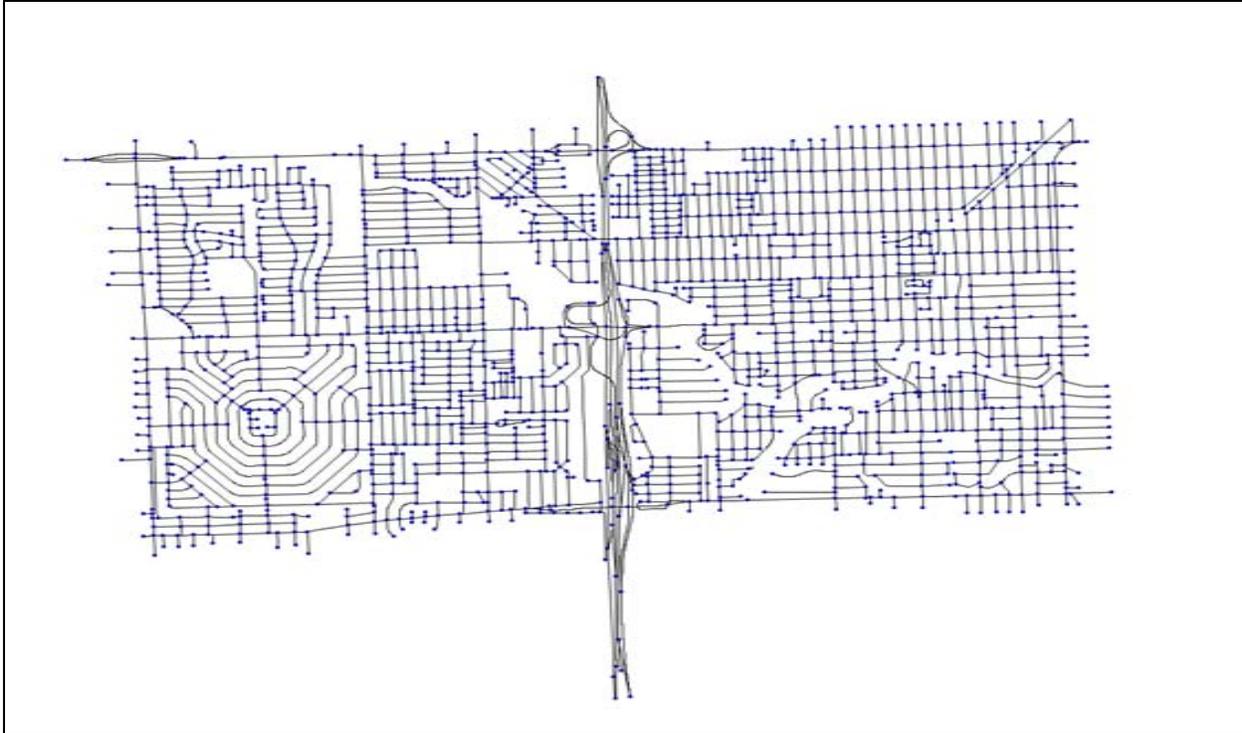
Figure 3- GIS Centerline Model of the Study Area

The models used in this study are described in more details:

1. Network Model: This model encompasses all six major corridors of the study area to help the Broward County Traffic Engineering Department (BCTED) retime their traffic signals. These particular corridors were chosen based on the need of Broward County and the overall level of congestion. BCTED is trying to reduce delays on its major corridors by increasing overall throughput. This model consists of six corridors: Oakland Park Blvd, Sunrise Blvd., Broward Blvd., Davie Blvd., SR-7, and US-1.

2. Broward Blvd. Model: This model includes the primary corridors of the study area. Broward Blvd. represents the heart of Fort Lauderdale and is the center to many businesses, entertainment, and attraction areas. Broward Blvd. was chosen as a test bed for a new Traffic Responsive Pattern Selection (TRPS) system because the overall traffic performances and level of service were at very low levels in the network model, which was developed for the PM peak (4:00-6:00 PM). The Broward Blvd. corridor was extracted and filled with the traffic data of an entire day (6:00AM-Midnight) with 45 minutes of warm up period.

1.6.2. Task 2: Identify Types and Formats of Traffic Data from the Field Sensors

The existing ITS infrastructure in Broward County is enhanced by the TSM&O program. The program will install and use the existing Intelligent Transportation Systems (ITS) infrastructure, which includes data collection and communication devices to facilitate traffic monitoring and management in the central Broward County major arterials. In this task, the FAU research team investigated available data sources in the study area. The team also used literature to select

appropriate performance measures. The following ATMS data sources were identified as useful in the area:

1. Bluetooth BlueTOAD (Traffic Cast): the Bluetooth travel time origin and destination (BlueTOAD) devices detect anonymous Bluetooth signal from mobile devices (cell phones, tablets, laptops, etc.) inside vehicles. The devices can collect travel time, speed, and origin-destination (O-D) data from the field.
2. Microwave Detector Stations (Wavetronix): two types of Wavetronix sensors of Smart Sensor V and Smart Sensor HD have been installed in the Broward County. Smart Sensor V can accurately monitor up to eight lanes of traffic and can collect volume, speed, occupancy, and vehicle classification from the field. Smart Sensor HD can monitor up to 22 lanes of traffic. They can record volume, average speed, occupancy, 85th percentile, average headway, average gap, speed bin counts, direction counts, and classification counts.
3. Video Detection Systems (ITERIS and Traficon): the video detection systems (VDS) are used to detect vehicles and actuate traffic signals operations. Broward County uses VDS from two vendors of ITERIS and TRAFICON. TRAFICON video cameras are more frequent in the area. The systems can collect turning movement counts and speed data, but their accuracy depends on their location. Vehicle counts, speed, occupancy, density, headway, gap time, vehicle classification can all be retrieved from VDS.
4. Automated Vehicle Identification (SIRIT): Automatic Vehicle Identification (AVI) systems are usually used in toll or high occupancy lanes. They are designed to read license plates numbers. The AVI systems can be utilized to determine travel habits, frequency of travel, origin and destination points, and travel time data. The detectors can also provide information for congestion or variable rate tolling based on travel time or land load.
5. INRIX: a traffic information system, which is being used on a national level and covers nearly 260,000 miles of roads in real-time. The website covers major arterials and city streets in 52 cities with population over one million people. The information system provides real-time, historical and predictive travel time and speed in a user-friendly interactive user interface. Also, link free-flow speed, congestion alerts, incident data, and traffic maps can be acquired from the website.
6. SunGuide (Florida Intelligent Transportation System): ATMS software that helps FDOT to control and monitor roadside equipment and vehicle resources. The software facilitates traffic and incident management in the state of Florida. It also disseminates traveler information to the monitoring public. The software communicates with Road Rangers and supports I-95 express lane pricing. Multiple traffic control and management devices are controlled by SunGuide such as dynamic message signs, variable speed limit signs, toll message signs, and ramp signals. (Sunguide, 2013)
7. ATMS.now (Trafficware): a central management system used by the Broward County TMC to control and manage traffic Nazdec traffic controllers remotely and enables traffic operators to change the signal timing in real-time. The systems also enable operators to provide Closed Circuit TV (CCTV) surveillance footage.

Also, Changeable Message Signs (CMS) are controlled using the software. Broward County has about 1,300 signal controllers, where almost half of them have been transferred to the new ATMS.now system.

1.6.3. Task 3: Identify Performance Measures for Traffic Demand

In this task, available data sources were investigated and appropriate performance measures to estimate traffic demand were identified. Volume, occupancy, spot speed, and travel time selected as potential traffic performance measures, which can impact traffic demand.
Also, geometrical performance of the link length, which may potentially impact the traffic demand, is considered in modeling the traffic demand.

1.6.4. Task 4: Develop Methods to Derive Traffic Demand from Available Field Data

Traffic demand is an important input parameter in both transportation planning and operations. However, it is not possible to estimate traffic demand from the field data directly. Traffic demand needs to be estimated from its surrogates, which have been identified in Task 3. For this need, a methodology was developed to estimate virtual traffic demand through a set of meaningful relationships between available data in the field and real traffic in the VISSIM microsimulation model.

A set of simulation tools is developed to determine link-based traffic demand at each signalized approach. The link based true traffic demand is measured in the microsimulation model at the upstream entrance of the link and thus it represents a true traffic demand of vehicles that require a green light at downstream intersection. Traffic data inside the simulation model were acquired using both virtual and field-like traffic sensors. Data collection points collect volume, occupancy, and spot speed of each link and travel time detectors collect travel time and speed data in the microsimulation model. The data were utilized to develop appropriate demand from the estimation models.

1.6.5. Task 5: Identify Traffic Demand Thresholds to Activate Strategies

The objective of this task is to determine the traffic demand thresholds in which traffic condition changes from the normal condition and necessary action is required. The thresholds identify situations where certain strategies need to be implemented. It should be noted that there is a high correlation between tasks five, six, seven, and eight.

Thresholds in this study are introduced to assist TMC operators to recognize certain traffic patterns occurring in the field (recurring ones and not recurring ones). The thresholds are based on the results of traffic performance of the system (arterial network) exposed to various traffic scenarios (e.g. saturation, incidents, rail preemption). Each scenario has a distinctive signature which is indicated by how certain performance measures (travel times, volumes, speeds) on the neighboring links are changing under the impacts of the given scenario. Thus, the recommended thresholds are results of such after-the-fact analysis and they are not estimated/developed in real-time. However, the TMC operators can still use these thresholds in real time; e.g. if it is observable that certain performance measures are moving in certain directions the operators can use the operating guidelines to recognize a specific traffic scenario and react (e.g. retime signals to increase throughput).

First multiple traffic scenarios are defined and modeled in the microsimulation model. Each traffic scenario is monitored closely and the appropriate demand threshold is determined to activate strategies. In the next step, the implemented strategies are evaluated for effectiveness. If the strategies are not effective, traffic demand thresholds or strategy are modified and another iteration of analysis will be conducted. This cycle continues to ascertain that strategies are effective and demand thresholds are appropriate.

1.6.6. Task 6: Develop Strategies to Improve Traffic Condition

The FAU research team identified two major types of strategies that TMC operators will conduct when observing this network:

1. Signal retiming strategies: These strategies are also called "background strategies." In these types of strategies, traffic operators change the signal timing of certain signal controllers based on the current traffic condition. The signal plans are sometimes optimized to improve the mobility of the network traffic condition.
2. Information dissemination actions or 'immediate actions' may be performed at any time based on specific situations such as incidents and lane blockage in the field. Types of those actions are: displaying DMS messages, dispatching Road Rangers, and others.

1.6.7. Task 7: Identify and Model a Variety of Traffic Demand Scenarios

In this task, recurring and nonrecurring traffic scenarios are identified with the microsimulation model. The scenarios are identified using the literature and BCTED input. Another important factor in determining the location of the scenarios was the proximity of the field detectors to the sensor location because the scenarios need to be monitored closely and appropriate signatures should be captured.

Each scenario is modeled in the VISSIM microsimulation model, and respective demand threshold and strategies are identified. The recurring scenarios include base, saturated, and over-saturated scenarios, and nonrecurring scenarios are freeway incidents, left-turn spillover (LTSO), rail preemption, arterial incidents, and event traffic congestion scenarios.

1. Base scenario: In this scenario, all links in the microsimulation model are operating in the under-saturated condition. All other scenarios are compared to this scenario. Traffic is controlled by software in the loop (SIL) simulation, and management objective is to provide maximum progression in the arterial system.
2. Saturated: The volume is slightly higher than the capacity in some of the links (usually the ratio around 1.20). In some intersections, queue forms and dissipates sporadically but does not spill back to the upstream intersection. Similar to the base scenario, traffic is managed by an operator in the loop (OIL).
3. Oversaturated: The volume is considerably higher than the capacity, and queue spills to the upstream intersection in one or two links. Traffic is controlled by an OIL system. In this condition, queues have already formed, and they would not

dissipate unless a certain strategy is implemented. Therefore, the objective is to manage the queue efficiently in the system to avoid gridlock.

4. Freeway incidents: Incidents impose a severe traffic on the transportation system. Traffic operators deal with freeway incidents on daily basis. Therefore, it is beneficial for them to have a predetermined plan on managing the incidents. In order to identify accident-prone location, historical data were acquired from BCTED.

5. Left-Turn Spillover: Spilled back queue in the left-turn pocket may block the through movement path and impose delay on traveling vehicles. In this condition, traffic will be controlled by OIL and the management objective is to retime signals to alleviate the imposed congestion.

6. Rail preemption: Long trains can impose considerable congestion on the road network. Trains block both travel directions and can impose a considerable delay on the arterial streets.

7. Arterial incidents: Similar to freeway incidents, arterial incidents can also impose a considerable amount of delay on the transportation network. Since the speed limits on the surface streets are usually lower than on freeways, the severity of such incidents is less than freeway incidents. The FAU research team identified arterial incidents locations based on the historical data acquired from BCTED.

8. Event traffic: Traffic events can also create a severe congestion inside the transportation network. Art performances, festivals, and sport competitions are common examples of special events that happen inside of the transportation network. Traffic in this scenario will be controlled by OIL. The management objective is to manage queues in the transportation system. The location of the event traffic scenario was determined based on the BCTED input.

1.6.8. Task 8: Evaluate Impact of the Selected Strategies on the Road Network

In this task, the FAU research team tested multiple proposed strategies. For each defined scenario an appropriate strategy is proposed. The effectiveness of the strategies was monitored using emulated field detectors and artificial detectors inside the simulation models. Several performance measures were monitored to evaluate the impact of each strategy on the traffic network. The mobility performance measures include throughput, travel time, spot speed, and travel time. Other performance measures are also considered based on the strategy type and definition.

1.6.9. Task 9: Develop and Evaluate TMC Operating Guidelines

The modeled scenarios, identification strategies, strategies, and other related information are documented in a form of guideline to help traffic operators to manage different scenario more effectively. The traffic operators' guideline is submitted as a separate document.

1.7. Document Organization

This final report is presented in five chapters. Chapter two provides a review on the literature. Chapter three describes the applied methodology in details. Chapter four shows the evaluation

results. Chapter five summarizes the research findings and provides future recommendations for additional research.

There are also 6 appendices attached to this report. Appendix A contains calibration and validation charts of the network microsimulation model. Similarly, Appendix B shows calibration and validation charts of the Broward Blvd. microsimulation model. Appendix C shows the charts developed for crash data analysis. Appendix D encompasses multiple traffic demand parameters. Appendix E contains traffic parameters visualization based on the simulation detectors.

2. Literature Review

2.1. Microsimulation Calibration and Validation

Park and Won (2006) developed a calibration and validation handbook that tests the procedure for various network conditions. The study recommended that traffic engineers should calibrate and validate microscopic simulation models by using enhanced procedures such as performance measure-based procedures before using them for any engineering application to ensure reliable results. The study also recommended that microsimulation calibration and validation field data should be collected from multiple days to obtain reliable results. In order to build the simulation network, traffic counts, heavy vehicle percentage, traffic signal settings, detector locations, geometrical characteristics, and posted speed limit data were collected. In order to calibrate and validate the microsimulation model, traffic counts, travel times and maximum queue lengths data were selected because these are the types of data that directly reflect field traffic conditions. The study suggested collecting the field data from Tuesday to Thursday. The enhanced procedure with multiple performance measures was proposed for the calibration and validation task.
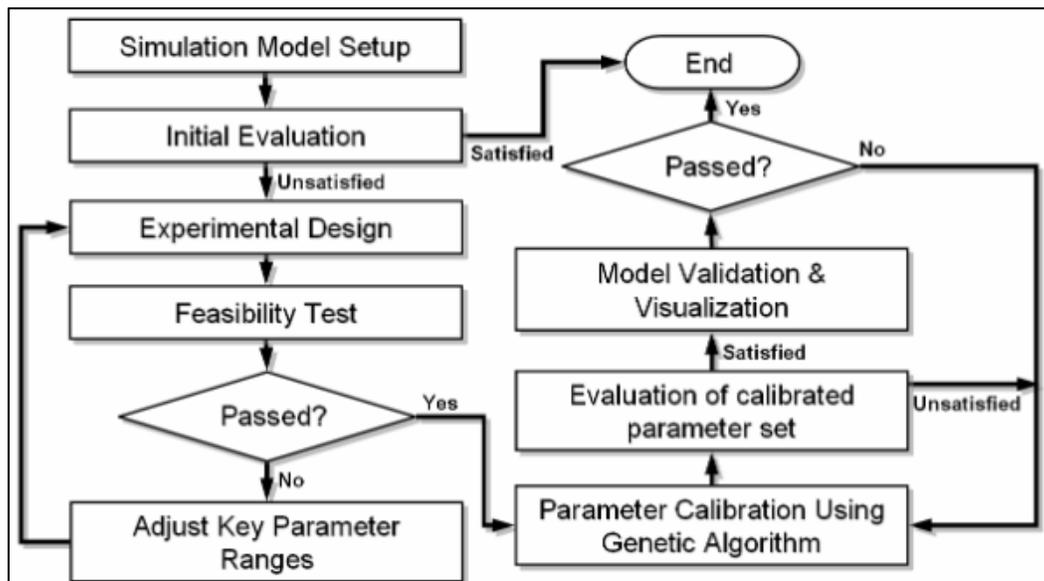
Figure 4- Calibration and Validation Procedure Flowchart (Source: Park and Won. 2006)

The simulation model setup step consists of the definition of study scope and purpose, determination of the performance measure, field data collection and reduction, and network coding. The initial evaluation step tests whether the default calibration parameters are acceptable by comparing the distribution of a selected performance measure. If the default parameters are not acceptable, a modification is made in the experimental design step. In the next step, the calibration parameters are verified. This is done by comparing the distributions of simulations outputs with multiple performance measures from the field. If the feasibility test shows that the ranges of parameters are not acceptable, adjustments should be made. With X-Y and 3D contour plots, and analysis of variance (ANOVA), key parameters are identified and adjustments are made using those key parameters. Once the ranges of calibration parameters are found to be feasible, a genetic algorithm (GA)-based optimization tool is applied to obtain the optimal set of calibration parameters. The evaluation of the parameter set step confirms that the optimization

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parameters obtained from the GA optimization can replicate field conditions. In the last step, the calibrated parameters are validated with a new data set that has not been used in the calibration procedure. This is done by comparing a predicted condition under the calibrated parameter with the validation performance measure. (Figure 4)

Tan et al., (2012) presented the development of a microscopic simulation model that aims at the safety assessment of signalized intersections. The proposed simulation model integrates many key behavioral models of road users such as the stop/go decision at the onset of yellow, turning paths, turning speeds; start up response time and pedestrian gap acceptance models and so on. The main feature of these empirical models is that they consider the stochastic behavior of road users. Furthermore, they are sensitive to the layout and the operation of signalized intersections. It can reasonably represent road user movements as well as the conflict occurrence. The model provides a better understanding of collision risks and impact factors that cause collisions through conflict analysis at signalized intersections. An initial validation process was performed to test whether the estimated results well correlate with the filed observation. The results imply that the simulation model can reasonably and realistically represent the maneuvers of through and right turning vehicles as well as the corresponding conflicts inside intersections. Limited by the experiment conditions, the presented validation just focuses on one conflict type at one intersection. The results are tentative to demonstrate the process. Collecting more data is necessary in the future for the validation of other conflict types.

Liu et al. (2013) used several data sources to build up and calibrate the simulation model for the Downtown Seattle. Morning peak hour demand (including vehicle classes) were provided by Seattle Department of Transportation (SDOT) as well as the volume split, existing signal timing plans at each intersection and speed limit at different corridors. Also video cameras were also recorded at major intersections to help calibrate the simulation model by collecting model and queuing information. Furthermore, incident analysis was conducted a section of I-5 to identify accident hotspots and corresponding properties such as incident duration and severity. The researchers also calibrated the driving behavior parameters of the VISSIM model. In order to calibrate and validate traffic In order to calibrate and valid traffic behavior parameters, several parameters are adjusted according to the observed field data. For the freeway corridor, the adjusted parameters include standstill distance, headway time, and maximum deceleration for lane changing. For arterials system, the adjusted parameters include average standstill distance, desired speed, safety distance and minimum headway distances. The performance metrics for measuring the VISSIM model calibration results include flow, average speed (for freeway and arterial), and average queue length (for arterial). However, with the available collected data (loop detector and video cameras), the difference between the calibrated simulation output and field data is controlled at less than 15% in average in terms of traffic volume, space mean speed, and segment based travel time.

2.2. Identify Types and Formats of Traffic Data from the Field Sensors

Zhang et al., (1997) The primary goal of this two-phase research project was to develop a better travel time model for arterial traffic using information provided by inductive loop detectors in current installation patterns. Their literature review identified five approaches to arterial travel time estimation: regression, dynamic input-output, pattern matching, sandglass, and BPR. These approaches encompass a variety of travel time estimation models with diverse data requirements and application ranges. Despite the theoretical appeal of the pattern matching and dynamic input-

output models, they have limited applicability to arterials where traffic surveillance systems cannot provide short interval traffic data. The sandglass models, like the pattern matching and input-output models, require traffic data (queue length) that cannot be accommodated by current surveillance systems. The BPR models, on the other hand, only need volume data (routinely supplied by loop detectors) but are not accurate enough for dynamic, short-term traffic management applications. Regression models, with their ability to take various factors into account, are the most practical considering the type of data provided by existing traffic surveillance and control systems. All regression models developed thus far are link-specific and the calibration and validation are limited. The need for further development of such models is evident from the review. The literature review they conducted showed clearly the need for a good travel time database. They carried out a ten-day data collection effort on a segment of Snelling Avenue in Minneapolis. The data collection site has three four-leg intersections of typical detector layout. Travel time data were collected by four floating cars from 6:00 AM to 9:00 AM and from 3:30 PM to 6:30 PM; traffic flow and occupancy data gathered at five-minute intervals and produced by all the detectors were downloaded daily from local controllers; turn volumes not covered by detectors were counted manually; and signal timing data were extracted from the event log of the master controller during the data collection period.

Laval et al. (2012) presented a stochastic extension of Newell's "three-detector method", which aims to incorporate uncertainty in both the input data and the fundamental diagram predicting traffic flow in between detector stations. This problem is known in the literature as Newell's "three-detector problem". The stochastic extension model enabled obtaining the probability density function of the cumulative count curve at any time and space point. This capability is significant because one is able to map uncertainty in input data to uncertainty in model predictions, allowing the statistical inference of the model output such as confidence intervals of any traffic flow variable of interest. The stochastic extension considered three possible sources of uncertainty: sensor detection errors, variability in the fundamental diagram parameters (speed, flow, and density), and day-to-day variations in the arrivals. The model is appealing because it enables the variability of model inputs to be considered and extends a number of directions such as the continuous space limit for all locations in between two upstream and downstream given points. Furthermore, the model can be utilized for forecasting and real-time implementation when the information from the middle detector could be used in real-time to adjust the predictions. Also, the uncertainty can be further reduced by taking into account additional detectors.

Coric et al. (2011) proposed to reconstruct the high-resolution measurements from the aggregated ones, and use them to correct the state estimates at every time step. We considered several reconstruction techniques from signal processing, including kernel regression and a reconstruction approach based on convex optimization. The proposed approach was evaluated on real-world next generation simulation (NGSIM) data collected at Interstate I-101, located in Los Angeles, California. They demonstrated how the reconstructed signal is used with the Ensemble Kalman filter employing velocity cell transmission model in two different modes of operation, online one-interval delay mode and offline analysis mode. Experimental results showed that signal reconstruction leads to more accurate traffic state estimation as compared to the standard approach for dealing with aggregated measurements. The results show the benefits of the

proposed approach, which outperformed the existing methods and improved accuracy of the underlying traffic model.

Deng and Zhou (2012) focused on how multiple data sources, including loop detector counts, AVI Bluetooth travel time readings and GPS location samples, estimate the inside microscopic traffic states on a homogeneous freeway segment. First, a stochastic version of Newell's three-detector model was proposed to utilize multiple data sources to estimate microscopic traffic states for a homogeneous freeway segment. The traffic state of any intermediate point on a freeway segment was directly estimated from the boundary conditions through a minimization operation. A generalized least squares estimation framework was considered as a solution for the stochastic three-detector problem using heterogeneous data sources (detectors, AVI, and GPS mobile devices). A numerical experiment was used to demonstrate the proposed methodology. When this goal was accomplished, the accuracy of traffic state estimation for each cell was directly linked with the variability of the boundary conditions. AVI data, which are obtainable from mobile phone Bluetooth samples, represent an emerging data source, but they have been primarily used in link-based travel time estimation applications or origin-destination demand estimation rather than in the estimation of within-link traffic states such as cell-based density.

Ossenbruggen et al. (2012) performed exploratory analysis of traffic performance data. The research study showed that there is a better than a three-in-four chance that a roadway will breakdown with a sudden drop in speed and less than a one-in-four chance that it will maintain a free-flow speed. Congestion can be triggered before the "road capacity" is reached. It is a well-known that as traffic flow increases, traffic conditions become more unstable or volatile, which may have dire effects on the best designed systems. It is hypothesized that this duality effect - triggering or not triggering congestion - can be explained by short-term traffic flow history and volatility in the traffic data with a generalized linear binomial model. The term volatility is used in a statistical sense to describe variability in the data. A simulation is an efficient way to describe the conditions that trigger congestion events, particularly the role that volatility plays. In this paper, simulations of three simple traffic flow scenarios were analyzed and compared. The authors suggested that a short-term traffic flow history of small magnitude coupled with volatility is needed to trigger congestion. This simulation analysis was performed to isolate the significant triggering conditions previously identified in the empirical data. Moderate levels of traffic flow coupled with the effects of volatility were sufficient to trigger congestion, suggesting that both factors must be an integral part of traffic management or a control strategy to be successful.

A study conducted at Lehman Center for Transportation Research (2012) includes tests conducted as part of the FDOT District 6 Arterial Travel Time project. The project involves evaluating potential technologies that support travel time estimation on arterial streets. The results presented in this document focus on the evaluation of the BlueTOAD and INRIX website data.

This study compares the travel time estimates using BlueTOAD, INRIX data, and test cars utilizing the 15 minutes aggregation level of data for weekdays. The assessment is based first on the average travel times over the days of the analysis and then for individual days. There are differences in the values of the travel times measured by the three sources. The average times

estimated based on BlueTOAD data are generally higher than those estimated based on INRIX data, and are closer to the results from the test car method for three of the four test segments. The reverse was observed for the fourth segment.

2.3. Identify Performance Measures for Demand

Chen et al. (2007) proposed a method to estimate the traffic state of downtown areas. The initial stage included matching the collected global positioning system (GPS) define locational data onto geographic information systems (GPS) map in a real-time context and indexing the locations by their vehicle IDs. Next, the tracking process of each vehicle according to its consecutively matched locations was performed. Then, the calculations and distribution of the average velocities along the vehicle tracks were formulated. Finally, by allocating these velocities to each related link, the final estimates were calculated. The problem considered involved assorted vehicle tracks from different vehicle IDs that generally share several common road link, while disparate average velocities exist during the same time period. Real-data experiments conducted in the downtown area of Shanghai using real-time taxi scheduling signals indicate that the proposed method provides reasonable results and sufficient real-time purposes.

Lin et al. (2005) proposed systematic review of the field of travel-time prediction. The purpose aimed to broaden the perspective of research beyond individual techniques and then to provide a detailed overview of travel-time prediction information for future research of travel time estimation. In an area with relatively stable traffic conditions, a fairly simple estimation may be used, but in areas with rapidly changing conditions, a prediction model is essential. Most of the conventional short-term forecasting techniques were categorized under two approaches: regression methods and time series estimation methods. A third approach combined the first two approaches, which is known as data fusion. The paper introduced several prediction methodologies and techniques from previous research studies and projects that include prediction theories, types of adopted traffic data, prediction accuracy criteria such as historical data estimation where travel time can be estimated by analyzing traffic information from fields; artificial intelligence where artificial neural networks are used to estimate and predict travel times based on traffic detectors and simulation software or to predict travel times of non-detector segments based on the data from detector segments; statistical techniques such as the recursive cell processing (RCP) model for dynamic travel time estimation on instrumented freeways based on the data from induction loop detectors. The limitations of related travel-time studies based on the literature include data resources, facilities of data collection, prediction techniques, and interference traffic environment. Transport simulation techniques have been greatly improved, and this technique provides the potential to substitute real data collection. Adapting micro-simulation techniques to be a test-bed may solve the data shortage problem and also perform various strategies on the test-bed. The final stage of the research will still involve the use of real traffic data from field surveys to validate and adjust the developed travel-time prediction model.

2.4. Develop Methods to Derive Traffic Demand from Available Field Data

Kong et al. (2009) used the federated evidence fusion model (FEFM) to fuse the data from the loop detectors and GPS probe vehicles as well as other information sources such as cameras and mobile phones. Based on engineering practices, the researchers found that different evidence sources have different reliabilities in estimating the same state, and the authors used the same

assumption to develop an improved evidence reliability measure called reliability weight, which represents the degree of the reliability that the evidence corresponds to each state. This measure was then utilized to establish the reliability matrix between all the results from different sources and independent states to be recognized. By considering evidence reliability, the uncertainty and inaccuracy decreased. The next step in building an adaptive and dynamic fusion model is creating the FEFM frame in a structure with feedback based on the theory of the Federated Kalman Filter. Two experiments were undertaken to demonstrate the effectiveness of the proposed model compared to the other fusion models. The first experiment incorporated the synthetic traffic data and ran the simulation test. The second experiment considered the real-time traffic data including two types of traffic mean speeds derived from the data collected with Sydney coordinated Adaptive traffic system (SCATS) loop detectors and GPS vehicle data compared to the data from 24-hour surveillance video screening and average speeds that have been computed every five minutes. According to these two experiments, the estimation accuracy of the model was extremely high. Also, the model shows better accuracy in estimating real-time traffic state by fusing two types of data and by comparing the same sources provided separately.

Zhao et al. (2011) introduced the Curve-Fitting Estimation Model (CFEM), which is one of the typical methods using GPS data to estimate the traffic flow state. After that, detailed analysis of how many probe vehicles the CFEM requires in order to ensure enough estimated accuracy. Furthermore, a sample size algorithm is developed to calculate the minimum sample size of the CFEM. In the algorithm, the road type, the length of road section, and sample frequency are taken into account. Finally, the proposed algorithm of sample size analysis is tested by the experiments using the data collected from the road network of the whole center region of Shanghai. The experiment result shows that the errors of the estimated speeds become smaller with increasing of the number of the GPS sampling points. The sample frequency influences the sample size of the probe vehicles greatly. Setting a higher frequency for empty vehicles and a lower frequency for heavy ones could increase the average sample frequency and reduce the sample size of the probe vehicles effectively.

2.5. Identify Traffic Demand Thresholds to Activate Strategies

Kong et al. (2009) proposed an online information fusion approach for urban traffic state estimation. This approach consists of three parts of algorithms, including the evidential fusion, the data processing of loop detectors, and the data processing of GPS probe vehicles. Among them, the loop detector algorithm uses a single loop detector buried at the end of a link to estimate the spatiotemporal mean speed along the whole link. It proves that the stop bar detector data (such as that from SCATS) can be used to develop reliable estimates of link average speeds. The probe vehicle algorithm is made up of three parts: 1) coordinate transforming; 2) map matching; and 3) curve approximating. According to the experiment results, it is believed that the GPS-equipped taxies are also an excellent detector to measure traffic states, if there is sufficient market penetration and if appropriate processing methods are used. The application of the evidential fusion model, both loop detector data and GPS probe vehicle data are organically integrated so that the traffic states can more comprehensively be estimated and with more accuracy than those attained by any one of them. In addition, the proposed evidential fusion model can be extended to fuse data from other types of traffic detectors such as cameras and mobile phones.

Choi and Chung (2002) created an algorithm for fusing multiple travel time data sources to generate a unique value in terms of link travel time. The paper focused on fusing the link travel time data obtained from the detector with GPS probe vehicle data using the developed algorithm, which involved the voting technique, fuzzy regression and the Bayesian pooling method. Data fusion is the process of integrating data; therefore, the arithmetic mean was treated as the simplest form of the data fusion method and was used for comparison with the fusion algorithm. Evaluation of the results based on the mean absolute percentage error (MAPE) showed that the fused link travel time is superior to the pure arithmetic mean method and is more reliable, accurate and realistic. With the increasing development and deployment of different traffic data collection mechanisms, the algorithm in question could be adopted by any ITS and Advanced Traffic Information System (ATIS) project.

2.6. Develop Strategies to Improve Traffic Condition

Chang et al. (2000) described a queue length estimation algorithm designed for use with a highly responsive real-time signal control system. The algorithm required only a single passage detector, set back from the stop-bar. The detector utilized counts and occupancy, the kinematic properties of vehicles traveling on a signalized approach and knowledge of the signal state. The RT/IMPOST signal control policy relied upon accurate estimates of the *standing* queue length on each approach for each signal cycle. The RT/IMPOST real-time traffic control policy achieved its objectives by limiting this extended queue to avoid spillback into the upstream intersection. The control policy adjusted signal timing largely based on knowledge of the standing queue length. Also, the policy predicted the length of the extended queue only if it is provided an accurate estimate of the standing queue as defined. The algorithm determined when this lead stopped vehicle crosses the detector located upstream of the stop-bar by estimating its trajectory between the detector and the stop-bar. The algorithm estimated the time in advance of the known start of the red phase by calculating an estimate of this vehicle's travel time from the detector to the stop-bar. The algorithm also estimated the earliest time that the first vehicle in the secondary platoon (i.e., turn-in traffic) will arrive at the detector. This estimate was based on the known start of the red phase at the upstream intersection and on a calculation of this vehicle's travel time from the upstream stop-bar to the detector. Finally, the algorithm estimated the time that the first vehicle in the incoming primary platoon will arrive at the detector, assuming that the standing queue length does not extend past the detector. Despite its reliance on a single passage detector, simulation testing has demonstrated that it provides reliable queue length estimates over a range of representative approach lengths, signal timing and traffic demand.

Due to the limitations of both travel demand models (TDM) and microsimulation models in analyzing complex traffic incident management scenarios, Luo et al. (2012) proposed a new multi-resolution modeling approach with mesoscopic simulation based dynamic traffic assignment (DTA). The paper illustrates the approach through a case study. The case study investigated traffic management strategies during a major freeway crash that occurred in the Phoenix metropolitan region. The sequential steps were followed:

     1-Obtain the initial vehicle origins, destinations and volumes from TDM;
     2-Apply a mesoscopic simulation-based DTA model, to conduct scenario analysis and
     obtain the space and time dependent volumes, vehicle paths and resulting travel times;

3- Import the output into VISSIM, a micro-simulation model, for more detailed analysis at certain hot spots when necessary.

The overall concept included utilizing the macro level TDM to estimate the overall travel pattern and major trip origins and destinations. Based on the outputs from the TDM and the data observed in the field, the mesoscopic simulation-based DTA model generated space- and time-dependent O-D tables, the resulting space and time dependent travel times, vehicle route choices and others for both baseline and scenario cases. Most of the analysis was conducted at this level of detail. When necessary, the outputs from the DTA model were imported into the microsimulation model for more detailed analysis at certain "hot spots". Using this approach, macro, meso and micro models can be applied to conduct relevant analyses and at the same time overcome their insufficiency by supplementing with the strength of other models.

Fu et al. (2001) presented a model that can be used to estimate one of the congestion measures, namely real-time overflow queue at signalized arterial approaches. The model is developed on the basis of the principle of flow conservation, assuming that time-varying traffic arrivals can be obtained from loop detectors located at signalized approaches and signal control information is available online. A conventional microscopic simulation model is used to generate data for evaluation of the proposed model. A variety of scenarios representing variation in traffic control, level of traffic congestion and data availability are simulated and analyzed. The evaluation results indicate that the proposed model is promising in terms of the accuracy it can provide and advantages it has over existing models. The sensitivity analysis has shown that the model is relatively accurate under a wide range of operating environments, and is robust with respect to the polling rate and projection speed. With the integration of the self-correcting scheme, the proposed model was able to accurately track the evolution of real-time overflow queue lengths in realistic traffic environments with any rough estimate of the maximum flow rate.

2.7. Identify and Model a Variety of Traffic Demand Scenarios

Chandler and Hoel (2004) examined the effect of light rail crossing on average delays experienced by vehicles using the VISSIM microsimulation model. Four scenarios were examined: isolated crossings of two-lane and four-lane roads, a case in which light rail transit is located in the median of the street, and a larger network that includes four crossings. The effects of variable traffic volumes and light rain crossing frequencies were studied in the isolated intersection scenarios. The scenarios with light rail transit in the median and the larger network examined the effects of different crossing frequencies as well as full traffic signal preemption. The results of the simulated test scenarios indicated that the average additional delays from light rail transit crossings increase with increasing light rail crossing frequencies and increasing traffic volumes up to the capacity of the roadways. The scenario simulation demonstrated that as the road enters the oversaturated condition, the average total delay continues to increase. Preemption of traffic signals near light rail crossings increase the total delay experienced by vehicles that are in conflict with the light rail crossing, but it tends to improve travel time for the no conflicting movements due to the increased green time. The study concludes that traffic volumes at crossings and the frequency of the light rail crossings are important factors that impact the average additional delays experienced by vehicles.

Yin et al. (2010) developed theoretical delay models of protected left-turn operations at a pre-timed signalized intersection under heavy traffic. The study objective was mainly focusing on the correction of uniform delay terms in the HCM methods. The study modeled the left-turn spillover by adding more vehicles to the opposing direction through movement. In this condition, the queue extends at the left-turn bay and blocks the through movement. Firstly, the delay was investigated during a leading protected-only left-turn operation. More specifically, the probability of blockage by through traffic was calculated by estimating the through residual queue. Accordingly, a delay model with leading protected left-turn operation was developed on the basis of queuing diagram. The study used a well-designed VISSIM microsimulation model as the test bed for the analysis.

Consoli et al. (2013) studied several event traffic scenarios for Amway Center in Orlando. The Amway Center is home of the National Basketball Association's (NBA) Orlando Magic, and in addition, it also hosts concerts, arena football games, and other various events. They optimized the signal timing of the adjacent intersection using Synchro software. One of the challenges that the researchers faced was the limitation of the available field traffic data such as demand. The demand data was limited to number of season ticket holders only. Therefore, intuitive ITS design decisions had to be made. The research recommended to proposed two signal-timing plans for before and after the events. Enhancement of current ITS infrastructure in the area was also recommended.

Liu et al. (2013) used the pioneer integrated corridor management (ICM) site in Seattle to demonstrate quantitative analysis of ICM strategies under different scenarios. The study utilized microsimulation model to determine how to divert traffic from major freeways as a means of incident management. As traffic is diverted into the arterials, the freeway system performance will improve but the performance in the arterial system will degrade. Therefore, it is necessary to carefully study the overall trade-offs in network level analysis. A well calibrated VISSIM simulation model was developed based on the field data. In order to better understand the effectiveness of traffic diversion strategies upon accidents on freeways, several scenarios were modeled with the microsimulation model. Several quantitative analyses were implemented on the network by monitoring network-wide delay, throughput, and travel time.

The VISSIM simulation software does not have a specific built-in incident function module. The study used a parking event with specified dwell time to emulate incidents using VISSIM. The incidents can be emulated in VISSIM using parking lots and their respective routing decisions. Before running the model, a parking lot with one space needs to be placed at the location of the predetermined incident. An appropriate routing decision needs to be set up to send an appropriate vehicle to the parking lot. A partial route decision is thus required for directing vehicles to use the connector. A connector needs to be placed for vehicles to pass the incident spots from the unblocked lanes. By configuring the parking event dwell time, the incident duration can be modified in the simulation model.

2.8. Evaluate Impact of the Selected Strategies on Road Network

Mazzamatti et al. (1998) presented the results of three surveys of "Before-After'' studies to measure the changes which were obtained with the implementation of the real-time control systems. Three areas with different traffic features were selected as samples in such a way that these cases could be representative of the entire project. Another criterion used in the selection of

the survey areas was that these three areas should be controlled by systems provided by different suppliers. Each area was surveyed by a survey car which measured journey times and traffic signal delays. The gain obtained by split cycle offset optimization technique (SCOOT) on these roads is exceptional. It can be explained by the fact that both roads connect two motorways and the beltway of the city, where traffic varies a lot, mainly due to high volume of trucks coming from other cities. Besides, traffic in this area is very saturated, where any kind of incident causes a rapid propagation of congestion, resulting in intersection blockage. SCOOT is able to handle these situations in a more efficient way than fixed time plans. The results that were achieved exceeded the initial project's expectation of 15 % to be obtained by the implementation of real-time control systems. The progressive implementation of real-time control systems in the city of Sao Paulo had demonstrated consistency with the results reported here. Back in November of 1997, there are around 500 intersections controlled by real-time systems.

2.9 Develop and Evaluate TMC Operating Guideline

As one of the key deliverables of this research project, FAU research team developed a sample TMC guideline to help traffic operators to manage and control the selected scenarios. FDOT Traffic Engineering and Operations Office (2013) developed a standard operating guideline to manage multiple events that require the attention of the operator. The guideline prioritizes several activities and provides guidance on how to handle each task in a timely manner. The guideline emphasizes that it is vital that the operators be aware of all messaging devices available on the roadway:

1. Assess the event degree of risk to public safety and advise emergency agencies.
2. Report to the appropriate emergency agency as soon as possible.
3. Detect and send messages for changes in event severity.
4. Detect and send messages for changes in event severity.
5. Detect and send messages for significant changes to traffic events.
6. Detect and send messages for any other traffic incidents and traffic event changes.

The guideline notes that it is important to be aware of the priorities of the DMS message in relation to the goal and considerations. The guideline recommends five main considerations when prioritizing corridor events:
- Personal injury and risk to the public
- Severity of the event (e.g. full closure)
- Proximity
- Impact on other traffic in both directions of travel
- Significance of event changes, for example a change in the lane block pattern or clearance of the incident.

Palm Beach County Traffic management Center (PBC TMC) in collaboration with FDOT District 4 started the Active Arterial Traffic Management "Living Lab" pilot project in 2012 to actively monitor, manage, and improve arterial operations along major corridors. As part of the project, PBC TMC developed Signal Timing Control for Incident Management in Palm Beach County traffic operator's guideline. The guideline provides a summary of signal timing changes that were developed and implemented (in real-time) by the TMC coordinator during incidents and major congestions. The following information for each scenario is documented:

1. Date and time
2. Location
3. Travel Direction
4. Lane Blockage
5. CCTV #
6. Description of Signal Timing Changes
7. Pictures of the Scenarios
8. Expected Benefits of the Signal Timing Changes

The expected benefits are reported as an estimated value using the real-time performance data obtained from BlueTOAD devices. If the BlueTOAD system is not available, the benefit is reported as an estimate value using an empirical formula. The report notes that 74% of total crashes are due to incidents, 11% due to roadwork, 8% due to recurring congestion and 7% are related to disabled vehicles. The application of the Active Arterial Traffic management Program results in estimated monthly benefit of total of $828,039.

Table 1- Estimated Monthly Benefits Summary of the Active Arterial Management Program in Palm Beach County

Performance Measure	Benefits (in dollars)
Travel Time/Delay Savings	$624,026
Reduction in Emissions	$35,649
Reduction in Fuel Consumption	$94,444
Safety Benefits	$ 73,920
Total Benefits	$828,039

3. Methodology

The research methodology is described in details in this chapter. Task 1 addressed building, calibrating and validating two microsimulation models used in this study. The FAU research team identified available data resources in the area in task 2. In task 3, the method to identify types and format of the performance measures to identify traffic demand data was developed. In task 4, statistical models to estimate traffic demand from the available field data were created. Traffic demand thresholds to activate appropriate strategies were identified in task 6. Several strategies to control and manage traffic congestion in defined scenarios were developed in task 7 and multiple traffic scenarios were defined in task 8. In task 9, the developed strategies were evaluated to select the most effective strategy.

3.1. Build, Calibrate, and Validate a Microsimulation Model

3.1.1. Overview

To achieve the project objectives, two high fidelity microsimulation models were developed using the VISSIM software:

1- Network Model: This model encompasses all six major corridors of the study area to help the BCTED retime their traffic signals. These particular corridors were chosen based on the need of Broward County and the overall level of congestion. BCTED is trying to reduce delays on its major corridors by increasing overall throughput.
 This model consists of six corridors:

1. Oakland Park Blvd.
2. Sunrise Blvd.
3. Broward Blvd.
4. Davie Blvd.
5. SR-7
6. US-1

This model provides a robust platform for network level analysis. The interaction between the freeway system and the arterial system are monitored using this grid network microsimulation model. The model includes nearly 200 signalized intersections and thousands of traffic links. The model simulates traffic from 4:00 PM to 6:00 PM with a warm up period of 45 minutes.
2- Broward Blvd. Model: This model includes the primary corridor of the study area. Broward Blvd. represents the heart of Fort Lauderdale and is the center to many businesses, entertainment, and attraction areas. The Broward Blvd. corridor was extracted and filled with the traffic data of an entire day (6:00AM-Midnight) with 45 minutes of warm up period. The imported data for building the models include:

1. Traffic counts obtained from FDOT, Broward County and an online interactive map available at official FDOT website. (FDOT Traffic Online, 2013)
2. Signal timings and signal patterns for weekdays obtained from BCTED
3. School zone areas
4. Time schedule for public transportation such as the Tri-Rail and Florida East Coast (FEC) rail

When the models were built, they were checked to ensure that all the signals work properly. Microsimulation models will serve as a test bed for the primary project analyses. When the models were completely developed, the FAU research team put a significant amount of effort into calibrating and validating the simulation model. The models were calibrated using the field traffic counts and validated against probe data. At the end of this task, the FAU team developed two models that were fully calibrated and validated against the field data.

3.1.2. Building the Simulation Model

The models were developed inside the VISSIM 5.40 microsimulation software platform. VISSIM is high-end microscopic multi-modal traffic flow simulation software developed by the PTV group based in Germany. The VISSIM software provides the user with analysis flexibility, which allows the user to customize minute details of their simulation. Advanced users are also able to customize their simulation runs by modifying simulation parameters and settings through the VISSIM COM interface. The microsimulation output is in text format, which is easy to read and analyze.

Multiple data sources have been used to accomplish this task. Broward County Metropolitan Planning Organization (MPO) data and Google Maps were used for roadway classification, initial speeds, volumes, and others. In addition, the data were also supplemented by the GIS centerline files, high-resolution aerial imagery, video streams, traffic volumes, signal timing data, and etc. The FAU research team consulted with FDOT, Broward County and consulting companies that performed recent studies in this area to obtain as much data as possible. Figure 5 depicts an overview of the network microsimulation model. The network model consists of 200 signalized intersections in Central Broward County.
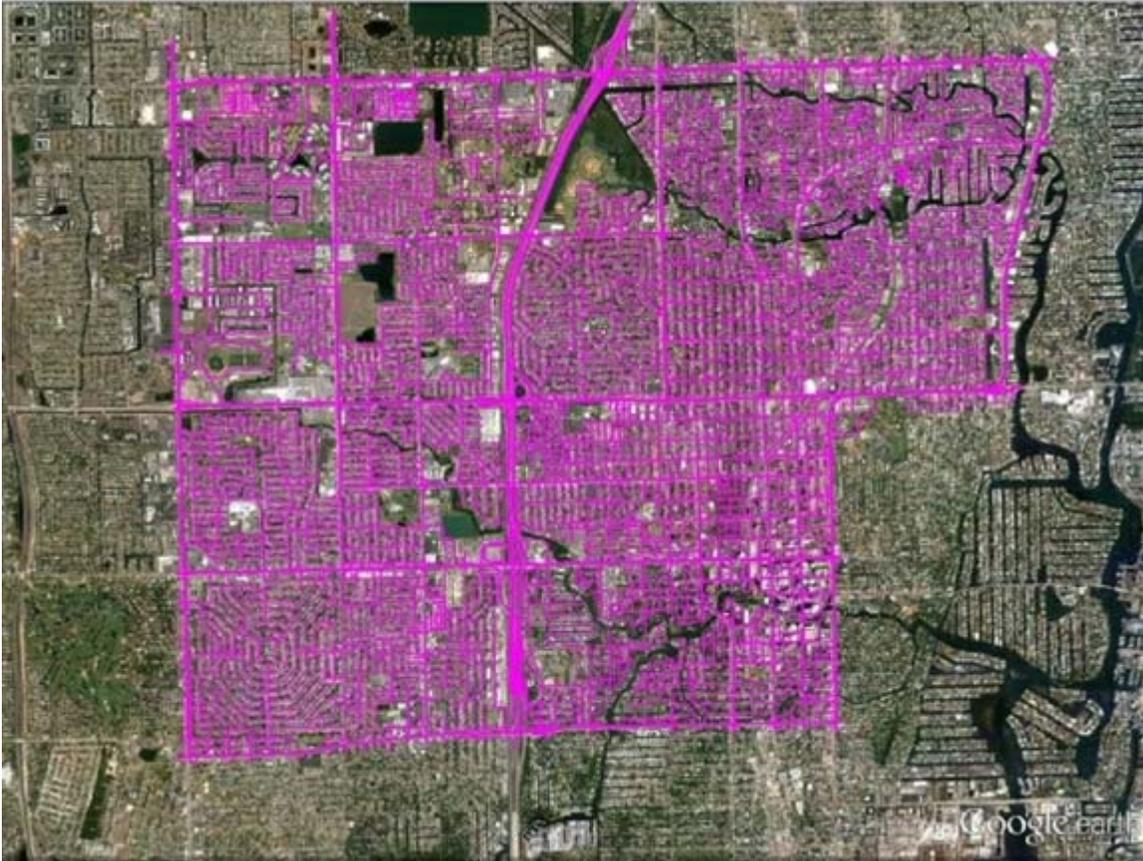
Figure 5- Overview of the Network Microsimulation Model

Initially, the study area was extracted from the GIS centerlines file and exported to the VISUM microsimulation model, and necessary adjustments were made to the model. Particularly, all the turning movements at the intersections and links direction were assessed. When all the initial checks were finished, the model was exported to the VISSIM microsimulation software for further refinement of the geometric data based on aerial images retrieved from Google gadgets in Google Map and Google Earth because VISSIM provides the user with the ability to import background images.

a) Davie Blvd.   b) Oakland Park Blvd.

c) Sunrise Blvd.   d) Federal Highway

Figure 6- Examples of Geometrical Fine-Tuning in VISSIM

Figure 6 depicts several examples of geometrical fine-tuning of the model. All the links and intersections inside the model were checked to match the exact field condition. Several parts of the model were already available as fully developed VISSIM models from FDOT consultants. One of the available traffic models was for Oakland Blvd. from SR-7 to I-95 and the other model included Broward Blvd. from SR-7 to Federal Hwy. The models were merged with the VISSIM model exported from VISUM. Merging the microsimulation models saved a considerable amount of time and energy for the FAU research team because no further adjustments or refinements were necessary for newly imported models. Speed limits on all streets in the network were also inserted. This task was accomplished using the Google Maps Street view mode, and they were all incorporated into the model.

In the next step, two railroad tracks were modeled inside the simulation model. The first track is used by Amtrak and Tri-rail trains, and the other track is for freight trains. The train schedule replicates the real schedule and accurately represents the field condition. Transit lines are also part of the study area. Seventeen bus lines are present within this area as well as Amtrak and Tri-Rail train lines. To successfully create the transit routes, several elements were created in the VISSIM model such as bus and train stops, vehicle types, and vehicle classes for each transit line. Timetables were created for each transit line according to the schedules of operations obtained from official Broward County, Tri-Rail and Amtrak websites. For each bus stop and transit line, boarding information (in persons per hour) was incorporated. Boarding data were

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obtained from Broward County transit department as total boarding per day per stop and then recalculated to obtain the number of persons boarding per hour per transit line.

Another important component inside the simulation model involved entering the traffic demand. Time variable traffic volume was defined in 15-minute time intervals. Traffic volumes and turning movement counts were provided by several sources. BCTED provided turning movement counts for 99 intersections. The FDOT data collection unit collected approximately 50 intersections. The FAU students employed on this project went to the field and collected 11 additional intersections using Jamar counters provided by Albeck Gerken. In the next task, stop signs were added to the simulation model by observing the Street View feature of Google Map. In total, approximately 1,300 stop signs were placed in the network. Conflict areas define priorities at the intersections and drivers accordingly plan how to cross the conflict area. Adding the stop signs was a time consuming task in the VISSIM model because more than 4,000 conflict areas were created. Also, routing decisions were entered inside the model that indicated the origin destination points and turning movements. In all the steps, the model was controlled for quality and consistency. Figure 7 depicts snapshots of the model building tasks.
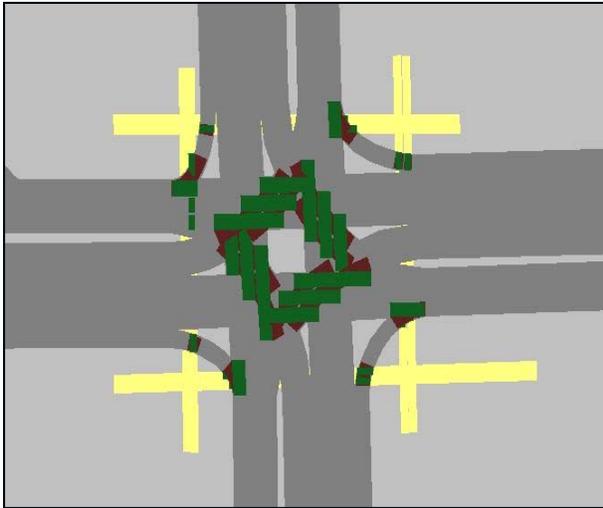
a) Conflict Zones
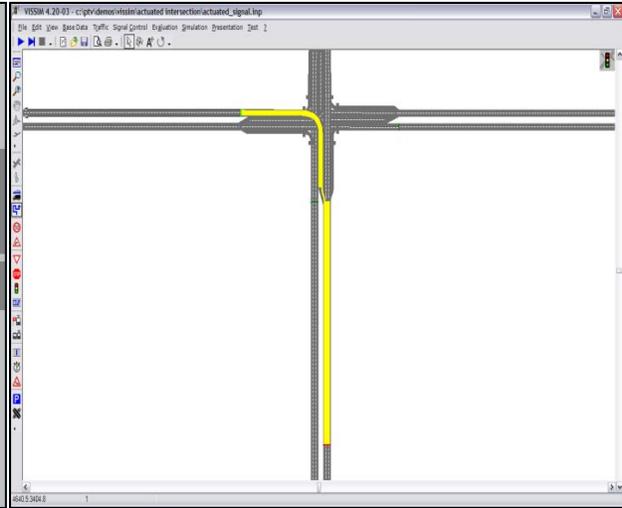
b) Routing Decisions
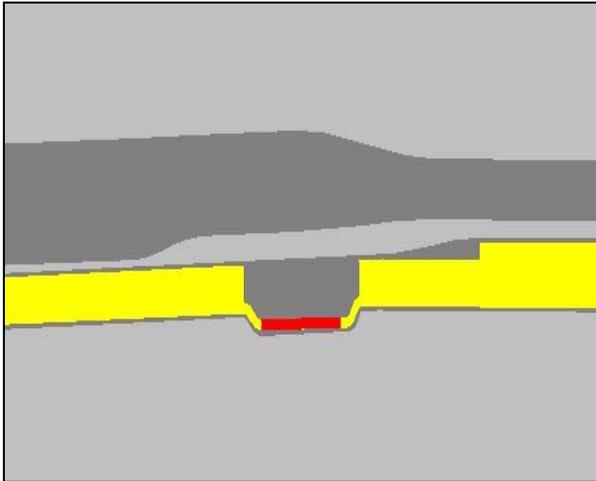
c) Bus Routes

d) Quality and Consistency Control

e) Vehicle Input

f) Stop Signs

Figure 7- Snapshots of Various Simulation Model Building Tasks

3.1.3. Signal Heads Modeling

This model includes approximately 200 intersections. The signal design sheet, basic signal timing sheets, and pattern signal timing sheets were collected from BCTED. Synchro files for 80 intersections were provided by BCTED and incorporated in VISSIM as ring barrier controllers (RBC). For the intersections with no a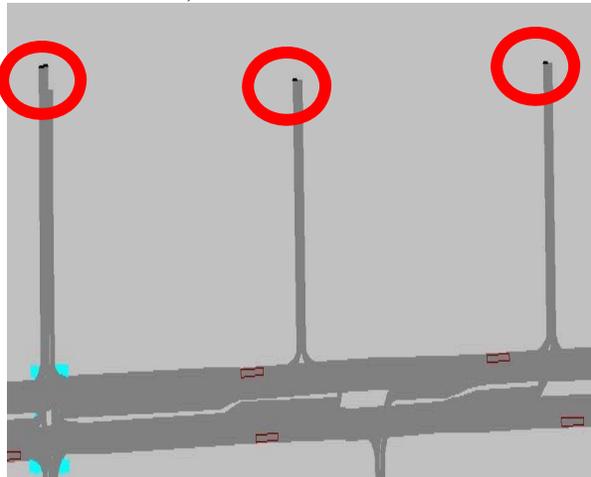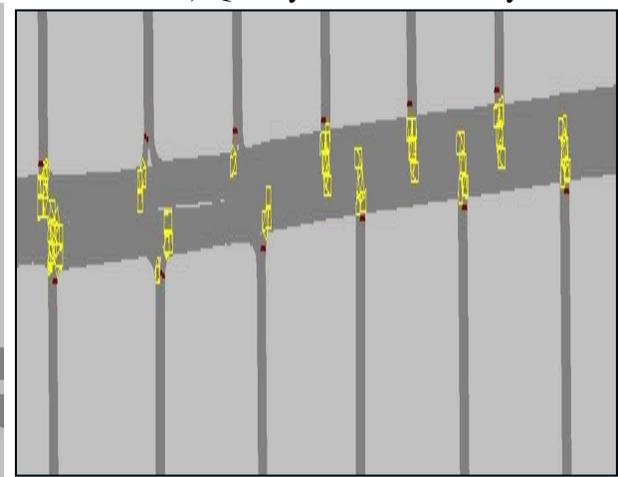vailable Synchro files, the pattern timing and other signal parameters were entered manually using signal timing and pattern data sheets provided by BCTED. It should be noted that importing data directly from Synchro is more efficient. Traffic signal sheets provide input parameters such as max green time, yellow time, all red time, and pedestrian timings. They also provide descriptive information such as the status of the left-turn movement (either permitted or protected), detector responding time, and others.

BROWARD COUNTY TRAFFIC ENGINEERING
ACTUATED TRAFFIC SIGNAL TIMING SHEET

Intersection Number	1013		Initial Operation Date	6/17/53
Controller Type	2070 LN		System Number	1013
Modification Number	16		Modification Date	02/15/2012
Drawing/Project No	411440-1-52-01		FPL Grid Number	87883014001
Intersection	FEDERAL HWY. (US 1/SR 5) AND OAKLAND PARK BLVD.(SR816)			
Municipality	FORT LAUDERDALE			

Controller Phase	1	2	3	4	5	6	7	8
Face Number	1	2,6	5				4,7	3,8
Direction	SBL	N/S	NBL				EB	WB
Initial Green(MIN)	5	7	5				6	6
Vehicle Ext.(GAP)	1.5	3.0	1.5				2.0	2.0
Maximum Green I	18	30	18				35	35
Maximum Green II								
Yellow Clearance	4.0	4.0	4.0				4.0	4.0
All Red Clearance	1.0	3.0	1.0				3.0	3.0
Phase Recall	OFF	MIN	OFF				OFF	OFF
Detector Delay								
Walk		7					5	5
Pedestrian Clearance		31					28	34
Permissive	DUAL		DUAL					
Flash Operation	RED	RED	RED				RED	RED
Green Return	7	1,2	8				4	6

Attachment

| Channel/Drop | 46 / 2 | | IP Address | |

NOTES:
1. IP: 10.191.34.047, MASK: 255.255.255.128, GWAY: 10.191.34.1, PORT: 5037.
2. CONTROLLER OPERATION IS LEAD/LAG. SBL LEAD, NBL LAG.
3. MOD. 16 DEPLOYS SIGNAL ONTO ATMS.NOW.

Figure 8- Sample of Traffic Signal Timing Sheet

Pattern timing plan sheets contain information regarding cycle length, offsets, coordination groups, and patterns. They also include Time of the Day (TOD) timing plans for AM, Mid-Day, and PM time periods. Also, there is a separate signal-timing pattern during the weekends.

a) Sample Pattern Timing Plan   b) Traffic Signal Design Sheet

Figure 9- Sample Pattern Timing Plan Data Sheet

The traffic signal design sheets provided necessary geometrical information of each intersection. The sheets also included signal timing phasing information, and as was previously noted, another important source of geometrical information involved the street view feature of Google Map. For each signalized intersection created in VISSIM, the following components were defined:

1. Signal Head
2. Stop Sign
3. Traffic Detector

If right turn on red (RTOR) is allowed, a stop sign should be in place at the intersection. Traffic detectors identify the presence of the vehicle and send a request to extend the green time at a particular approach. If the detectors are not properly connected to the traffic signals and RBC controllers, the traffic light will never turn green for a particular approach. Once all these elements are placed at the intersection, they have to be connected to a unique RBC file for that intersection. Otherwise, the field conditions will not be realistically represented. Figure 10 depicts creating a sample RBC controller in VISSIM.
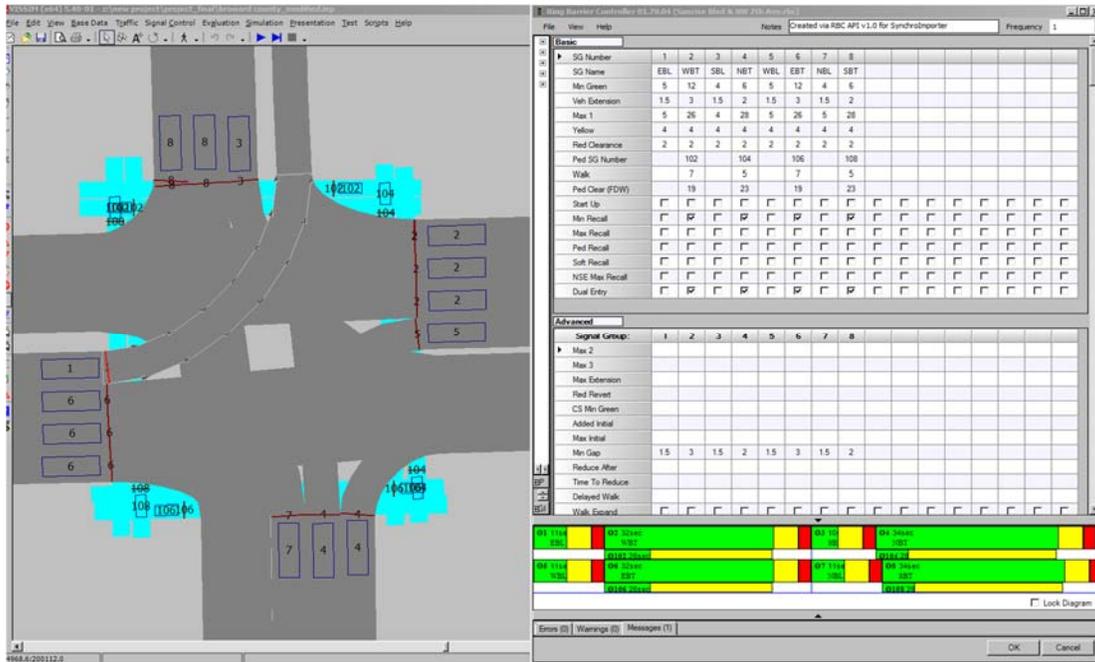
Figure 10- Signal Head Modeling

3.1.4. Data Collection

To build, calibrate, and validate the model, certain data components are necessary. This section provides a description regarding the data collection process from different sources.

3.1.4.1. Turning Movement Counts

Turning movement field counts for approximately 100 intersections were collected from BCTED and processed in electronic format for further use to populate traffic demand in the VISSIM model. Also, turning movement data for nearly 50 intersections were collected by FDOT, and the FAU research team collected data for nine intersections.

3.1.4.2. Traffic Volume

Traffic volumes were obtained from FDOT Florida Traffic Online (2013) website, the website provides multiple traffic reports including annual average daily traffic (AADT) by County for every segment of Florida's State Highway System, as well as other information such as vehicle classification and various factor category information. Traffic data reports for each Florida County exist in the following format:

1. Annual Average Daily Traffic
2. Annual Vehicle Classification
3. Peak Season Factor Category
4. Volume Factor Category Summary
5. Weekly Axle Factor Category
6. Historical AADT Data

The website also provides daily passenger car and truck traffic information for the users. Figure 11 shows traffic map of FDOT traffic online website.
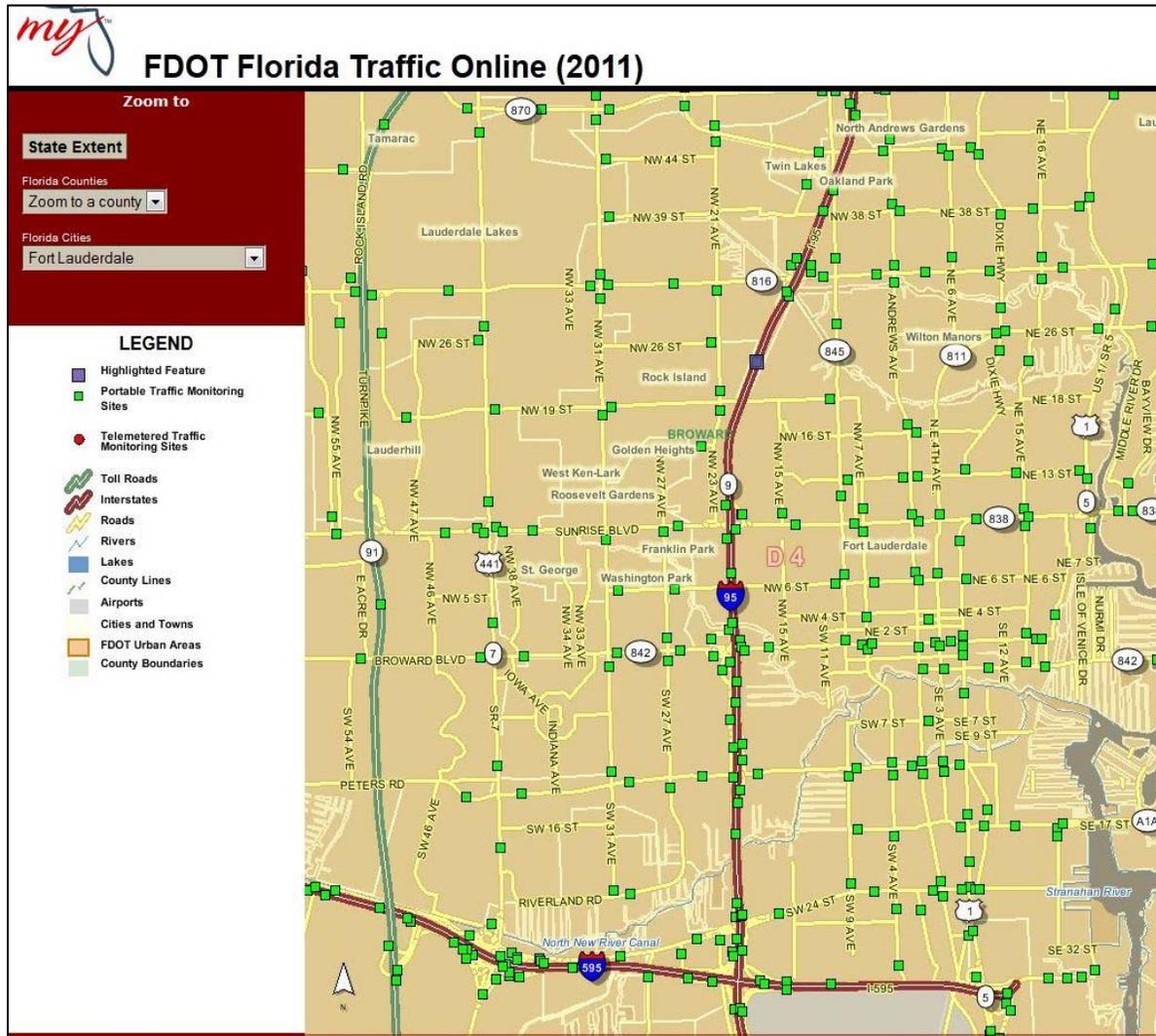
Figure 11- FDOT Traffic Online Website Overview

Each sensor station is shown as green square on the website map as shown in Figure 11. By clicking on each sensor station the following information is revealed:

1. Road Name
2. Site Number
3. Site Description
4. Section Number
5. Mile Post
6. AADT
7. Site Type
8. Class Data
9. K Factor
10. D Factor

Figure 12 depicts sensor station data download dialog box.

Figure 12- FDOT Traffic Online Sensor Station Information

Summary of volume data is available in 15-minute resolutions for each direction of travel. The volume data are provided each 15 minutes and for hourly resolution. The average daily volume for three time periods of AM, PM, and entire day is also provided in daily traffic reporting sheets. Figure 13 shows a snapshot of hourly traffic volume data of a specific sensor station.

```
COUNTY:          86
STATION:         2500
DESCRIPTION:     SR 9 / I-95 - S OF SR 816/OAKLAND PARK BLVD
START DATE:      05/03/2011
START TIME:      0000
-------------------------------------------------------------------------------
                   DIRECTION: N                      DIRECTION: S          COMBINED
TIME    1ST    2ND    3RD    4TH   TOTAL    1ST    2ND    3RD    4TH   TOTAL   TOTAL
-------------------------------------------------------------------------------
0000    709    585    559    437   2290    381    349    271    240   1241    3531
0100    455    419    338    298   1510    225    183    154    136    698    2208
0200    284    244    261    253   1042    158    142    161    144    605    1647
0300    236    274    294    294   1098    166    223    208    203    800    1898
0400    321    336    393    390   1440    240    312    382    400   1334    2774
0500    432    525    730    876   2563    511    653    793    843   2800    5363
0600    933   1184   1597   1738   5452   1149   1391   1652   1688   5880   11332
0700   1853   2131   2415   2370   8769   1733   1808   2153   2235   7929   16698
0800   2368   2347   2273   2135   9123   1922   1854   1850   1962   7588   16711
0900   1933   1976   2045   1973   7927   2059   1960   1752   1788   7559   15486
1000   1926   1799   1859   1937   7521   1826   1752   1926   1714   7218   14739
1100   1829   2043   2083   2060   8015   1760   1861   1825   1731   7177   15192
1200   2029   2058   1966   1916   7969   1751   1839   1886   1706   7182   15151
1300   1968   2047   2089   2124   8228   1880   1878   1800   1725   7283   15511
1400   2032   2204   2317   2407   8960   1761   1700   1928   1902   7291   16251
1500   2247   2054   2353   2205   8859   1870   1862   1970   1864   7566   16425
1600   2248   2200   2194   1873   8515   1960   2084   2012   2232   8288   16803
1700   2096   2328   2337   2294   9055   2301   2114   2217   2156   8788   17843
1800   2310   2205   2025   1860   8400   2062   2008   1800   1602   7472   15872
1900   1730   1710   1637   1642   6719   1379   1478   1281   1142   5280   11999
2000   1367   1477   1319   1344   5507   1039   1042   1029    970   4080    9587
2100   1332   1289   1358   1250   5229   1044    920    902    773   3639    8868
2200   1149   1151   1139   1070   4509    812    811    699    596   2918    7427
2300   1064    937    812    681   3494    628    537    364    348   1877    5371
-------------------------------------------------------------------------------
24-HOUR TOTALS:                   142194                          122493  264687
-------------------------------------------------------------------------------
                          PEAK VOLUME INFORMATION
          DIRECTION: N               DIRECTION: S          COMBINED DIRECTIONS
        HOUR      VOLUME           HOUR      VOLUME         HOUR      VOLUME
A.M.     730       9500             730       8164           730      17664
P.M.    1715       9269            1645       8864          1700      17843
DAILY    730       9500            1645       8864          1700      17843

TRUCK PERCENTAGE   7.85                       9.09                    8.43
```

Figure 13- FDOT Traffic Online Hourly Volume Data

3.1.4.3. Travel Time

Travel time data was collected by both FDOT and FAU research team. FDOT travel time data
were collected for 12 road sections in the area. The data were transferred to the FAU research
team in Microsoft Excel form. Table 2 summarizes major corridors and roads covered by FDOT
travel time collectors. The travel time data were collected in 4 seconds resolution.

Table 2- FDOT Travel Data Collection

No	Travel Time Runs	Time of the Day			Dates			
		AM	MD	PM	10/5/10	10/6/10	4/7/10	4/8/10
1	Broward Blvd. from SR7 to Federal Hwy	x	x	x	x	x		
2	Federal Hwy from Oakland to Las Olas	x	x	x	x	x		
3	Oakland Park from 31st to Federal	x	x	x	x	x		
4	Oakland Park from University to NW 31st Ave	x	x	x	x	x		
5	SR7 from Oakland Park to Broward Blvd.	x	x	x	x	x		
6	Sunrise Blvd. 46th Ave. to Federal Hwy	x	x	x	x	x		
7	Broward Blvd.	x	x	x			x	x
8	Oakland West	x	x	x			x	x
9	Route 2 Oakland PK East	x	x	x			x	x
10	Route 6 US 1	x	x	x			x	x
11	SR7 from Oakland Park to Broward Blvd.	x	x	x			x	x
12	Sunrise Blvd.	x	x	x			x	x

Also the FAU research team collected travel time data in two different time periods:

1. Spring 2010: Two days on January 13th and January 14th, 2010.
2. Fall 2013: July 23rd, 24th, and 30th, 2013.

The second travel time data collection runs were conducted to complete the first set of data for travel time validation task. The FAU research team collected data using QStarz travel recorder and the travel data was analyzed using the associated software: "QTravel V1". In order to collect the most accurate travel time data, the recorder travel time resolution was set to 1 second. Travel time data were collected for all six major corridors in the study area as showed in Table 3.

Table 3- The FAU Research Team Travel Time Data Collection

No	Travel Time Runs	Time of the Day	Spring 2010		Fall 2013		
		PM	01/13/10	10/14/10	07/23/13	07/24/13	07/30/13
1	US-1 from Davie Blvd. to Oakland Blvd.	x	x	x			x
2	SR-7 from Davie Blvd. to Oakland Blvd.	x	x	x	x	x	x
3	Oakland Blvd. from US-1 to SR-7	x	x	x	x	x	
4	Sunrise Blvd. from US-1 to SR-7	x	x	x	x	x	
5	Broward Blvd. from US-1 to SR-7	x	x	x		x	
6	Davie Blvd. from US-1 to SR-7				x	x	x

3.1.5. Network Model Calibration and Validation

The models were calibrated using field data such as turning movement counts and traffic volume. Once the calibration task was completed, the models were validated against field travel time observation. To validate the microsimulation model against the field travel time data, the following parameters were modified accordingly:

1. Traffic Volume
2. Turning Movement Counts
3. Speed Data

When the models were validated, the calibration results were checked again to make sure that they are still in an acceptable range. After several iterations both calibration and validation results fitted in the acceptable range.

Table 4 depicts the final calibration results when the validation task was completed. Note that the R^2 value for both calibration and validation was between 0.80 and 0.96, which is acceptable. The calibration and validation of a network level microsimulation model is a challenging task because major arterials and freeways interact dynamically. The FAU research team devoted a significant amount of time to fulfill these tasks. The final results are presented in Table 4 and Table 5 shows an acceptable point where both calibration results are in an acceptable range.

Table 4- Network Model Calibration Results for Different Corridors

	Oakland	Sunrise	Broward	Davie	SR7	US1
R^2	0.90	0.92	0.91	0.96	0.92	0.94

Table 5- Network Model Validation Results for Different Corridors

R^2	Oakland	Sunrise	Broward	Davie	SR7	US1
EB	0.86	0.82	0.89	0.85	0.83	0.90
WB	0.80	0.84	0.83	0.92	0.89	0.84

To fully observe the status of model calibration and validation, multiple charts were created to visualize the results. The visualization of the results provides a better understanding of the data and helps to identify problematic intersections and approaches. Figure 14 depicts a sample calibration visualization chart of Sunrise Blvd. The vertical axis represents traffic volume in vehicles per hour, and the horizontal axis represents all the approaches at intersections for Sunrise Blvd. The red bars show field data vehicle counts, and the blue bars show simulation vehicle counts retrieved from data collection points inside the simulation model. The purple shade shows the overlap of two data series.
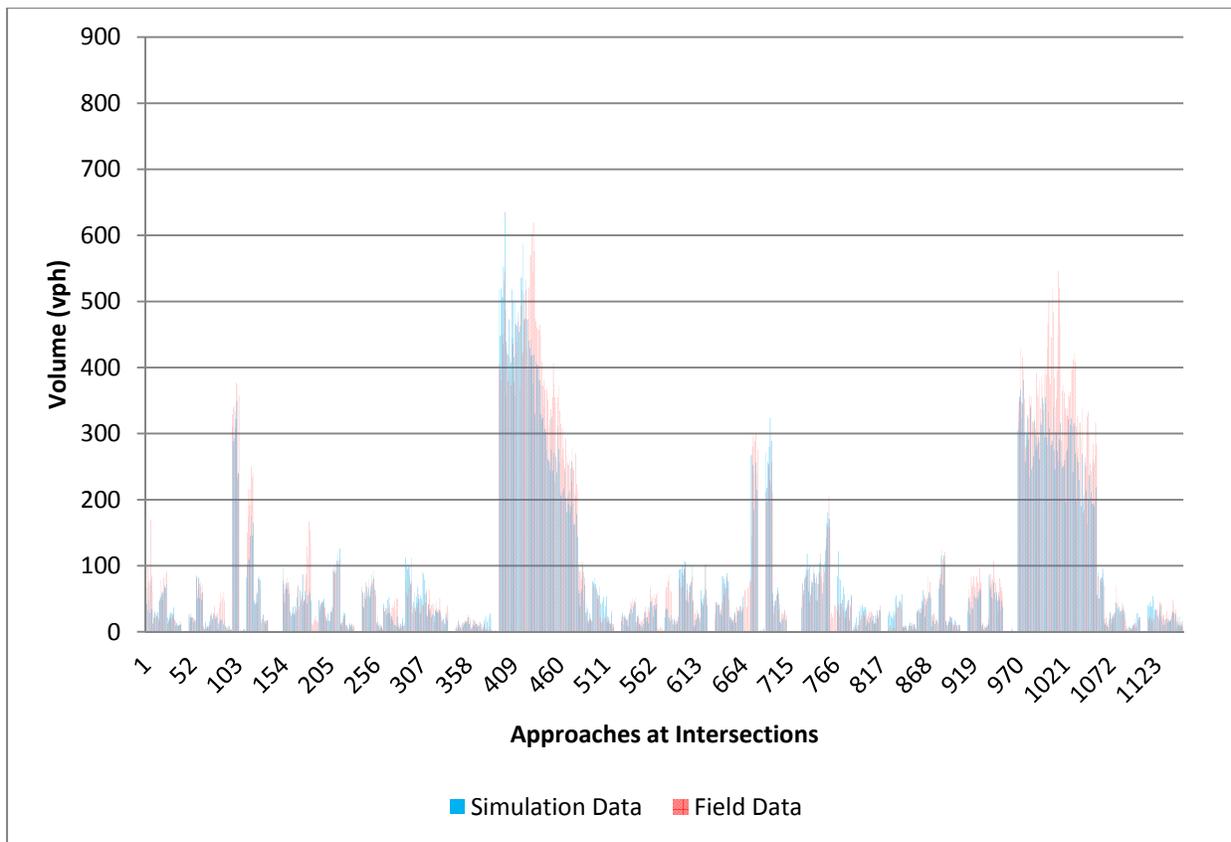

Figure 14- Sample Calibration Visualization of Approaches at Different Intersections for Sunrise Blvd.

Figure 15 illustrates the sample validation visualization chart for different road segments at Davie Blvd. in the network model. The vertical axis represents travel time in minutes, and the horizontal axis represents the road segments at Davie Blvd. Similar charts were created for other corridors. For more information please refer to Appendix A.
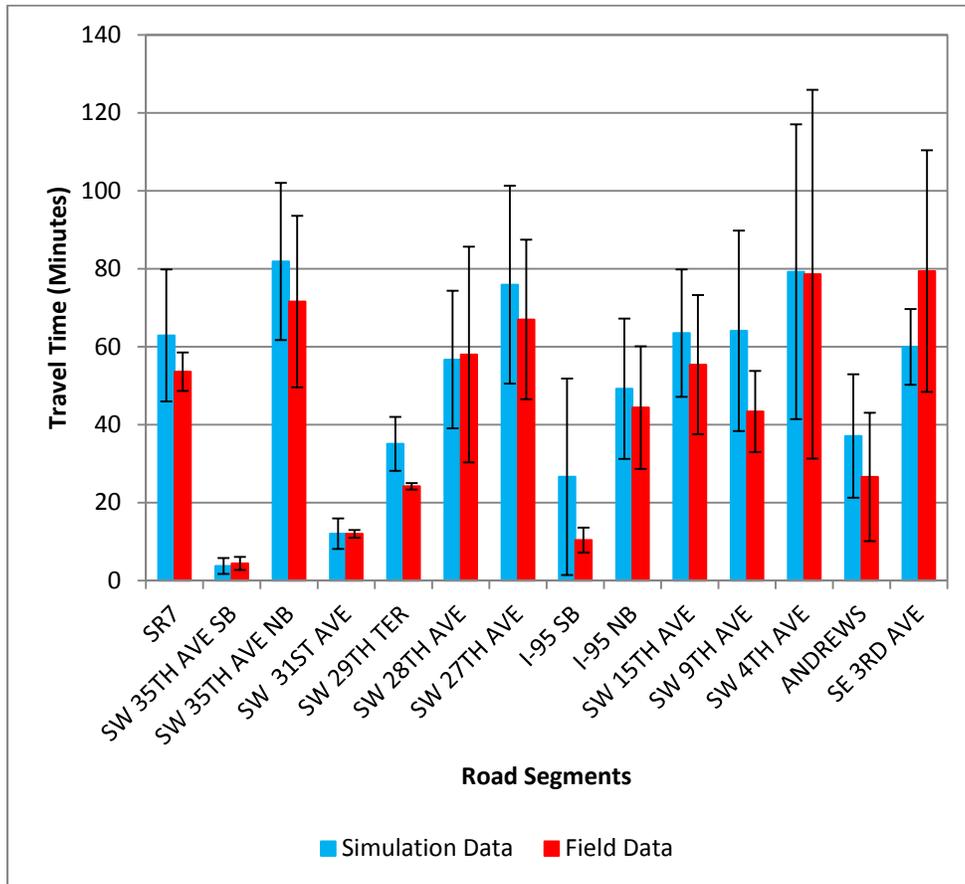
39

Figure 15- Network Model Sample Validation Visualization Chart for Different Road Segments on Davie Blvd.

3.1.6. Broward Blvd. Calibration and Validation

The Broward Blvd. model was calibrated based on the turning movement and traffic counts data. The simulation data were compared against the field detectors. A total of five traffic detectors are present on Broward Blvd., which have been used for model calibration purposes. The name and location of the traffic detectors are represented below:

1. M-17 (NW 38th Ave.)
2. M-18 (NW 27th Ave.)
3. M-19 (NW-31st Ave.)
4. M-20 (NW-9th Ave.)
5. M-21 (NW 7th Ave.)

Hourly traffic volume was obtained from 6:00 AM to 11:00 PM from the simulation model and was compared to the field traffic counts. Table 6 shows an entire day's calibration result for different traffic detectors.

Table 6- Broward Blvd. Detail Calibration Result for Different Intersections

	M-17 (NW 38th Ave.)	M-18 (NW 27th Ave.)	M-19 (NW- 31st Ave.)	M-20 (NW 9th Ave.)	M-21 (NW 7th Ave.)	Overall
R^2	0.34	0.84	0.74	0.89	0.96	0.76

Please note that despite the tremendous effort in calibrating the microsimulation model, the R-squared value is slightly lower compared to the network level model. This discrepancy can be explained by considering that the Broward Blvd. microsimulation model was developed for an entire day (18 hours) compared to the network model (two hours).

Figure 16 depicts the Broward Blvd. model calibration visualization for the M-18 traffic detector near NW 27th Ave. The y-axis shows total vehicle counts on both directions, and the x-axis represents the hour of day in the simulation model. Please refer to Appendix B for a complete set of calibration and validation charts of the Broward Blvd. model.
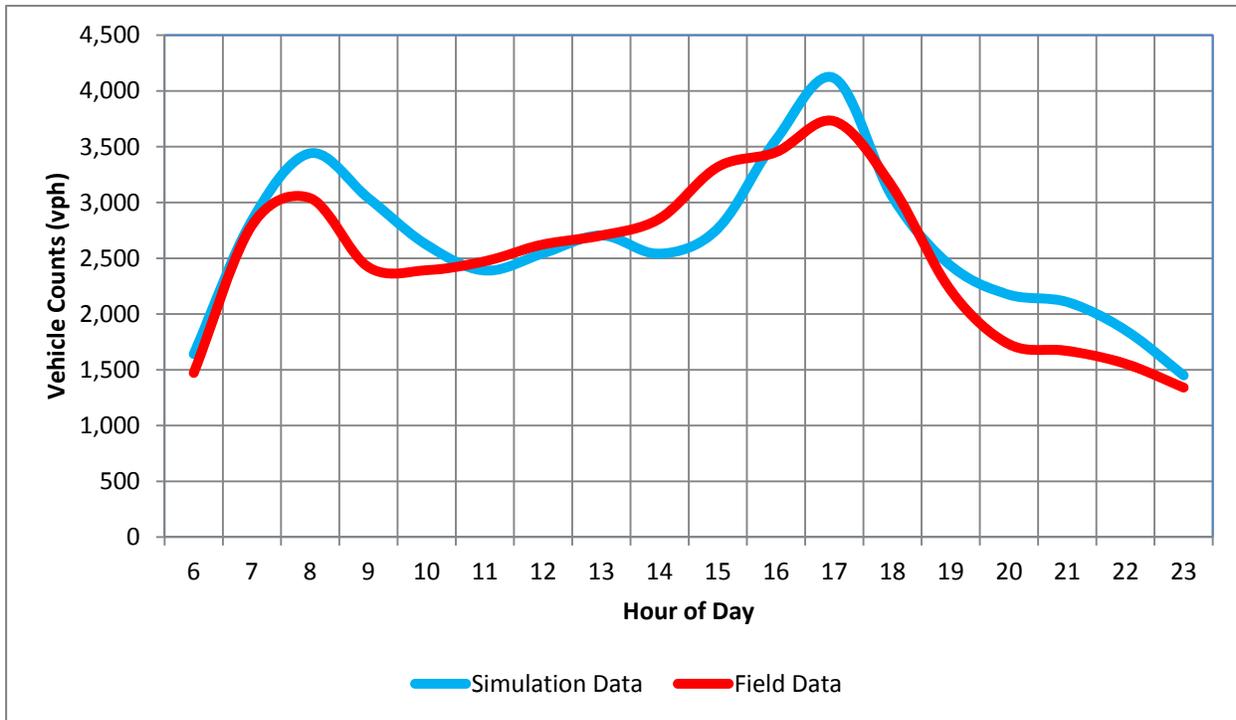
Figure 16- Broward Blvd. Model: Calibration Visualization for M-18 Detector near NW 27th Ave (total traffic count on both directions)

Broward Blvd. was also validated utilizing travel time data obtained from FDOT. The model was calibrated for three different time periods:

1. AM Peak (7:00 AM to 9:00 AM)
2. Mid-Day (11:00 AM to 01:00 PM)
3. PM Peak (4:00 PM to 6:00 PM)

Table 7- Broward Blvd. Detail Validation Results for Different Time Periods (R − Squared)

	AM	Mid-Day	PM
EB	0.87	0.85	0.88
WB	0.95	0.95	0.89
Average	0.91	0.90	0.88

Table 7 depicts the validation results of the Broward Blvd. microsimulation model for different time periods at each travel direction. The model has high fidelity with the field data. Similar to the network model, several charts were developed to visualize the Broward Blvd. validation task. Figure 17 depicts a sample validation visualization chart for different road segments in Broward Blvd.
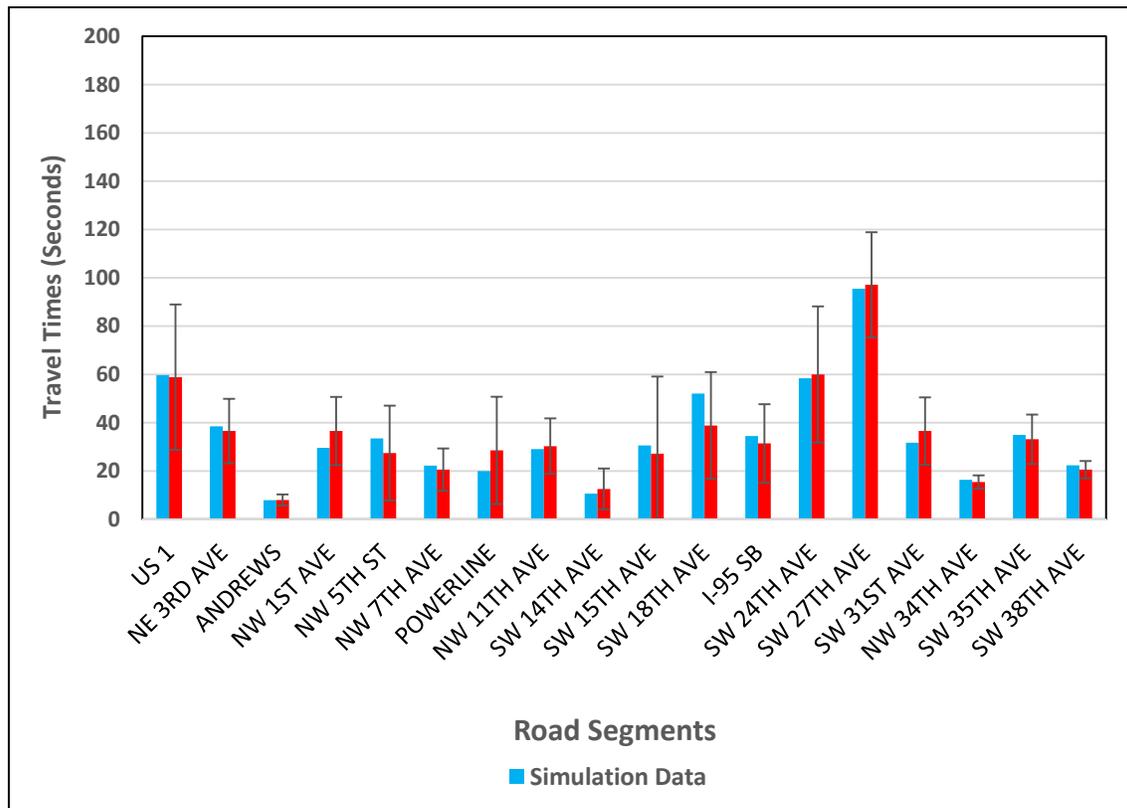
Figure 17- Broward Blvd. Model: Sample Validation Visualization Chart for Different Road Segments

3.2. Identify Types and Formats of Traffic Data from the Field Sensors

The TSM&O program aims to optimize the performance of the existing multi-modal infrastructure by implementing systems, services, and projects to preserve the capacity and improve the security, safety, and reliability of the Florida transportation system.
As part of the program, the Florida Department of Transportation will deploy an ATMS in central Broward County major arterials. The program will install and use the ITS infrastructure, which includes data collection and communication devices to improve the monitoring and management of the traffic conditions in central Broward County. Although the data collection

infrastructure provides traffic management centers with extensive data, the development of an analytical framework to provide guidelines for traffic management center operations and management activities is necessary. The available ATMS data sources in the area are presented in more detail in this section.

3.2.1. Bluetooth BlueTOAD (Traffic Cast)

Traffic Cast BlueTOAD detects anonymous Bluetooth signals from mobile devices (cell phones, tablets, laptops, etc.) inside vehicles. The devices collect the following information from the road sensor:

1. Travel Time
2. Speed
3. Origin Destination Data

The devices can be positioned to provide travel times on alternative routes. Each device can be paired with multiple devices also installed in the field, and these pairs can be stitched together to create routes. The basic outline of the function of BlueTOAD devices is shown in Figure 18.
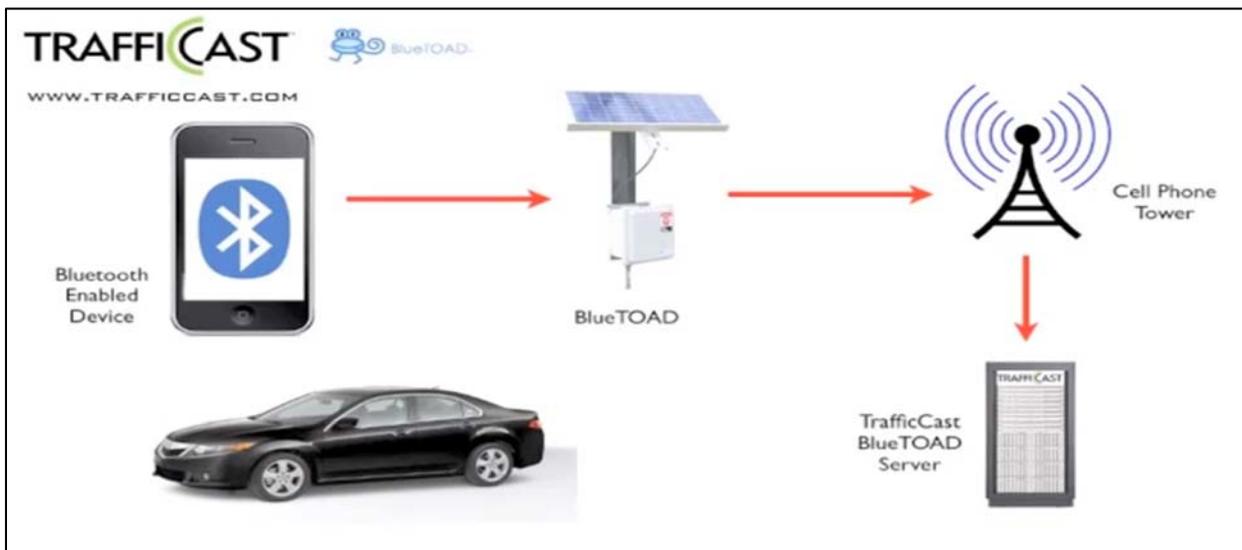
Figure 18- BlueTOAD System Information Flow

The BlueTOAD system also keeps track of the origin and the destination of each vehicle. This feature benefits transportation engineers in conducting O-D studies. Broward County has 30 devices placed in the field. Figure 19 depicts the actual positions of these devices.
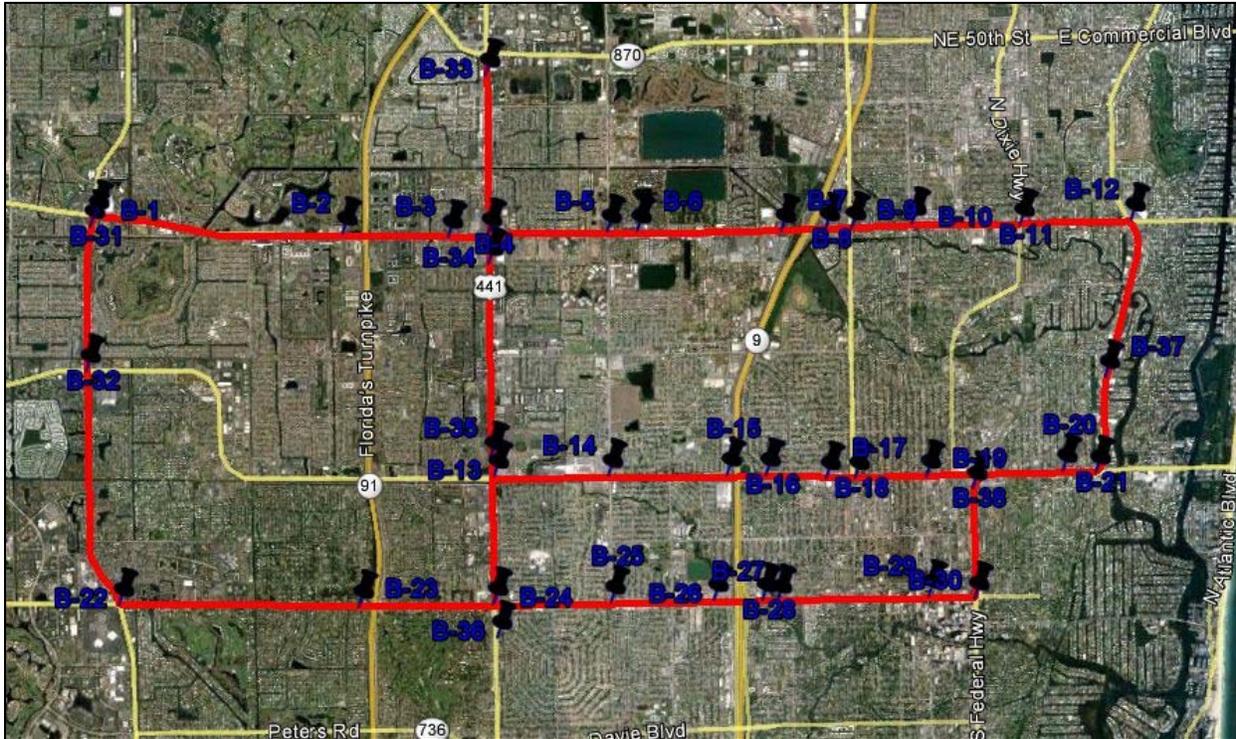
Figure 19- Position of BlueTOAD Devices in the Field

3.2.2. Microwave Detector Stations (Wavetronix)

Broward County purchased and installed two types of Wavetronix sensors – Smart Sensor V and Smart Sensor HD. The Smart Sensor V accurately monitors up to eight lanes of traffic and collects the following data per lane:

1. Volume
2. Speed
3. Occupancy
4. Vehicle Classification

The Smart Sensor HD monitors up to 22 lanes of traffic. The detections are based not on lanes but on vehicles and even if vehicles change lanes, detection remains accurate. This sensor records the following data: (Figure 20)

1. Volume
2. Average Speed
3. Occupancy
4. 85th percentile speed
5. Average Headway
6. Average Gap
7. Speed Bin Counts
8. Direction Counts
9. Classification Counts

a)

NAME	VOLUME	occu-pancy (%)	Speed (MPH)	85% Speed (MPH)	C1 10	C2 20	C3 30	C4 255	C5	C6	C7	C8	HEADWAY	GAP
LANE_01	4	0.6	66.3	67.0	0	1	2	1	–	–	–	–	75.0	74.6
LANE_02	18	2.0	65.5	69.8	0	14	1	3	–	–	–	–	16.7	16.3
LANE_03	27	3.7	68.0	73.5	1	14	4	8	–	–	–	–	11.1	10.7
LANE_04	11	0.9	73.2	80.0	0	8	2	1	–	–	–	–	27.3	27.0
LANE_05	2	0.2	72.9	76.0	0	0	2	0	–	–	–	–	150.0	149.7
LANE_06	3	0.2	73.4	79.0	0	2	1	0	–	–	–	–	100.0	99.8
LANE_07	6	0.3	75.7	79.0	1	5	0	0	–	–	–	–	50.0	49.8
LANE_08	11	1.0	71.0	76.0	1	7	2	1	–	–	–	–	27.3	27.0
LANE_09	12	2.2	63.7	66.0	1	4	1	6	–	–	–	–	25.0	24.5
LANE_10	3	0.4	55.4	59.0	0	2	0	1	–	–	–	–	100.0	99.7
LANE_01	5	0.4	61.7	68.0	0	4	1	0	–	–	–	–	60.0	59.7
LANE_02	9	1.4	63.7	68.5	0	6	0	3	–	–	–	–	33.3	32.9
LANE_03	14	1.1	70.2	75.0	0	10	2	2	–	–	–	–	21.4	21.2
LANE_04	8	0.5	74.8	78.0	0	7	1	0	–	–	–	–	37.5	37.3
LANE_05	1	0.1	66.3	67.0	0	1	0	0	–	–	–	–	300.0	299.8
LANE_06	0	0.0	73.4	79.0	0	0	0	0	–	–	–	–	0.0	0.0
LANE_07	7	0.4	76.1	80.0	2	5	0	0	–	–	–	–	42.9	42.7
LANE_08	12	1.0	68.6	72.0	2	8	1	1	–	–	–	–	25.0	24.8
LANE_09	15	1.7	68.0	72.0	1	11	0	3	–	–	–	–	20.0	19.7
LANE_10	3	0.2	63.5	67.0	1	2	0	0	–	–	–	–	100.0	99.8
LANE_01	3	0.2	72.0	77.0	0	2	1	0	–	–	–	–	100.0	99.8
LANE_02	21	2.8	68.5	76.0	0	12	3	6	–	–	–	–	14.3	13.9
LANE_03	20	1.9	67.0	69.0	3	12	2	3	–	–	–	–	15.0	14.7
LANE_04	4	0.3	76.6	79.0	0	3	1	0	–	–	–	–	75.0	74.8
LANE_05	2	0.1	73.8	75.0	0	2	0	0	–	–	–	–	150.0	149.8
LANE_06	0	0.0	73.4	79.0	0	0	0	0	–	–	–	–	0.0	0.0
LANE_07	4	0.3	70.6	73.0	0	4	0	0	–	–	–	–	75.0	74.8
LANE_08	15	1.9	70.8	80.0	1	8	1	5	–	–	–	–	20.0	19.6
LANE_09	16	2.2	66.0	71.0	3	8	0	5	–	–	–	–	18.8	18.3
LANE_10	2	0.2	53.1	59.0	0	2	0	0	–	–	–	–	150.0	149.7

a)

b)

SENSOR TIME YYYY-MM-DD HH:MM:SS	SP1 10	SP2 20	SP3 30	SP4 40	SP5 50	SP6 60	SP7 70	SP8 75	SP9 80	SP10 85	SP11 90	SP12 95	SP13 100	SP14 105	SP15 255	Correct	Wrong
2008-09-09 00:00:00	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	4	0
2008-09-09 00:00:00	0	0	0	0	0	3	13	2	0	0	0	0	0	0	0	18	0
2008-09-09 00:00:00	0	0	0	0	0	1	17	8	1	0	0	0	0	0	0	27	0
2008-09-09 00:00:00	0	0	0	0	0	1	2	5	1	1	1	0	0	0	0	11	0
2008-09-09 00:00:00	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2	0
2008-09-09 00:00:00	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	3	0
2008-09-09 00:00:00	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	6	0
2008-09-09 00:00:00	0	0	0	0	0	0	5	3	2	1	0	0	0	0	0	11	0
2008-09-09 00:00:00	0	0	0	0	0	2	10	0	0	0	0	0	0	0	0	12	0
2008-09-09 00:00:00	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3	0
2008-09-09 00:05:00	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0	5	0
2008-09-09 00:05:00	0	0	0	0	0	1	8	0	0	0	0	0	0	0	0	9	0
2008-09-09 00:05:00	0	0	0	0	0	0	6	6	2	0	0	0	0	0	0	14	0
2008-09-09 00:05:00	0	0	0	0	0	0	1	3	3	0	1	0	0	0	0	8	0
2008-09-09 00:05:00	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
2008-09-09 00:05:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008-09-09 00:05:00	0	0	0	0	0	0	2	2	2	0	1	0	0	0	0	7	0
2008-09-09 00:05:00	0	0	0	0	0	0	7	4	0	1	0	0	0	0	0	12	0
2008-09-09 00:05:00	0	0	0	0	0	0	10	3	2	0	0	0	0	0	0	15	0
2008-09-09 00:05:00	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	3	0
2008-09-09 00:10:00	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	3	0
2008-09-09 00:10:00	0	0	0	0	0	2	9	6	4	0	0	0	0	0	0	21	0
2008-09-09 00:10:00	0	0	0	0	0	0	18	2	0	0	0	0	0	0	0	20	0
2008-09-09 00:10:00	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	4	0
2008-09-09 00:10:00	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0
2008-09-09 00:10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008-09-09 00:10:00	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	4	0
2008-09-09 00:10:00	0	0	0	0	0	0	7	5	1	1	1	0	0	0	0	15	0
2008-09-09 00:10:00	0	0	0	0	0	2	11	1	2	0	0	0	0	0	0	16	0
2008-09-09 00:10:00	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	0

b)

Figure 20- Wavetronix Microwave Detection System Sample Log Files

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There are 33 of Wavetronix sensors in the field. The Field locations of the devices are shown in Figure 21.
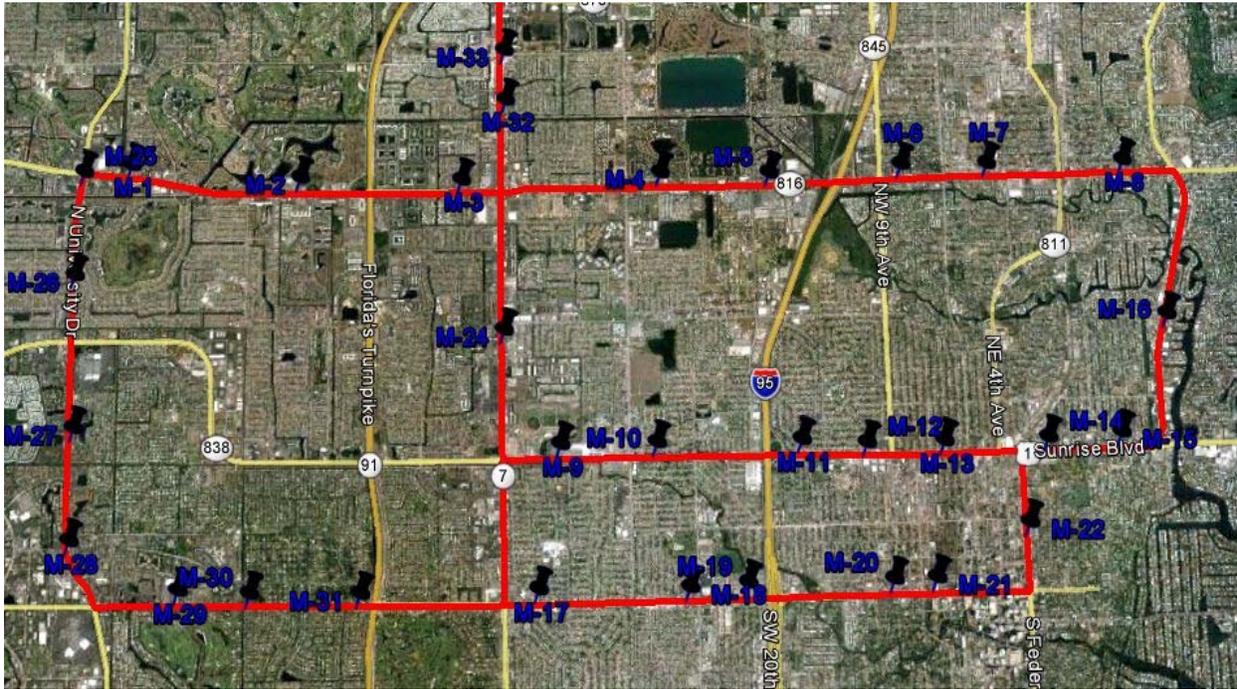

Figure 21- Locations of Wavetronix Sensors in the Field

3.2.3. Video Detection Systems (ITERIS and Traficon)

Video Detection Systems (VDS) are used to detect vehicles and actuate traffic signal operations. Broward County utilizes VDS (located on the mast arms or attached to a strain pole) from two vendors: ITERIS and TRAFICON (most frequent one). These devices have the ability to collect turning movement counts and speed data, but their accuracy depends on their location (on the mast arm vs. the strain pole locations). The systems report real-time traffic data, and video camera vendors are expected to enable this functionality on at least a few of the corridors such as Broward Blvd. in next few years. The following data can be retrieved from VDS:

1. Vehicle Counts
2. Speed
3. Occupancy
4. Density
5. Headway
6. Gap Time
7. Vehicle Classification

Broward County has also purchased the license for VIP3D1 and VIP3D2 from TRAFICON. VIP3D, a video-processing tool, provides traffic data such as volume, speed, gap time, occupancy, and vehicle classification. This tool automatically distinguishes five types of traffic flow. The system is also capable of emulating traditional double or single loop detectors. In addition to the traffic data, this tool provides pulses similar to those provided by inductive loops. Figure 22 depicts sample images of TRAFICON video detection system.

Figure 22- Traficon Video Detection System

Approximately 50 numbers of Traficon Video Detection systems are present in the area, which are shown in Figure 23.
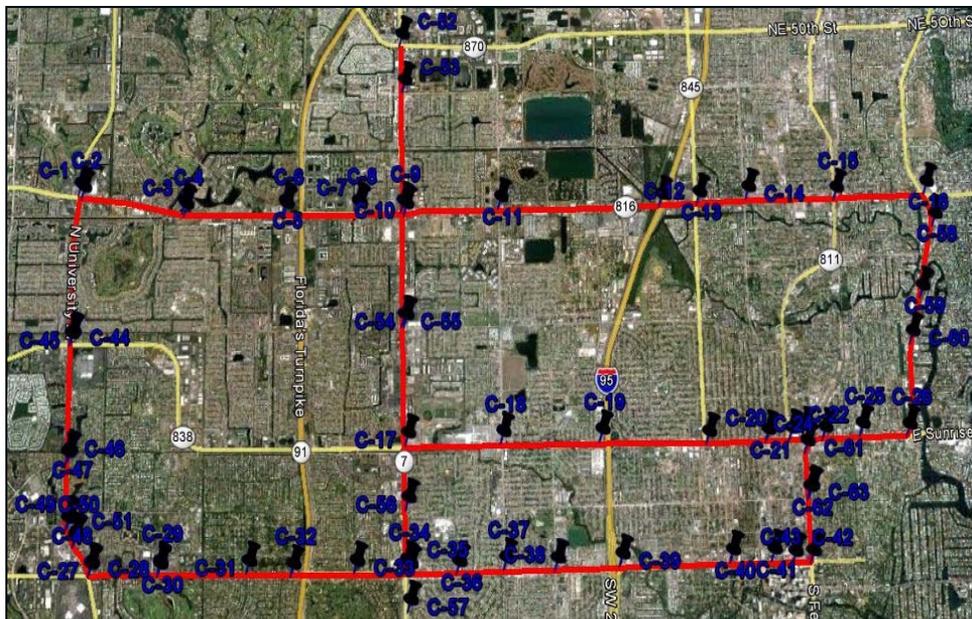
Figure 23- Locations of Traficon Video Detection Systems

3.2.4. Automatic Vehicle Identification (SIRIT)

The Automatic Vehicle Identification systems are usually used in toll or high occupancy lanes. The systems read license plate numbers and provide the following data:

1. Travel Time
2. Origin-Destination Data
3. Frequency of Travels

There are total of 16 AVI systems in the field as shown in Figure 24.
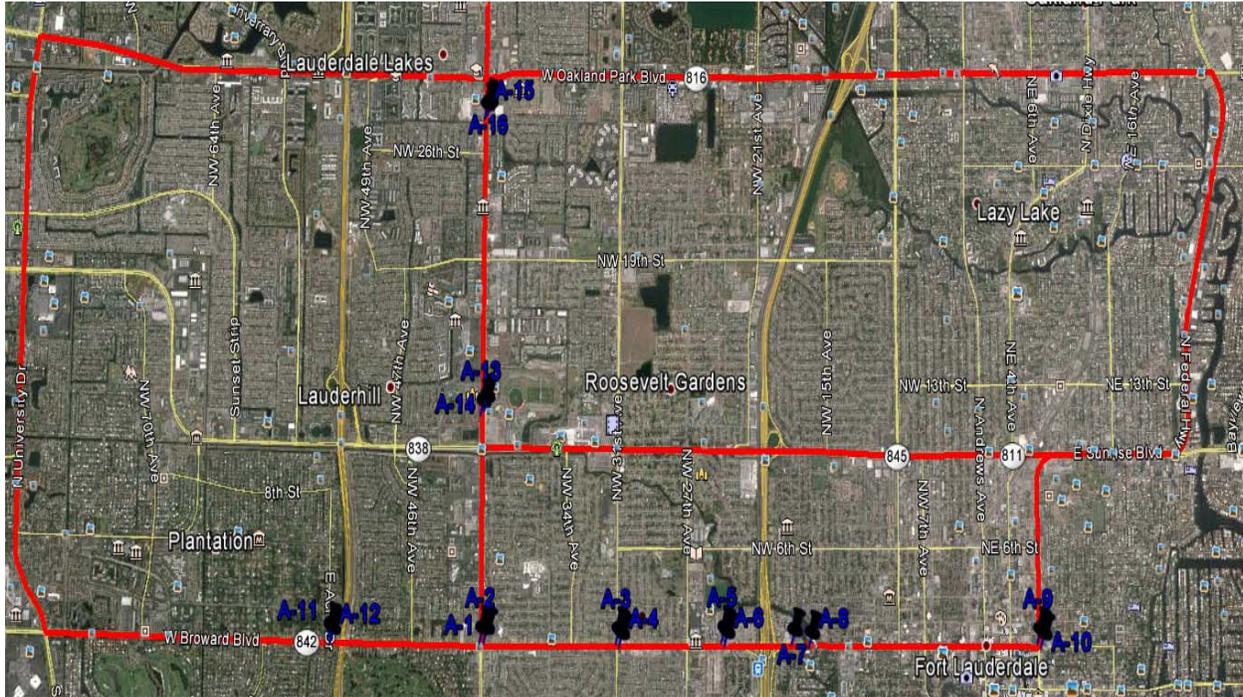
Figure 24- Location of Automatic Vehicle Identification Systems

3.2.5. INRIX

INRIX is a traffic information system that is used in 46 states and covers nearly 260,000 miles of roads in real-time. Also, this system covers major arterials and city streets in all 52 cities with a population over one million people. In addition, INRIX detects the location and incident type, monitors status and communicates the severity of abnormal traffic/travel conditions. The following data are retrieved from the web-based information system: (INRIX, 2013)

1. Real-time, Historical & Predictive Travel Time and Speed
2. Link Free-Flow Speed
3. Congestion Alerts
4. Incident Data
5. Traffic Maps

A sample of the INRIX arterial system is shown in Figure 25.
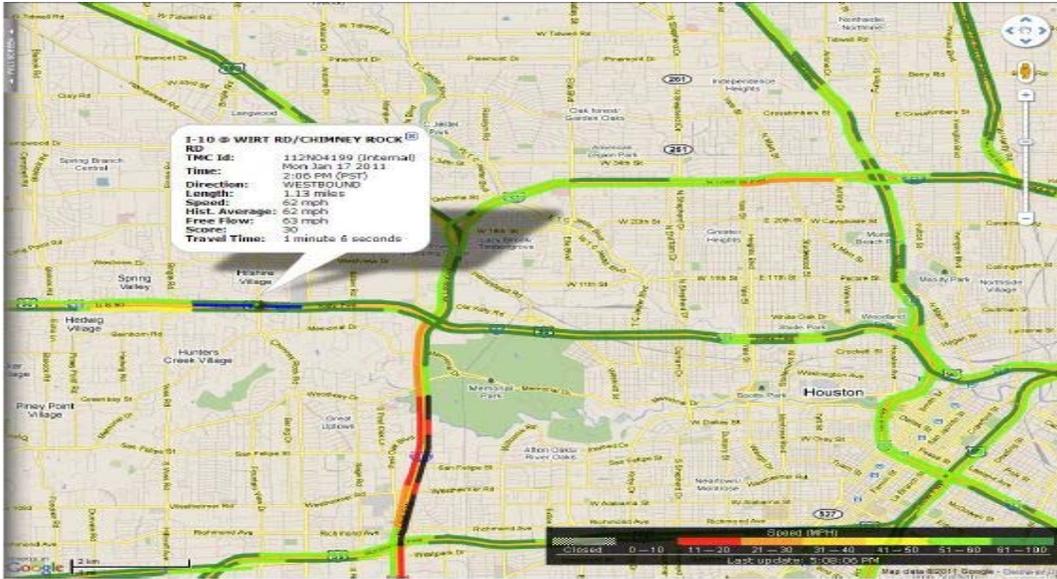
Figure 25- Sample INRIX Traffic Maps

INRIX archives travel time and speed data of each link in a tabular data form. The data are downloaded in comma delaminated format "*.csv" files. The archived database reports the following information for each link:

1. Average Speed
2. Travel Time
3. Std. Deviation
4. Speed Percentiles (10%, 25%, 50%, 85%)
5. Travel Failure Rate
6. Point Counts

An INRIX data example is shown in Figure 26.

Roadway: I-10 WB at Wirt Road/Chimney Rock Road
Friday: Morning and Afternoon Rush Hours

Time	Avg. Speed	Travel Time (secs)	Std Dev	10%	25%	50%	85%	Failure30	Failure50	Failure60	Point Count
6:00 AM	63	65	4.249	56	60	62	66	0	3	21	806
6:15 AM	62	66	4.783	55	60	63	66	1	4	23	832
6:30 AM	62	66	4.885	55	59	62	66	1	4	27	887
6:45 AM	62	66	4.731	54	59	62	66	1	4	29	873
7:00 AM	61	67	4.846	54	58	62	66	0	3	31	906
7:15 AM	61	67	4.534	54	58	61	65	0	3	35	956
7:30 AM	61	67	4.559	54	58	61	65	0	3	38	1,034
7:45 AM	61	67	4.751	54	58	61	65	0	3	38	1,162
8:00 AM	61	67	4.621	55	58	61	65	0	2	37	1,280
8:15 AM	61	67	4.531	55	58	62	66	0	2	33	1,356
8:30 AM	62	66	4.486	55	59	62	66	0	2	30	1,399
8:45 AM	62	66	4.34	56	59	62	66	0	1	29	1,437
9:00 AM	62	66	4.292	56	59	62	66	0	2	27	1,446
3:00 PM	60	68	5.036	52	57	61	65	2	7	39	1,571
3:15 PM	59	69	6.424	47	56	60	65	4	12	46	1,537
3:30 PM	57	71	9.405	35	53	59	64	7	19	53	1,545
3:45 PM	54	75	12.256	29	47	58	63	10	28	60	1,500
4:00 PM	50	81	14.29	26	40	55	63	14	38	67	1,463
4:15 PM	47	87	15.069	23	35	51	62	18	48	76	1,496
4:30 PM	42	97	15.662	22	30	42	60	25	62	84	1,563
4:45 PM	39	104	15.904	17	27	38	57	31	70	89	1,704
5:00 PM	38	107	15.653	18	27	37	57	33	71	90	1,760
5:15 PM	39	104	16.06	18	26	37	58	34	69	87	1,677
5:30 PM	41	99	16.83	19	27	43	60	30	59	84	1,543
5:45 PM	46	88	16.493	21	31	53	61	23	44	75	1,389
6:00 PM	51	80	15.149	22	41	57	63	17	31	66	1,298
6:15 PM	55	74	12.49	27	52	59	64	11	21	58	1,248
6:30 PM	59	69	8.127	40	56	60	65	7	13	46	1,154
6:45 PM	61	67	5.653	52	58	61	65	4	7	37	1,105
7:00 PM	61	67	4.611	54	58	61	65	3	5	33	1,029

Figure 26- Sample INRIX Tabular Data

3.2.6. Sunguide (Florida Intelligent Transportation System)

Sunguide software is an ATMS software that helps FDOT control and monitor roadside equipment and vehicle resources. The primary objectives of the software are:

1. Facilitate traffic and incident management
2. Disseminate traveler information to the motoring public
3. Exchange critical information among agencies
4. Collect and report data regarding the operation of the Florida transportation system

Sunguide allows TMC operators to monitor roadside sensors and video cameras to manage incidents. Sunguide also provides real-time traffic data to other agencies such as the FL511 phone system and website (FL511, 2013).

The software communicates with Road Ranger and supports I-95 Express Lane pricing. The following devices are supported by SunGuide:

1. DMS
2. Variable speed limit signs
3. Toll message signs (toll rate signs, lane status signs)
4. Ramp signals
5. Road weather information sensors
6. Highway advisory radios
7. Safety barrier cable system
8. Closed-circuit television cameras
9. Road sensors/detectors
10. Video wall
11. Toll equipment (license plate readers and automatic vehicle identification devices)
12. Connected vehicle roadside infrastructure equipment

The SunGuide system archives traffic data in multiple places. The aggregated operational data are stored in Oracle database files, and the raw data are stored in comma delaminated (*.csv) format. A recent study by Hadi et al. (2011) indicates that three archived files can be used for microsimulation analysis:

1. Incident Archive: The stored data includes timestamp, incident ID, operator, event details, and event history.
2. Detector Data Archive: The detector data archive consists of TSS text files , with each file including data for a 24-hour day. The files contain store data for each lane for each 20-second polling interval. Each TSS detector record includes the following information:

1. Timestamp (HH:MM:SS 24-hour format)
2. Detector identifier
3. Speed
4. Occupancy
5. Raw Count Data

3- Travel Time Archive: These archives include records of each travel time link, with one record per interval. Each record includes the following fields:

1. Timestamp
2. Travel Time link identifier
3. Travel Time
4. Link Status ("in service" or "failed")

3.2.7 ATMS.now (Trafficware)

ATMS.now is a central management system that combines traffic network data into a single repository for a real-time, integrated view of traffic operations. The management system has been installed in 250 locations across North America.
The system key features include:

1. CCTV.now: This feature provides closed circuit TV (CCTV) surveillance footage from IP, industrial Video and Control, and integrates with the user interface.
2. CMS.now: This feature allows users to remotely program Changeable Message Signs (CMS).
3. ATMS Bing Maps: The ATMS software integrates with Microsoft Bing Maps to provide high-resolution imagery.

The ATMS.now management system Nazdec controllers work remotely and enable traffic operators to change the signal timing in real-time. Broward County has approximately 1,300 signal controllers, and approximately half of the controllers are currently working on the ATMS.now system.

3.2.8. Conclusion

In conclusion, multiple data resources are presented in this section, and all available data sources have been identified. The traffic data exist in multiple formats and shapes.

Table 8- Summary of Data Sources and Available Traffic Data

Output Data Source	O – D data	Speed	Travel Time	Volume	Occupancy	Headway	Traffic Counts	Gap	Density	VMT
BlueTOAD	x	x	x							
VDS		x			x	x	x		x	
MVDS		x		x	x	x	x	x		
AVI		x	x							
INRIX		x	x							
SunGuide		x	x	x	x	x	x	x	x	X
ATMS.now					x					

3.3. Identify Performance Measures for Demand

After reviewing most of the state-of-the-art performance measures for demand reporting signal systems and considering available data sources in the study area, the following traffic performance measures were selected for demand modeling:

1. Volume (vehicles per 5 minutes): total number of vehicles traveling a particular link
2. Occupancy (%): percent time when a sensor is in the detection mode.
3. Spot speed (mph): average speed of vehicles at certain location.
4. Travel time (minutes): elapsed time to traverse a link or road segment.
5. Link Length (ft.): The length of the segment under study

Also link length (ft.) was considered as a geometrical factor which can impact traffic demand.

3.3.1. Setting up Microsimulation Model

Microsimulation model elements, which should be used to retrieve field-like data, were identified. Travel time estimation sensors in VISSIM are used to acquire travel time data. The collected travel time data in the simulation model are equivalent to BlueTOAD and AVI systems in the field. VISSIM data collection points will also be utilized to emulate Wavetronix detector data such as traffic flows, occupancy, speeds, and vehicle classifications.

3.4. Develop Methods to Derive Traffic Demand from Available Field Data

The recent technological improvements in computer technology have provided transportation practitioners and researchers with new opportunities. Nowadays, agencies have access to online databases and applications, which support real-time operational level facility monitoring. Current Web-based systems cover various performance measures such as speed/travel time, volume, occupancy, and vehicle class. For example INRIX (2013) provides users with high resolution traffic data of speed, volume, and occupancy is several parts of the nation. Also, Sunguide (2013) is ATMS software that allows FDOT to control and monitor roadside equipment and vehicle resources online.

However, the available technological improvements still do not provide an easy and accurate way to measure or estimate real traffic demand. Traffic demand here is defined as number of vehicles which are ready (without rerouting their trips) to travel between two signalized intersections and make one of the available turns at the downstream intersection. The main problem to capture all of the vehicles on the link between two intersections lies in the fact that contemporary traffic sensors (e.g. point-detection or link-based sensors) do not provide a complete picture of the traffic state on the link. A complete picture would require both information about all traffic sources and sinks (a traffic detector on each lane of each entering and exiting approach) and information about vehicles' routing preferences. In order to overcome these shortcomings of the field traffic demand measurements, the FAU research team has developed a method, based on second-by-second positioning of individual vehicles, to estimate true traffic demand in microsimulation. This method was used to assess effectiveness of other traffic demand estimation methods (based on limited data from field-like sensors) before they are deployed to develop TMC operating strategies.

3.4.1. Overview

In this task, the FAU research team developed a method to estimate virtual true traffic demand and calibrated its relationship with field-like traffic data. The relationship between traffic demand and field-like performance measures is developed by using microsimulation outputs in various statistical models. The generated statistical models will later be used to estimate traffic demand in the field operations as well.

The FAU research team has developed a set of simulation-based procedures to determine link-based true traffic demand at each signalized approach. The link-based true traffic demand is estimated in the microsimulation model at the upstream entrance of the link, representing true traffic demand consisting of vehicles that require a green light at the downstream intersection. A detailed description about this methodology is provided in the next section.
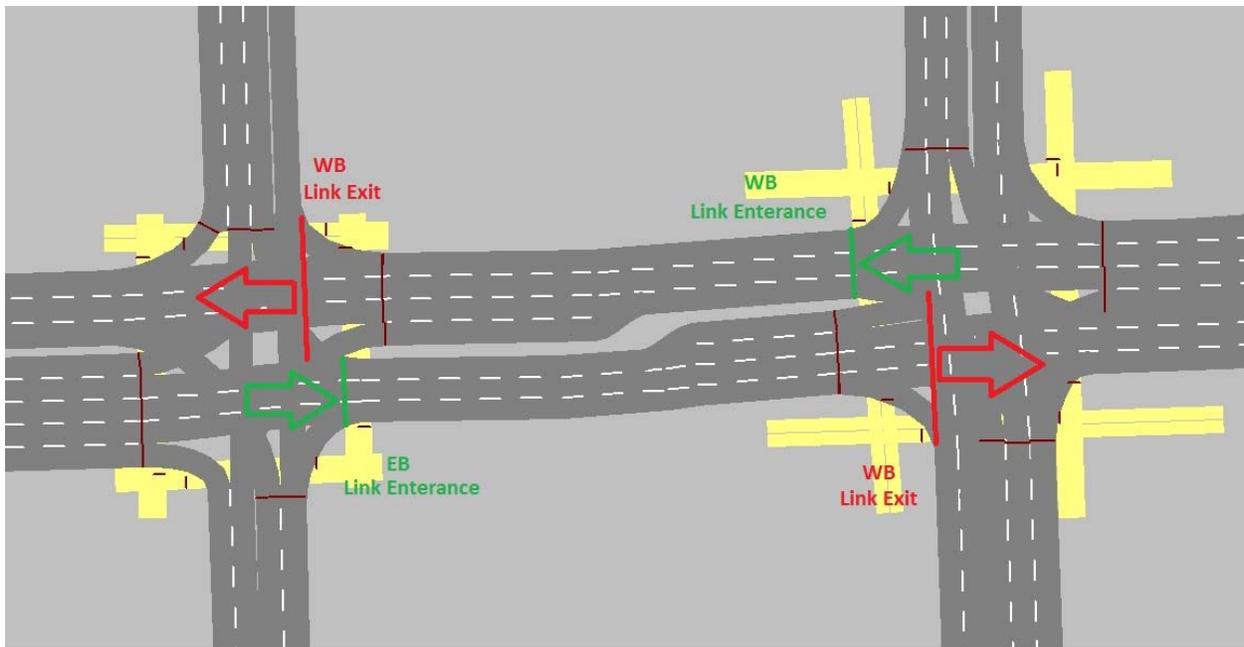
Figure 27- Link Entrance and Exit Demonstration

Link entrance is an imaginary line where vehicles from different movements (right, though, and left) enter a specific link. The link exit is also an imaginary line aligned with closer edges of the crossing road where vehicles exit the link in different movements

3.4.2. Algorithm for Determination of Arrival and Departure Rates

An algorithm developed to determine arrival and departure rates per movement in a VISSIM simulation environment is shown in part a) of Figure 28. The application collects information about all vehicles that can currently communicate with the infrastructure (Car2X vehicles in VISSIM). Based on the gathered information, the algorithm updates all the arrival and departure rates for each simulation time step in real-time.

For each vehicle approaching a traffic signal, the algorithm determines its link, routing decision and the route ID. If the traversing link is one of the predefined incoming links for a particular section and the vehicle has not already been arrived during the previous simulation steps, the insertion process is initiated. The predefined routing decisions and the route IDs are used to determine the movement of the vehicle within a section as showed in part b) of Figure 28. The movement is identified either as left or as through, where the later movement includes the vehicles going both: through and right. Once the vehicle has arrived and the counting variable for the arriving vehicles for this particular movement is increased, the algorithm inserts the vehicle into the list of vehicles "expecting to be departing". This list is created for two reasons. First, the arriving vehicles list is maintained at a constant size to avoid handling a fast growing list of vehicles each time step for each vehicle. Note that a list of vehicles is a list of records with all of the vehicle information required to process it. On the other side, the arrival counting variable is simply an integer representing the number of vehicle arrived with the particular movement. The second reason for creating the "expecting to be departing" vehicles list is that this list contains relatively small number of vehicles that is easy to handle while enabling smooth transition from arriving vehicle insertion to departing vehicle insertion process.

```
Step 0:  Initializing
        N, Number of vehicles in the network  (during current time step)
        veh = 0, current vehicle
        link, link of vehicle veh in current time step
        routingDecision, routing decision of vehicle veh in current time step
        routeID, route ID of vehicle veh in current time step
Step 1:  Testing Termination Criteria
        veh = veh+1
        IF veh <= N
                GO TO Step 2
        ELSE
                UpdateArivals&DeparturesRatesForEachMovement()
                Exit application and run next time step of VISSIM simulation
Step 2:  Testing Vehicle Arrival at Some Section
        IF link is one of the incoming links for section i
                IF veh is not in arrivedVehicles(i)
                        IF routingDecision is in routingDecisions(i)
                                ArrivedVehiclesInsertion(veh, i, routingDecision, routeID)
        GO TO Step 3
Step 3:  Testing Vehicle Departure from its Current Section
        IF link is one of the departing links for section i
                IF veh is not in departingVehicles(i)
                        DepartingVehiclesInsertion(veh, i, routingDecision, routeID)
        ELSE IF veh is in departingVehicles(i)
                        DepartedVehiclesInsertion(veh, i, routingDecision, routeID)
        GO TO Step 1
```

a)

```
movement = DetermineVehicleMovement(veh, i, routingDecision, routeID)
InsertIntoArrivedVehicles(veh, i , movement)
InsertIntoExpectingToBeDepartingVehicles(veh, i, movement)
```

b)

```
movement = DetermineArrivedVehicleMovement(veh, i, routingDecision, routeID)
RemoveFromDepartingVehicles(veh, i, movement)
InsertIntoDepartedVehicles(veh, i, movement)
```

c)

```
movement = DetermineArrivedVehicleMovement(veh, i, routingDecision, routeID)
RemoveFromExpectingToBeDepartingVehicles(veh, i, movement)
InsertIntoDepartingVehicles(veh, i , movement)
```

d)

Figure 28- Algorithm to Determine Arrival and Departure Rates per Movement in VISSIM
Simulation Environment

Analogously to arriving vehicle insertion, the departing vehicle insertion starts with the detection of the traversing link as one of the departing links for a particular section as showed in part c) of Figure 28. Once the vehicle becomes a departing vehicle for particular movement and section, the algorithm checks every time step if the vehicle is still traversing the departing link. If the currently traversing link is not among the departing ones anymore, the vehicle is considered as departed for that section and movement. (Figure 28 part d).

When the processing of one vehicle is completed, the algorithm examines the next vehicle. When all the steps for all of the vehicles in the network for current time step are completed, the files that allow us to see the arrival-departure rates are updated in real-time. A screenshot with the arrival and departure rates for a movement until the 5500th simulation second is shown in Figure 29. The x-axe represents simulation time, and the y-axe represents number of vehicles. The arrival rate is presented with the red line, while the departure rate is presented with the green line. To visualize the arrival and departure rates, Live Graph software is used. (Live Graph, 2013)
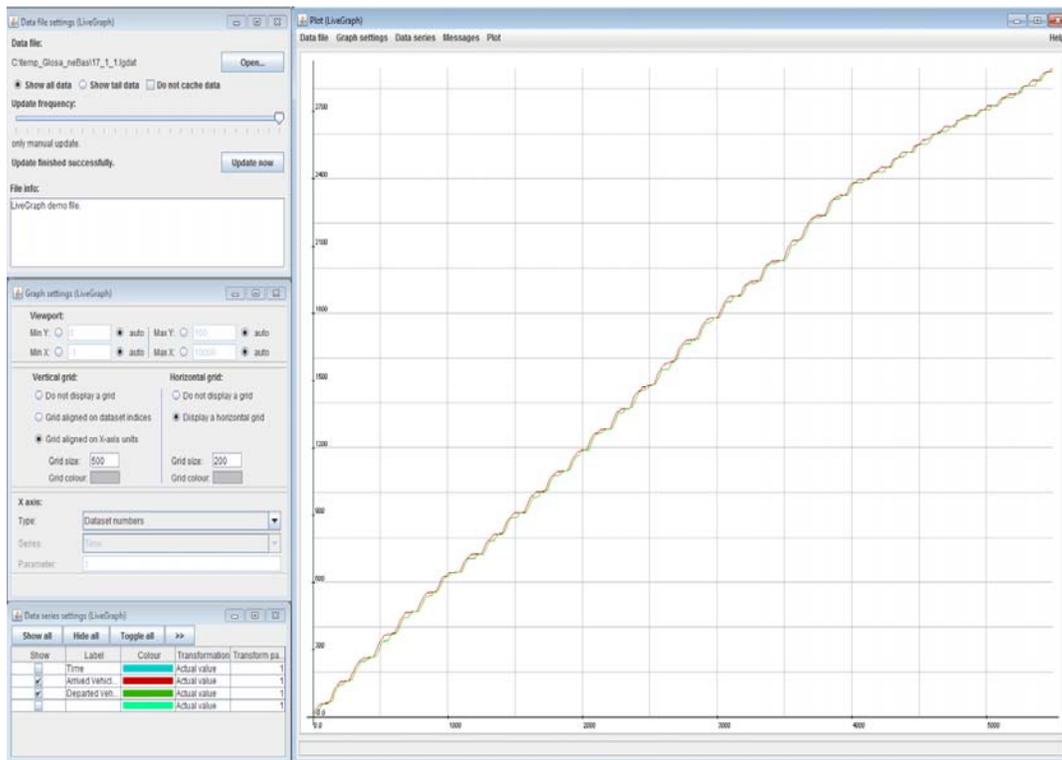
Figure 29 - Arrival-Departure Rates Graph in Live Graph Software

3.4.3. Demand Estimation Method

Overall, five different MOEs were selected as potential variables to investigate the relationship between the true demand and the field measurements. Here is the list of potential MOE's considered for statistical modeling:
1. Occupancy (%): percent time when a sensor is in the detection mode.
2. Volume (vehicles per 5 minutes): total number of vehicles travelling a particular link

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3. Spot Speed (mph): average speed of vehicles at certain location.
4. Travel Time (seconds): elapsed time to traverse a link or road segment.
5. Link Length (ft.): the length of a link in feet

The general form of the model is demonstrated in Equation 1:

$$Demand\ (vehilce\ per\ 5\ minutes) = a_1X_1 + a_2X_2 + \cdots + a_iX_i \quad (1)$$

Where,

X_i : ith MOE;
a_i : ith MOE coefficient;
$i = 1$ to n;
n= number of MOE's in the model

The simulation model output, which is in text file format, is handled through a C#-based data handling module. The output includes multiple MOEs. On the other hand, another tool captures the true demand values of each link from the simulation model. Figure 30 illustrates the demand estimation information flow.
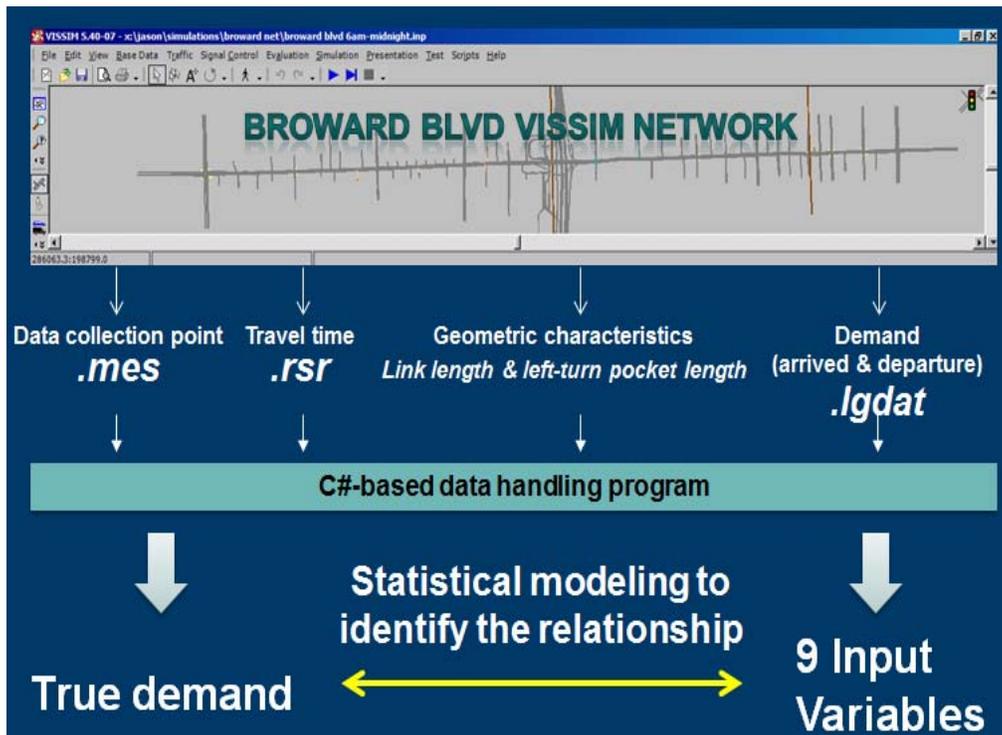
Figure 30- Demand Estimation Information Flow

Data collection points inside the simulation model collect occupancy, volume, and spot speeds. They provide a text file with a "*.mes" extension. Link travel times and speeds are collected by travel time detectors in text files with a "*.rsr" extension. Furthermore, a tool calculates the true demand of each link and stores them in a custom "*.lgdat" format.

All the files are text files in nature and are handled by a C# based text handling program. Once all the data are processed and cleaned, the statistical models will be developed using SPSS

software. Several statistical experiments are conducted in different time intervals to reveal the true relationship between the true demand and different MOEs.

To develop a statistical model from the microsimulation model, different methods were tested. The methods are actually a combination of various detector types in the microsimulation model and the statistical modeling approach. The following definitions illuminate the modeling process:

1. Demand: total number of vehicles on a particular link.
2. Equivalent Demand: total number of vehicles on a particular link divided by the jam density.
3. Through Demand: total number of vehicles in the through movement lane group.
4. Field Detectors: actual detectors that are installed in the field and, modeled inside the simulation model. (
5. Figure 31)
6. Simulation Detectors: artificial detectors inside the simulation model. The simulation detectors are data collection points in the middle of each link and also travel time detectors at the middle of each intersection. The simulation detectors do not exist in the field and are only used in the simulation data to provide more data for the analysis.
7. Aggregated Demand Modeling: modeling true demand by considering all the simulation links performance measures at the same time. In this case the demand is model based on all the aggregated performance measure in all of the links.
8. Average Demand Modeling: modeling true demand by considering each link performance measures individually. In this case demand models are developed for each link based on the link specific performance measures. The R-squared value in this approach is the average of all individual links' R-squared.

Figure 31- Broward Blvd. Field Detection System B: BlueTOAD Devices M: Mid-Block Detectors

Several combinations of detection scenarios were considered for demand modeling as follow:

1. All Detection System Available: in this case, the statistical models are developed based on the retrieved data from both mid-block detectors and Bluetooth devices. Throughput, occupancy rate, spot speed, travel time, and link distance are considered in modeling demand using all detection system.
2. Mid-block Detectors Only: the demand model was fitted to the data utilizing the mid-block detectors only. The performance measures that can be retrieved using mid-block detectors are considered under this detection scenario. The performance measures include: throughput, occupancy rate, spot speed, and link distance.
3. Bluetooth Only: the demand model was fitted to the data using travel time data retrieved from the Bluetooth detectors only. The performances measures that can be acquired from the Bluetooth devices are limited to travel time and link distance.

3.5. Identify Traffic Demand Thresholds to Activate Strategies

In order to control traffic congestion, appropriate strategies are activated at certain traffic conditions. The objective of this task is to define different traffic conditions based on the estimated demand. Multiple traffic scenarios are defined and modeled inside the simulation models. Each traffic scenario is monitored closely and an appropriate demand threshold is determined to activate strategies. In the next step, the implemented strategies are evaluated for effectiveness. If strategies are effective, the identified demand threshold would not change. In case that strategy is not effective, both strategies and the identified demand threshold are checked again and certain modifications are implemented. This process is implemented for several iterations until the equilibrium condition is reached. In this case, traffic demand scenarios and strategies are finalized.

There is a correlation between identifying traffic demand thresholds, developing strategies to improve traffic conditions, defining scenarios, and strategy evaluation. Figure 32 shows the correlation between project key tasks. Please note that two microsimulation models using VISSIM software have been developed in this research. The first model is the network model, which includes all the six major corridors in the study area and the second microsimulation model includes Broward Blvd., where most of the strategies and scenarios are tested in this model.
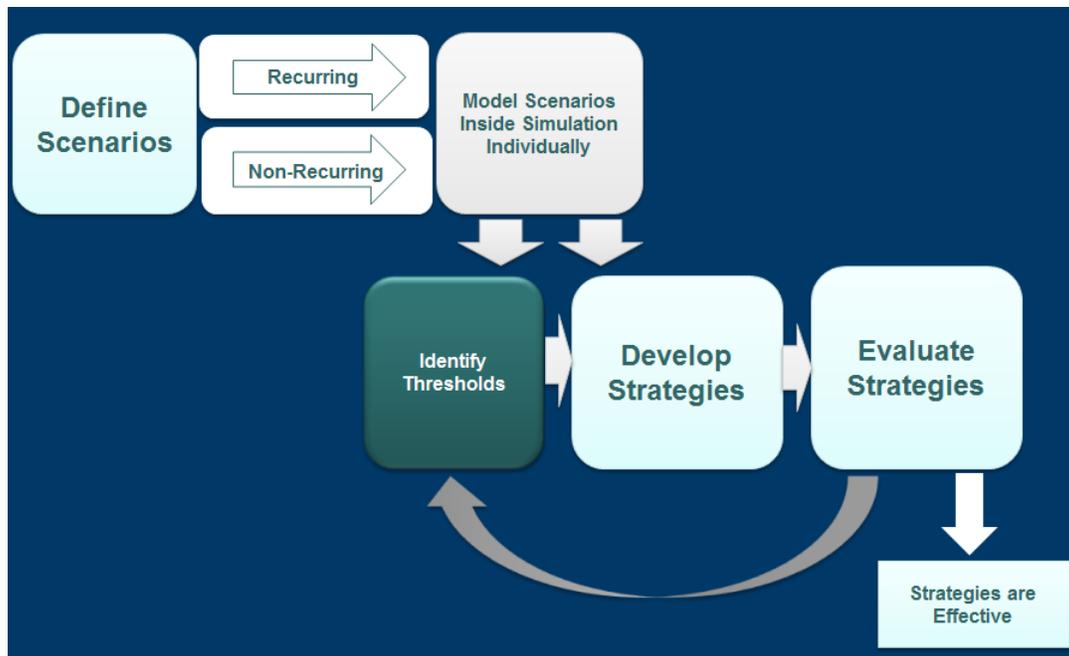
Figure 32- Correlation between Project Key Tasks

In the first step multiple traffic scenarios are identified as recurring and nonrecurring scenarios. The recurring scenario are identified as normal, saturated, and oversaturated scenarios while the nonrecurring scenarios are defined as freeway incidents, left-turn spillover, rail preemption, arterial incidents, and event traffic. When the scenario identification task is finished, each scenario will be modeled in the microsimulation model. All scenarios, except for freeway incident scenario, are modeled in the Broward Blvd. VISSIM model. The freeway incident will be modeled inside the network VISSIM model. The network simulation model enables the FAU research team to fully capture the interaction between freeway and arterial corridors in the study area. For each defined traffic scenario, traffic conditions are captured by monitoring selected MOEs such as speed and volume. The FAU research team has developed a tool to monitor key performance measures in VISSIM. The specific behavior of selected performance measures is recorded and termed as "scenario signature" in this study. Each scenario is expected to have a special signature. Traffic scenarios are described in the following:

1. Base: In this scenario, all the links in the simulation model are operating in the undersaturated conditions. The operational objective is to provide maximum progression in the system of arterial streets. All other scenarios are compared to this scenario to determine specific signatures of other scenarios. These signatures are captured by monitoring several performance measures such as: speed, volume, occupancy, and travel time.

2. Saturated: In this scenario, the volume is slightly higher than the capacity (usually volume/capacity ratio is around 1.20). Queue forms and dissipates in some of the intersections sporadically but does not spill back to the upstream intersection. Similar to the normal scenario traffic is managed using SIL. In this case, the management objective is to maximize the

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throughput or volume. In order to develop this scenario, the following tasks need to be addressed:

1. Increase the input volume near 20%
2. Identify time period when the arterial becomes saturated
3. Capture the saturated scenario signature
4. Identify thresholds
5. Evaluate strategies

3. Oversaturated: In this scenario, the volume is considerably higher than the capacity and queue spills to the upstream intersection in one or two links. Traffic is controlled by an OIL system. Queues have already formed and they are not dissipating unless a certain strategy is implemented. Therefore, an objective is to manage the formed queues efficiently in the system. Effective strategies in this case are retiming signals and utilizing DMS.

1. Increase the input volume near 50%
2. Identify time period when the arterial becomes saturated
3. Capture the oversaturated scenario signature
4. Identify thresholds
5. Evaluate strategies

4. Freeway Incidents: A freeway incident is modeled inside the simulation model in this scenario. The scenario is modeled in the network VISSIM model and is managed by OIL. The incident will impose a considerable delay on the network. Therefore, potential strategies are signal retiming, DMS utilizing, and dispatching. The following tasks should be addressed in developing freeway incident scenario.

1. Analyze crash data and identify problematic freeway links
2. Figure out how to emulate incidents in VISSIM
3. Model incidents in VISSIM
4. Capture freeway incident signature
5. Identify thresholds
6. Evaluate strategies

5. Left-Turn Spill-Over: Queue in the left-turn pocket sometimes spills back and blocks the through movement path. This causes congestion in the arterial system. The Broward Blvd. model will be used to model this scenario. The scenario will be controlled by OIL and the objective management is to retime signals to alleviate the imposed congestion by left-turn spillover scenario. In order to develop the scenario with the microsimulation model, the following tasks need to be addressed:

1. Identify scenarios based on FDOT data
2. Model scenarios in VISSIM
3. Capture the signature of the scenario
4. Identify thresholds
5. Evaluate strategies

6. Rail Preemption: Long trains can impose a considerable congestion on the road network. Rail preemption scenario is modeled in this scenario. The Broward VISSIM model will be used to

model this scenario. Traffic is controlled by OIL and the management objective is to clear the queue. The following tasks should be addressed to develop this scenario:

1. Identify scenarios based on FDOT data
2. Model scenario in VISSIM
3. Capture rail preemption signature
4. Evaluate strategies

7. Arterial Incidents: In this scenario, incidents on the arterial streets will be modeled. Arterial incidents are usually less severe than freeway incidents. Also, the incident clearance takes shorter amount of time. The scenario will be modeled in the Broward Blvd. VISSIM model. Traffic is controlled by OIL. Similar to freeway incidents, the potential strategies are signal retiming, DMS, and dispatching. The following tasks will be addressed to model arterial incidents inside the simulation model:

1. Analyze crash data and identify problematic freeway links
2. Figure out how to emulate incidents in VISSIM
3. Model incidents in VISSIM
4. Capture arterial incident signature
5. Identify thresholds
6. Evaluate strategies

8. Event Traffic: Art performances, festivals, and sport competitions are common examples of special events that happen inside the transportation network. The scenario will be modeled in the Broward Blvd. VISSIM model. Traffic in this scenario will be controlled by OIL. The management objective is to manage queues in the transportation system. Potential strategies to control the traffic under this scenario are retiming signals and using DMS. Similar to other scenarios, there are certain tasks that need to be addressed to model this scenario:

1. Identify scenarios based on FDOT data
2. Model scenarios in VISSIM
3. Capture the signature of the scenario
4. Identify thresholds
5. Evaluate strategies

3.6. Develop Strategies to Improve Traffic Condition

The strategies are implemented based on the traffic condition. The traffic condition is determined by using ITS infrastructure data sources such as Bluetooth travel time detectors, mid-block detectors, and CCTV cameras. The FAU research team identified two major types of strategies that TMC operators will conduct when observing this network: signal retiming strategies and information dissemination actions.

3.6.1. Signal Retiming Strategies

These strategies are also called "background strategies." In these type of strategies traffic operators change the signal timing of certain signal controllers based on the current traffic condition. The signal retiming strategies are implemented in two methods: optimized signal timing plans and manual signal timing plans.

3.6.1.1. Optimized signal timing plans

In this method a signal pattern is optimized using VISSIM-based genetic algorithm optimization of the signal timing (VISGAOST) tool. VISGAOST uses a genetic algorithm formulation that builds on the best of the recorder optimization methods. The tool optimizes four basic signal timing parameters of cycle length, green splits, offsets and phase sequences using VISSIM microsimulation as an evaluation environment. VISGAOST is featured with new optimization methods such as phasing sequence, multiple coordinated systems and uncoordinated intersections, and multiple time periods compared to CORSIM software. Figure 33 shows VISGAOST input dialog windows. (Stevanovic et al., 2007)
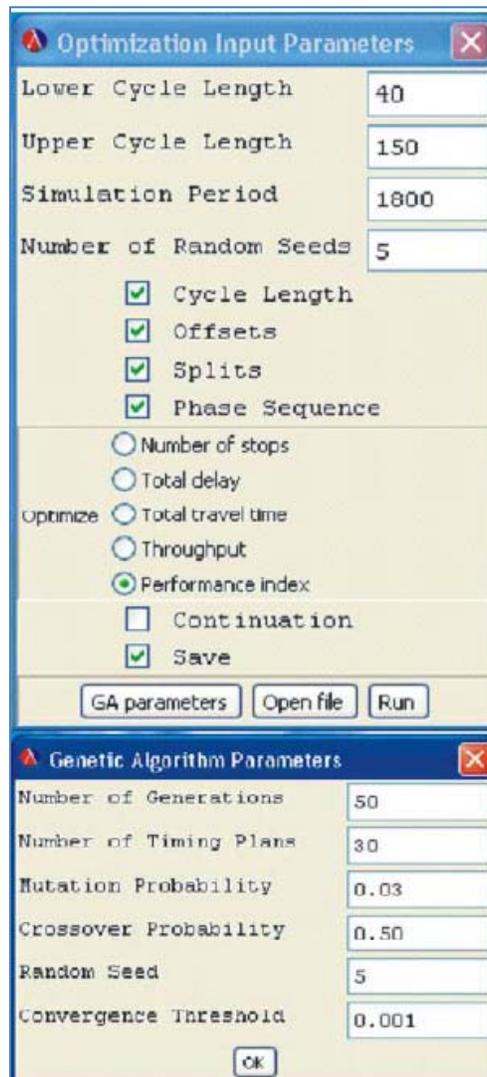
Figure 33- VISGAOST Input Dialog Windows (Source: Stevanovic et al., 2007)

VISGAOST is capable of optimizing signal timings from the field. The tool can work with VISSIM-ASC/3 SIL simulation to optimize the signal timings obtained from the field. In this method signal timing are downloaded from the field detectors, optimized by a software package,

and then uploaded to field controllers. The interface between VISGAOST and SILS enables optimization of ASC/3 controller signal timings, which are evaluated through VISSIM simulation. (Stevanovic et al., 2008)

3.6.1.2.: Manual Signal Timing Plans

In this method, the signal timings are modified by an OIL system. In this method, traffic operators monitor the traffic performance measures continuously and once certain performance measures exceed certain thresholds, the signal timing plans are changed to predetermined signal plans. The VNP tool was utilized to develop and evaluate several manual signal timing plans.

VNP was developed by a former Gardner Systems firmware programmer for the purpose of modeling NextPhase controller operation (specifically input/output logic tools) within the VISSIM traffic simulation software. VNP is a relatively simple utility with user friendly graphical user interface (GUI) and tools. The tool provides the user with a Disk Operating System (DOS) window, which emulates the front panel display of an early Nextphase 1.4 controller. The tool user interface resembles a 2070 controller data entry panel. Figure 34 shows the edit/view DOS window of the VNP tool. (Wright, 2004)
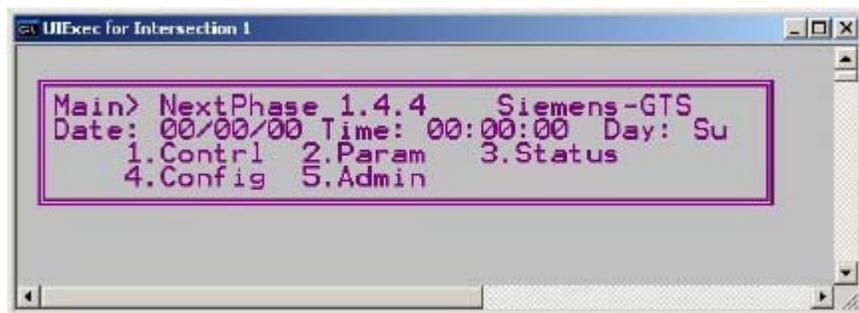
Figure 34- VNP Dataset Edit/View Window (Source: Wright, 2004)

One should note that incident trigger functions (as available in ATMS.Now) could be programmed to trigger introduction of signal timing patterns to cope with specific scenarios as defined by this research. However, one should note that such application would require interface/integration between traffic signal platform (ATMS.Now) and platforms which measure and report traffic conditions (TrafficCast for Bluetooth travel time data or SunGuide for mid-block volumes, speeds, and occupancies).

3.6.2. Information Dissemination Actions

These actions are also called 'immediate actions'. They may be performed at any time based on specific situations (e.g. incidents, lane blockage) in the field. Displaying DMS messages and dispatching Road Rangers are examples of such actions.

3.7. Identify and Model a Variety of Traffic Demand Scenarios

3.7.1. Overview

In this task several traffic demand scenarios were identified and modeled in the microsimulation models. Developed strategies were tested for strength in each scenario. The scenarios were selected based on discussion with BCTED and FDOT. It was decided to model both recurring and nonrecurring scenarios. Three recurring scenarios of base, saturated, and over-saturated and five nonrecurring scenarios of freeway incidents, left-turn spillover, rail preemption, arterial incident, and event traffic were identified for this study. Scenarios were modeled in the network or Broward. Blvd. VISSIM models. Also, the duration of some scenarios was modified and new sub-scenarios were developed. Each scenario or sub-scenario was run with five different random seeds to reduce the variability of the results.

3.7.2. Base Scenario

In this scenario all the links are operating in the undersaturated condition and volume over capacity ratio is less than one in all the links. All other scenarios are compared to this scenario. Three base scenarios are modeled as follow:

1. Broward Blvd. Model in the Morning Peak
2. Broward Blvd. Model in the Evening Peak
3. Network Model in the Evening Peak

3.7.3. Saturated Scenario

The volume is increased 20% in this scenario compared to the base scenario. In this case, the volume is slightly higher than the capacity in some of the other links. In some intersections, queue forms and dissipates sporadically but the queue does not spill back to the upstream intersection. In this condition, the traffic management objective is to maximize the throughput or volume. This scenario is modeled in the Broward Blvd. simulation model in both morning peaks.

3.7.4. Oversaturated Scenario

This scenario is similar to the saturated scenarios except that the volume is increased from 20% to 50% of the original value. Queues are being formed, but they do not dissipate unless a certain strategy is implemented. From the traffic management perspective, the objective is to manage the formed queues efficiently in the system. This scenario was run as an extension to the saturated scenario in Broward Blvd. simulation model.
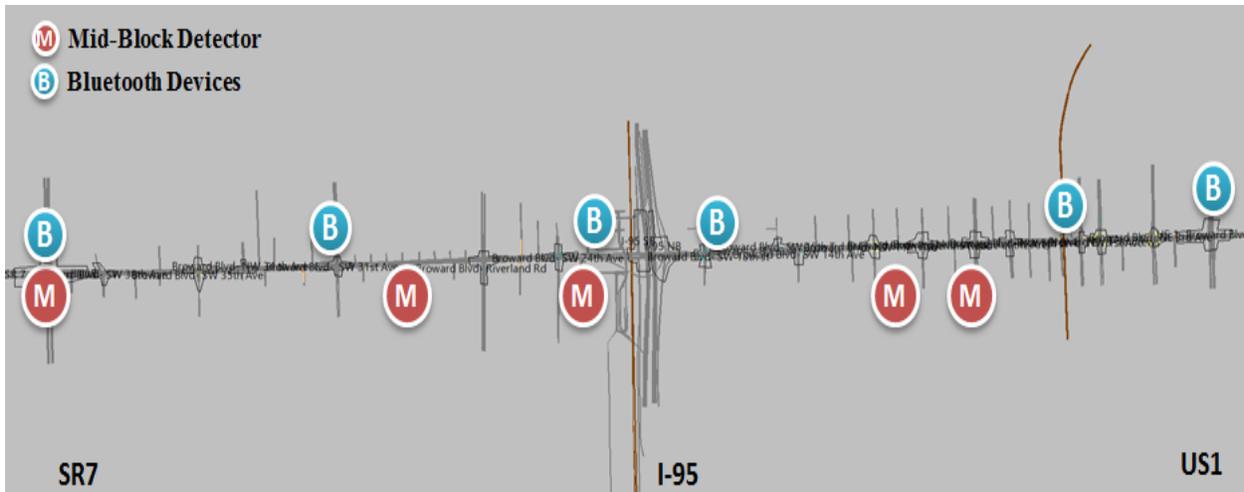
Figure 35- Saturated and Oversaturated Scenarios Scope in the Simulation Model

Figure 35 shows scope of saturated and oversaturated scenarios inside the simulation model. Field Bluetooth detectors are shown by (B) and the mid-block detectors are represented in (M). Figure 36 shows the location of saturated and oversaturated scenarios. The scenarios are modeled for entire Broward Blvd. corridor.
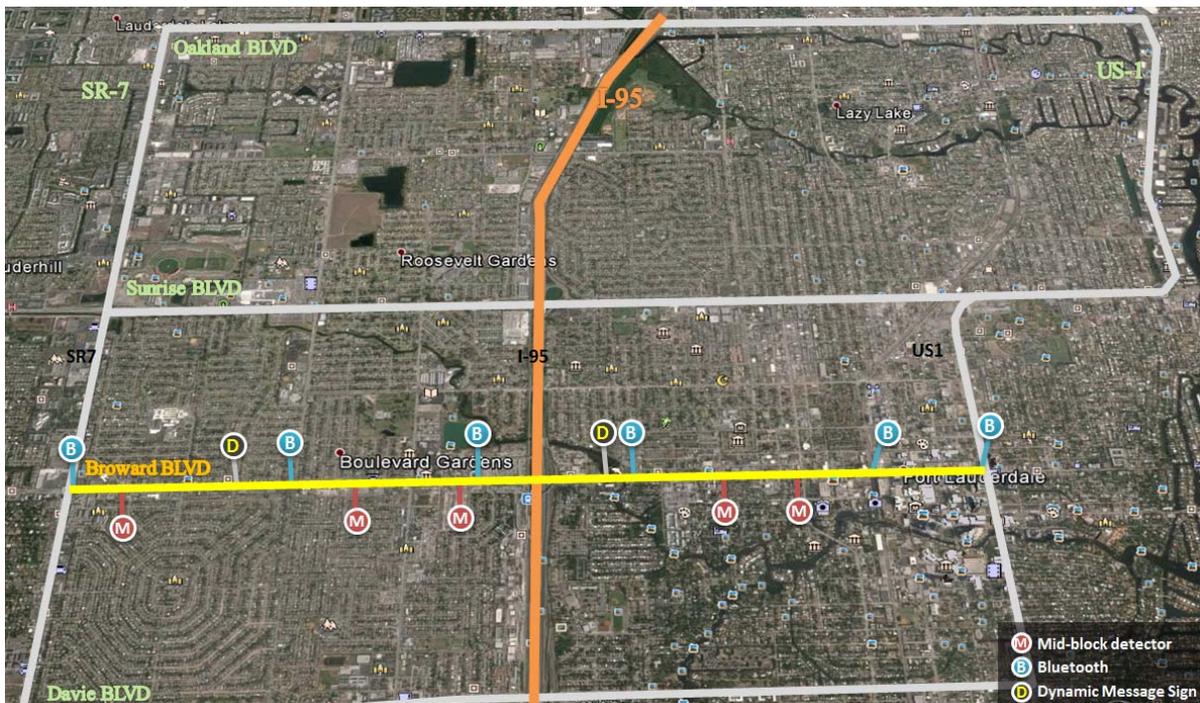
Figure 36- Saturated and Oversaturated Scenario Location

3.7.5. Freeway Incident Scenario

As freeway incidents impose a considerable delay to the transportation network, it is important to model and evaluate such conditions. An important factor in modeling the incident scenario was determining location of the incident inside the network model. Since the Broward Blvd.

represents the major corridor of the study area and considering the fact that it is equipped with adequate ITS infrastructure equipment, the location of the modeled incident was selected right after the Broward Blvd. on-ramp in the north bound direction. Figure 37 shows the selected location of the freeway incident inside the simulation model. . An incident at this area will create congestion on both freeway mainline, Broward Blvd. ramp, and even Broward Blvd. mainline.
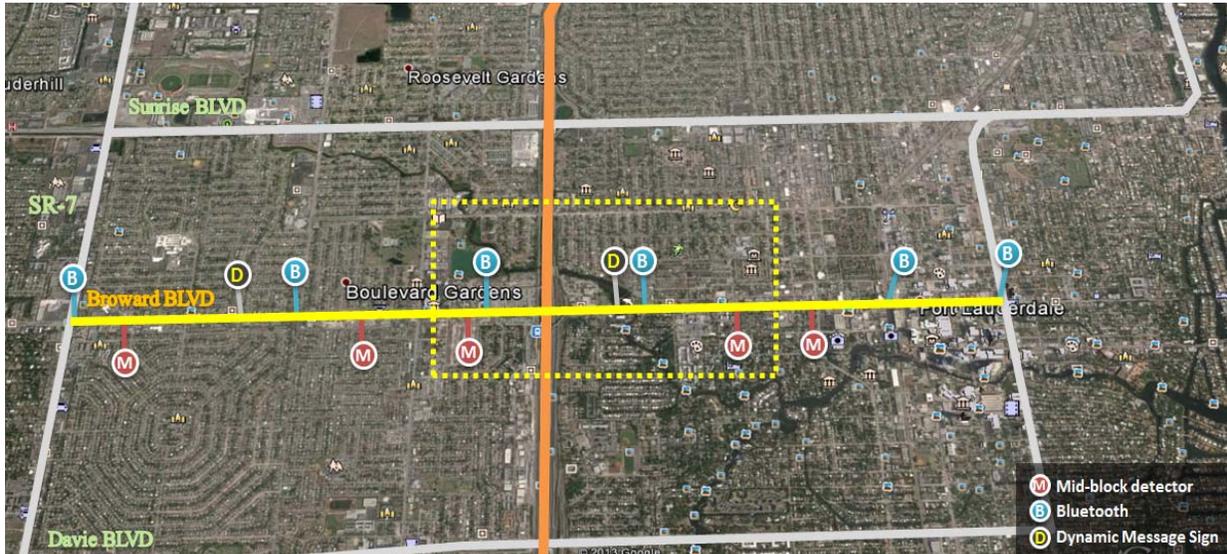
Figure 37- Freeway Incident Location

There is no direct way to simulate incidents in VISSIM. The freeway incidents were emulated by using parking lots as proposed by Liu et al. (2013). In this approach an incident is simulated by using parked vehicles in the freeway mainline. For this purpose, two out of four lanes were closed in the I-95 freeway right after Broward Blvd. on-ramp. Also, reduce speed zones are placed before the simulated incident so vehicles reduce speed before approaching the incident location. The freeway incident scenario has two sub-scenarios with different durations. The sub-scenarios have 30 and 60 minutes duration. The incident duration is modified by changing parking space dwell time inside the simulation model. Table 9 provides more detail on freeway sub-scenarios.

Table 9- Freeway Incidents Sub-Scenarios

Number	Duration (minutes)	Time	Simulation Time	Location	Method
1	30.	4:30-5:00	4,500-6,300	Broward I-95 NB on-ramp	Blocked two most right lanes using parking spaces.
2	60.	4:30-5:30	4,500-8,100		

Figure 38 shows a snapshot of the freeway incident scenario inside the simulation model. The freeway incident creates a severe congestion that impacts the Broward Blvd. corridor. The figure also shows the location of the mid-block detector and the Bluetooth device in the simulation model.

Figure 38- Freeway Incident Scenario in the Simulation Model

3.7.6. Left Turn Spillover Scenario

Queues formed in the left-turn pocket sometimes spill back and blocks the through movement path. The spilled back queue may impose a considerable amount of delay to the through movement vehicles. The scenario was modeled in the Broward Blvd. model at SW 24th Ave. The scenario was created inside the simulation model by adding more vehicles to the left-turn movement. The number of added vehicles to take the left-turn movement was determined based on the trial and error approach. After some iteration, it was decided to reroute 300 to 600 vehicles per hour from I-95 SB into Broward Blvd. The LTSO scenario was modeled in two sub-scenarios with 30 and 60 minutes durations. Table 10 depicts LTSO sub-scenarios.

Table 10- Left Turn Spillover Sub-Scenarios

Number	Duration (minutes)	Time	Simulation Time	Location	Method
1	30 min.	8:00-8:30	8,100-9,900	Broward Ave & SW 24th Ave WB	Rerouted the traffic (300-600 vehicles/h) from I-95 to Broward Blvd.
2	60 min.	8:00-9:00	8,100-11,700		

It should be noted that the location of the scenario was determined based on the discussion with BCTED and FDOT historical data and availability of adequate ITS infrastructure at this intersection. Figure 39 shows the location of the scenario, and Figure 40 depicts the left-turn spillover scenario inside the simulation model.
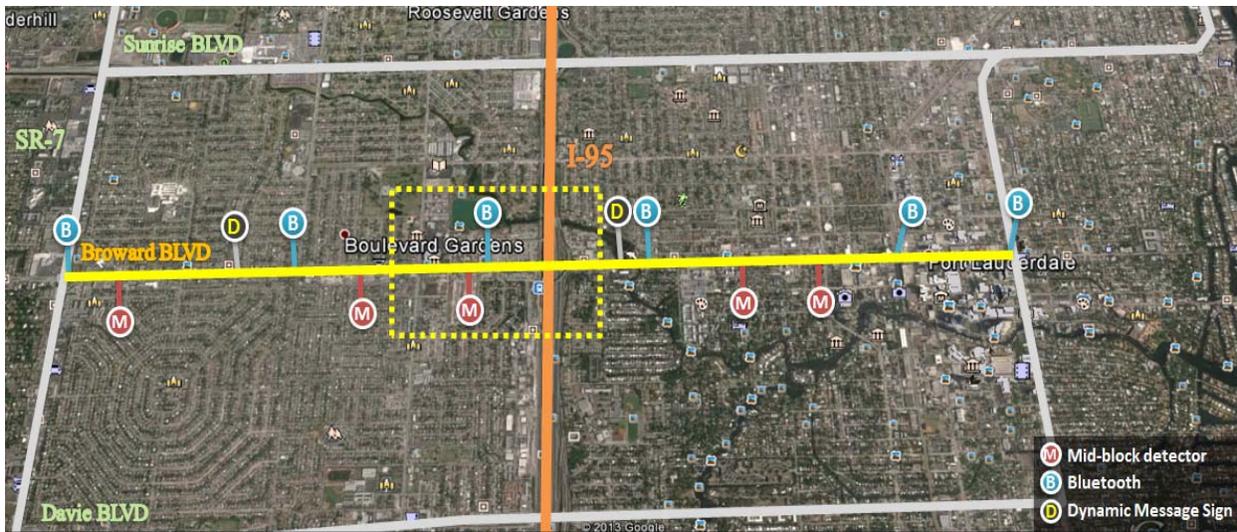
Figure 39- Left Turn Spillover Scenario Location
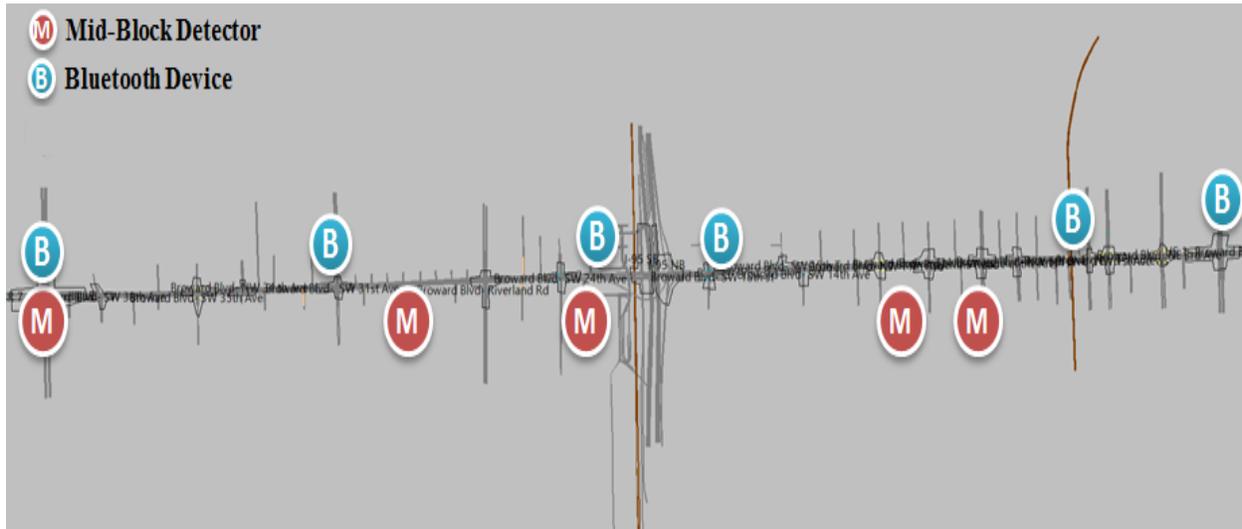
Figure 40- Left Turn Spillover Scenario in the Simulation Model

3.7.7. Rail Preemption Scenario

Long trains impose a significant delay to passing traffic. Therefore, it was important to model this scenario inside the simulation model. Considering the availability of the ITS infrastructure and BCTED and FDOT input, it was decided to model the rail preemption scenario at Broward Blvd. between NW 2nd Ave. and SW 1st Ave. Figure 41 shows the location of the rail preemption scenario. Figure 42 shows the modeled scenario inside the VISSIM software platform.
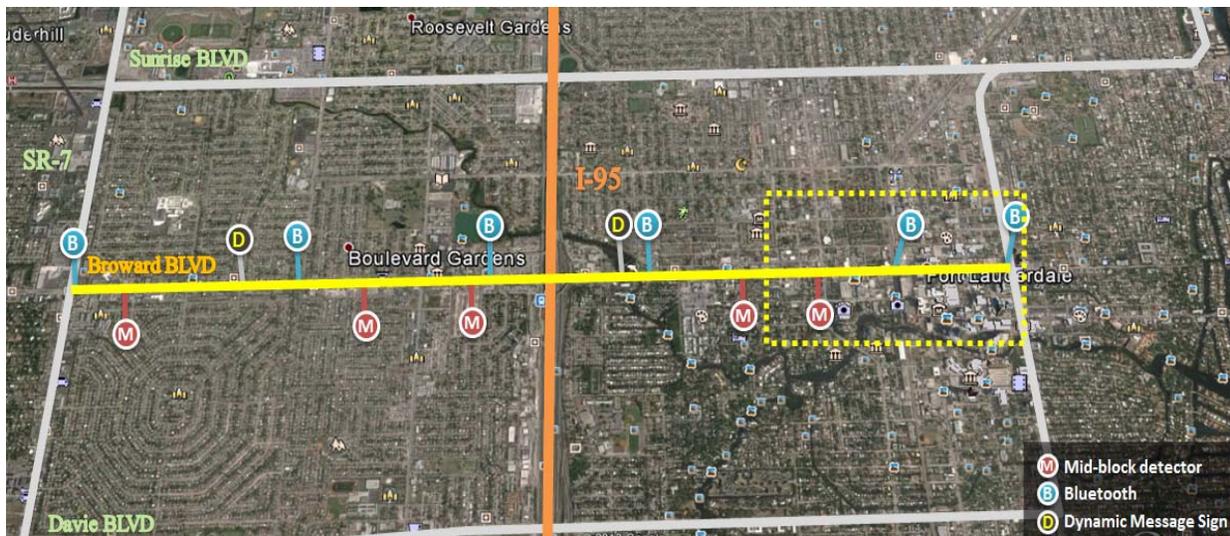
Figure 41- Rail Preemption Scenario Location
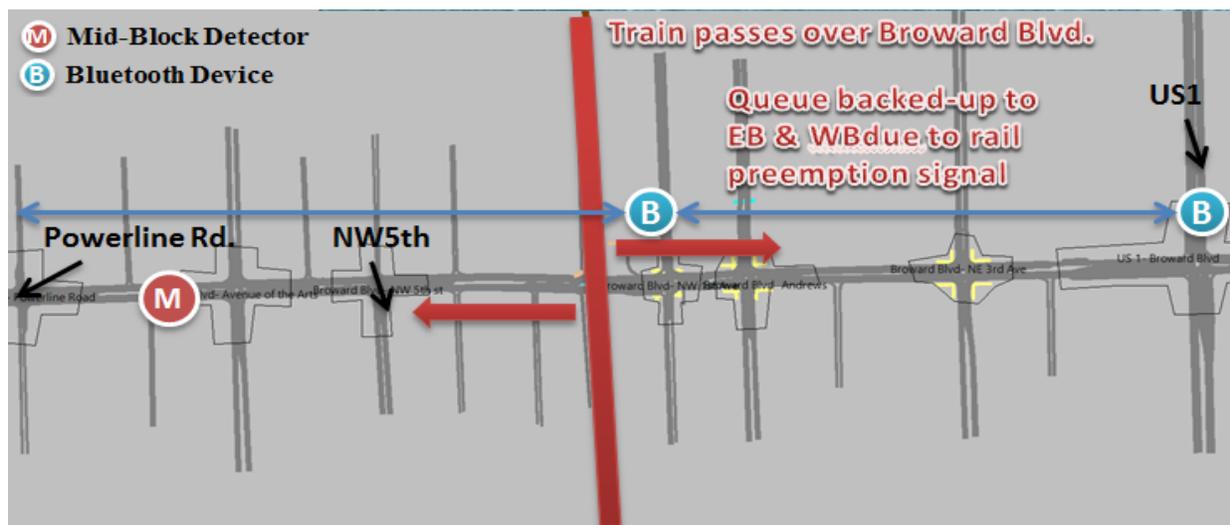
Figure 42- Rail Preemption Scenario in the Simulation Model

The rail preemption scenario was developed inside the simulation model by adding extra cars to the passing trains. There are two sub-scenarios for the rail preemption scenario with duration of 300 and 700 seconds. Table 11 depicts the rail preemption sub-scenarios in more details.

Table 11- Rail Preemption Sub-Scenarios

Number	Duration	Time	Simulation Time	Location	Method
1	300 sec.	7:58-8:03	8000-8300	Broward Ave. between SW 2nd Ave and SW 1st Ave	Added more cars to the train for making it longer
2	700 sec.	7:58-8:09	8000-8700		

3.7.8. Arterial Incidents Scenario

Similar to freeway incidents, arterial incidents impose a significant delay to the transportation network. The arterial incidents are usually less severe than freeway incidents. Also, the incident clearance time is usually shorter than the freeway incident. In order to select an appropriate location to simulate the incident in VISSIM, historical data were acquired from FDOT. The FAU research team analyzed the crash data from 2009 to 2011 in the study area.
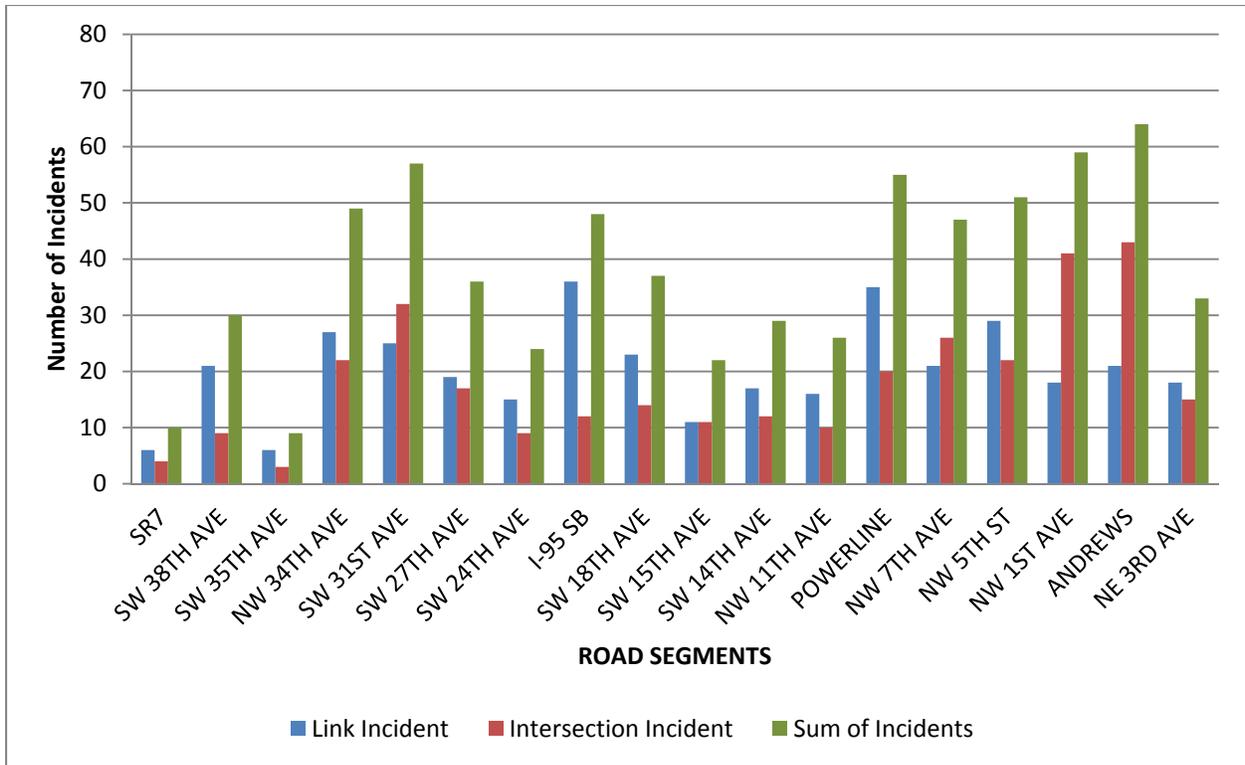
a) Eastbound
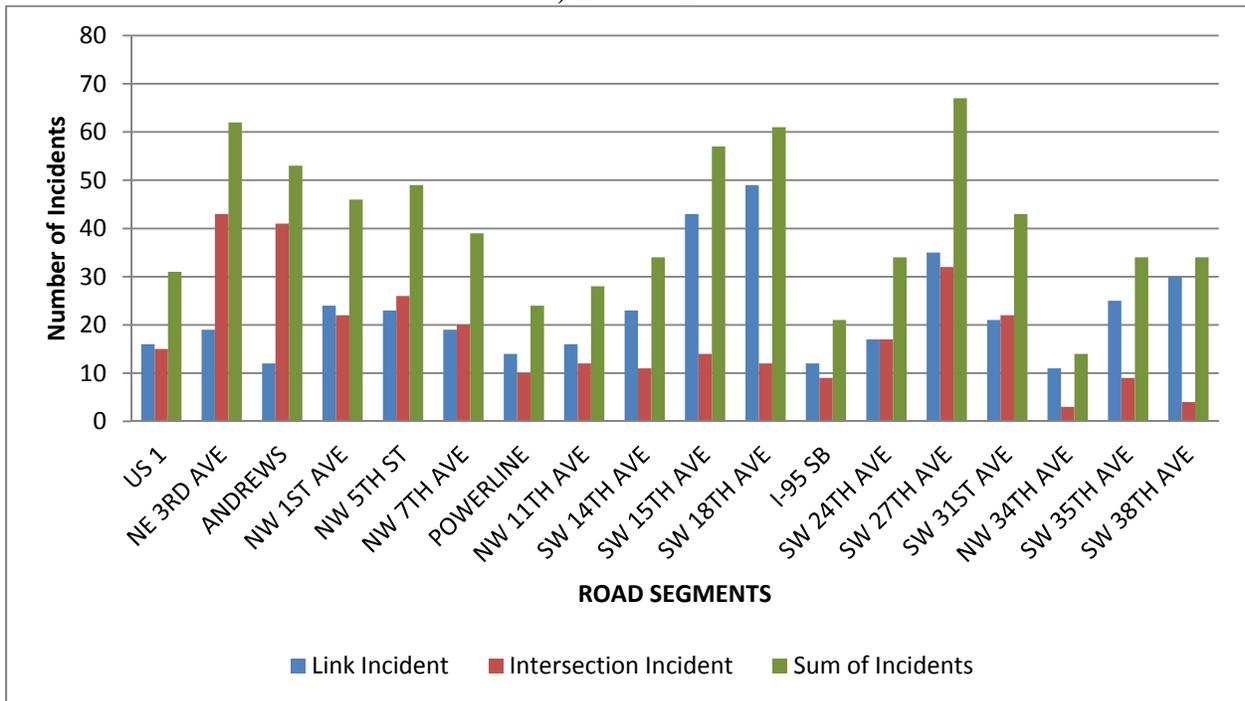
b) Westbound

Figure 43- Broward Blvd Crash Data Analysis (from 2009 to 2011)

Figure 43 shows the total number of incidents in the Broward Blvd. from 2009 to 2011 for eastbound (a) and westbound (b) directions. The link incident is total number of incidents that occurred either before or after the intersection. The intersection incidents are incidents that have occurred in the middle of intersections. The green bars show summation of link and intersection incidents. Similar crash data analyses were conducted for other corridors in the study area. For more information in this regard please refer to Appendix C.

In this research, the FAU research team was interested in analyzing link data since it is more frequent and incident clearance is more challenging task. To this end, the following intersections in the Broward Blvd. had the highest total number of link incidents:

1. I-95 SB (Broward Blvd. EB)
2. Powerline (Broward Blvd. EB)
3. SW 18th Ave. (Broward Blvd. WB)
4. SW 15th Ave. (Broward Blvd. WB)

All of the intersections presented above were considered as a potential arterial incident location. The Powerline intersection was selected as an incident location since there was adequate ITS infrastructure to closely monitor the scenario and develop appropriate traffic management strategies.
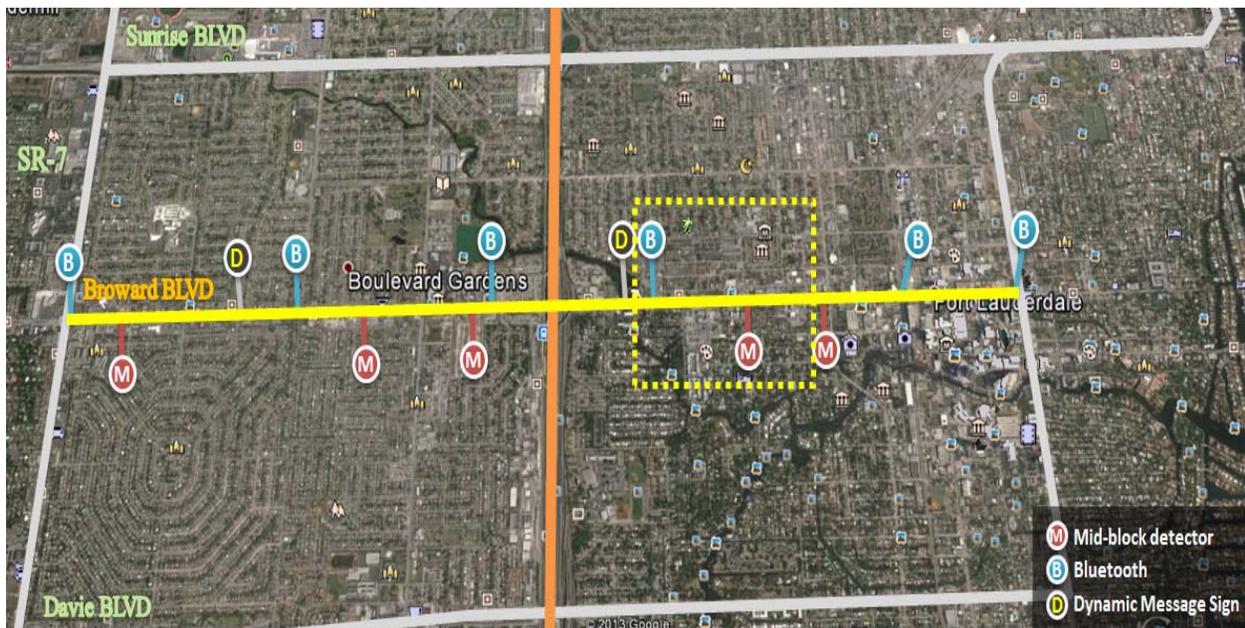
Figure 44- Arterial Incident Scenario Location

Similar to freeway incident, arterial incident scenario was emulated by parking spaces. A single parking space was created to block the leftmost lane. The incident duration was adjusted by modifying dwell time parameter. Also, multiple routing decisions were linked to the parking lot. shows a screenshot of the arterial incident scenario in the simulation model.

Figure 45- Arterial Incident Scenario in the Simulation Model

Arterial incident scenario has two sub-scenarios with different durations of 30 and 60 minutes.

Table 12- Arterial Incident Sub-Scenarios

Number	Duration(minutes)	Time	Simulation Time	Location	Method
1	30 min.	8:00-8:30	8100-9900	Broward Ave & Powerline Rd EB	Blocked single lane using a parking space
2	60 min.	8:00-9:00	8100-11700		

3.7.9. Event Traffic Scenario

Art performances, festivals, and sport competitions are common examples of traffic events, which happen inside the transportation network regularly. It is necessary to provide TMC operators with traffic management guidelines on how to handle such events. The location of the scenario was determined based on BCTED input. Discovery and Science Museum in the Broward Blvd. hosts multiple cultural and art events regularly. The events usually impose a considerable demand on the nearby intersections. In order to provide some useful guidelines for traffic operators, this location was selected as the event traffic location inside the simulation model.
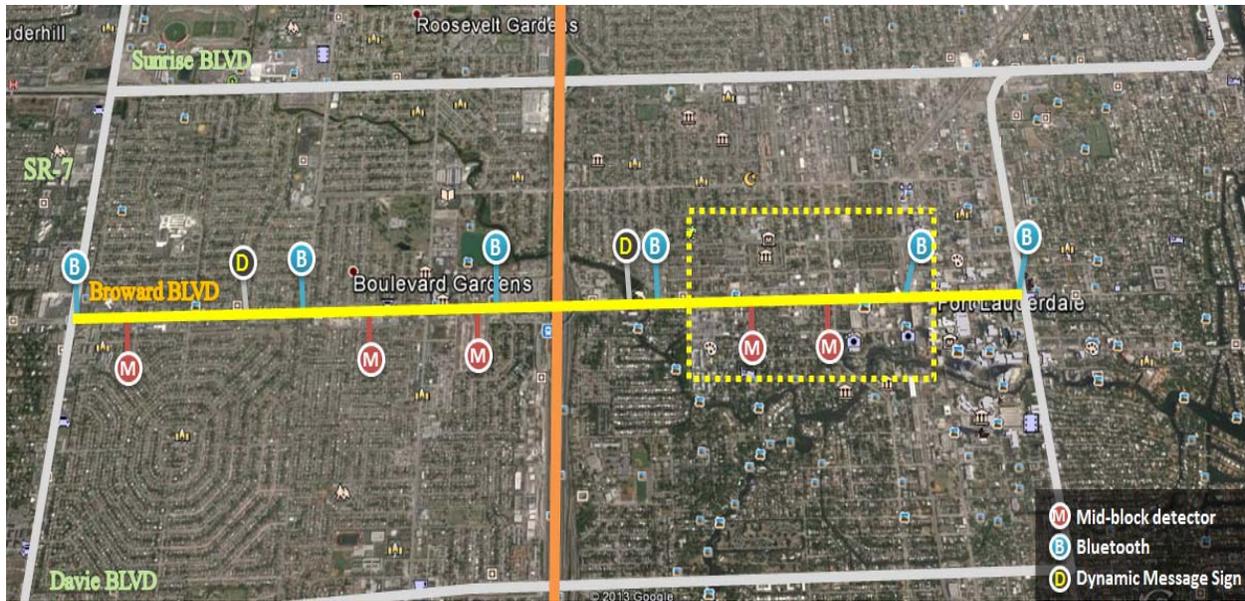
Figure 46- Event Traffic Location

The scenario was modeled by increasing the demand from four locations near Museum of Discovery and Science as follow:

1- I-95 SB to Broward Blvd. EB

2- I-95 NB to Broward Blvd. EB

3- NW 5th Ave. to Broward Blvd. WB

4- NW 7th Ave. (Avenue of the Arts SB Through Movement)

The demand was increased step by step until the traffic conditions in the microsimulation model resembled real-world traffic conditions at the event. After some iteration, it was decided to adjust routing decisions so that 60% of the traffic demand for the event arrives from I-95 SB and NB; while remaining 40% of the demands arrive from adjacent arterial streets of NW 5th Ave. and Avenue of the Arts. The simulated event traffic starts at 6:00 PM and lasts for an hour. Figure 47 shows the event traffic in the simulation model.
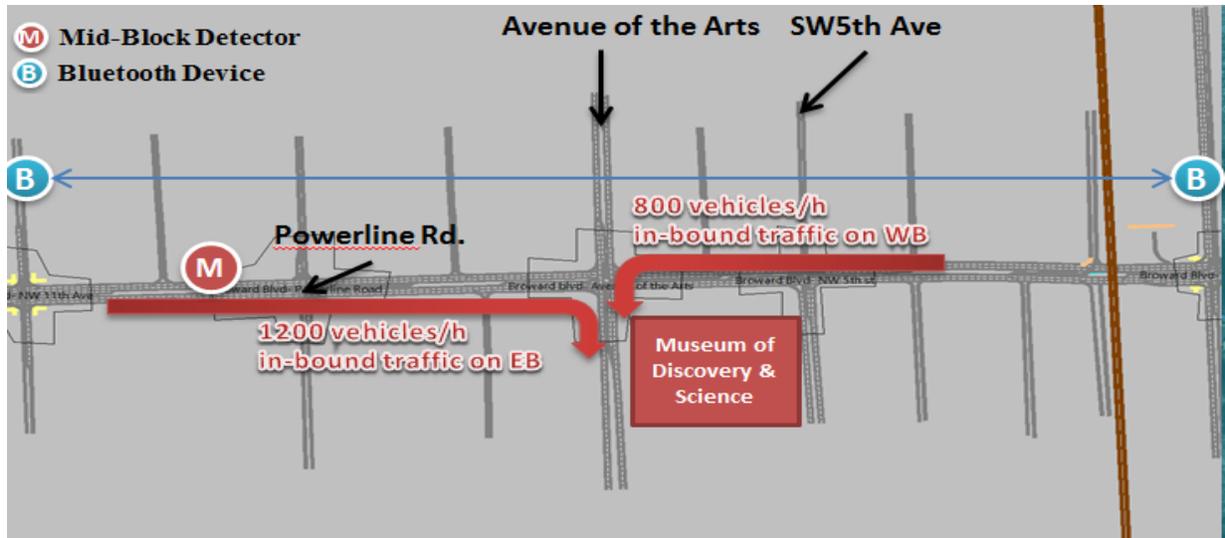
Figure 47- Event Traffic in the Simulation Model

3.8. Evaluate Impact of the Selected Strategies on Road Network

In this task, the FAU research team tested multiple proposed strategies. For each defined scenario an appropriate strategy is proposed. The effectiveness of the strategies was monitored using emulated field detectors and artificial detectors inside the simulation model. The following definitions illuminate the difference between field detectors and simulation detectors:

1. Field Detectors: actual detectors, which are already installed or are going to be installed in the field. The field detectors are modeled inside the simulation model. Bluetooth BlueTOAD travel time detectors and Wavetronix MVDS detectors are created inside the simulation model accordingly. BlueTOAD travel time detectors are emulated using travel time detectors and Wavetronix Mid-Block Detectors are emulated by data collection point sensors inside the VISSIM simulation model.

2. Simulation Detectors: a combination of data collection points and travel time detectors inside the simulation model. The data collection points exist in the middle of each link inside the simulation model. The travel time detectors are located at each intersection and provide travel time data for each link in the simulation model.

Figure 48 shows location of the field sensors in the study area. Broward Blvd. is highlighted in yellow since most of the scenarios and strategies are modeled for this corridor.

Figure 48- Location of the Field Detectors in the Central Broward County

Several performance measures were monitored to evaluate the impact of each strategy on the traffic network. Several mobility performance measures were selected for the evaluation task. Table 13 depicts mobility performance measures for strategy evaluation.

Table 13- Mobility Performance Measures for Strategy Evaluation

Category	Performance Measure	Unit
Network Evaluation	Delay Time	Minutes
	Number of Arrived Vehicles	Vehicles Per 5 Minutes
	Average Delay Time	Minutes
	Average Speed	MPH
	Travel Time	Minutes
Travel Time	Average Travel Time per Link	Minutes
Data Collection	Number of Vehicles	Vehicles Per 5 Minutes
	Spot Speed	MPH
	Occupancy	Percentage

4. Evaluation of Results

This chapter includes the results of the conducted analysis. Demand modeling efforts and scenario analyses are presented in this chapter.

4.1. Overview

To develop a statistical model from the microsimulation model, different methods were tested. The methods are combination of various detector types in the microsimulation model and the statistical modeling approach. The following definitions provide more support for this task:

1. Demand or True Demand: total number of vehicles on a particular link. This value is calculated by subtracting departure demand from the arrival demand.
2. Equivalent Demand: total number of vehicles on a particular link divided by the jam density.
3. Through Demand: total number of vehicles in the through movement lane group.
4. Field Detectors: actual detectors, which are installed in the field, modeled inside the simulation model. (
5. Figure 31)
6. Simulation Detectors: a combination of the field and artificial detectors inside the simulation model.
7. Aggregated Demand Modeling: modeling true demand by considering all the simulation links performance measures at the same time.
8. Average Demand Modeling: modeling true demand by considering each link performance measures individually. The R-squared value in this approach is the average of all individual links' R-squared.

4.2. Traffic Demand Modeling

Several statistical analyses were conducted with different time intervals to check if performance measures' time interval is a significant contributor to demand estimation modeling. In these experiments, the demand was modeled utilizing all of the selected performance measures with variable time intervals. The performance measures were retrieved using the simulation detectors. The analysis revealed that the performance measures' time interval is not a significant contributor to the model prediction power. Therefore, a default time interval of five minutes (300 seconds) was selected for the remaining analyses. The statistical models were developed considering field and simulation detectors. Several combinations of detection scenarios were considered for demand modeling as follow:

1. All Detection System Available: in this case, the statistical models are developed based on the retrieved data from both mid-block detectors and Bluetooth devices. Throughput, occupancy rate, spot speed, travel time, and link distance are considered in modeling demand using all detection system.
2. Mid-block Detectors Only: the demand model was fitted to the data utilizing the mid-block detectors only. The performance measures that can be retrieved using mid-block detectors are considered under this detection scenario. The performance measures include: throughput, occupancy rate, spot speed, and link distance.

3. Bluetooth Only: the demand model was fitted to the data using travel time data retrieved from the Bluetooth detectors only. The performances measures that can be acquired from the Bluetooth devices are limited to travel time and link distance.

The models were developed for both demand and equivalent demand performance measures using aggregated and average modeling approaches. The following figures show through and left-turn modeling plots utilizing simulation and field detectors. Throughputs, occupancy rate, and spot speed are retrieved from mid-block detectors and travel time data is retrieved from the Bluetooth detectors

Figures 49-52 show relationship between true traffic demand, as measured by the method presented in section 3.4, and relevant field-like performance measure from the microsimulation model. For example, each point in Figure 49 part a) shows a case when true traffic demand on a particular link (measured for a given time interval, usually 5 minutes) is compared/associated with throughput (number of vehicles that passed through a given point, representing the real-world detector) on the same link. Similar relationship points between true demand and throughput are then grouped together from all of the links and all of the time intervals within the entire simulation period. In this way a generalized relationship (which is not link and/or time dependent) between true traffic demand and throughput is developed.

a)

b)

c)

d)
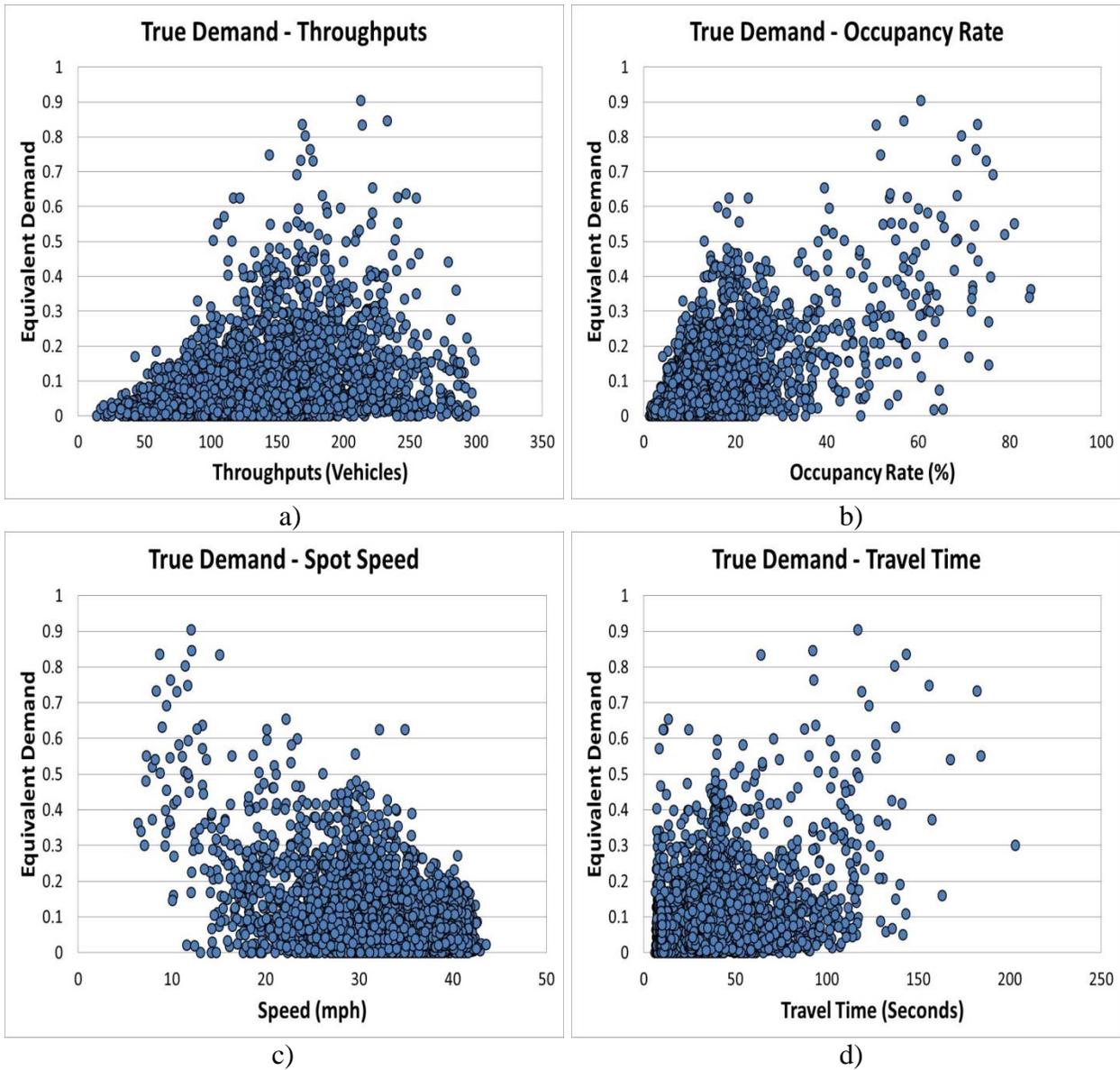
Figure 49- Through Demand Modeling Plots Utilizing Simulation Detectors
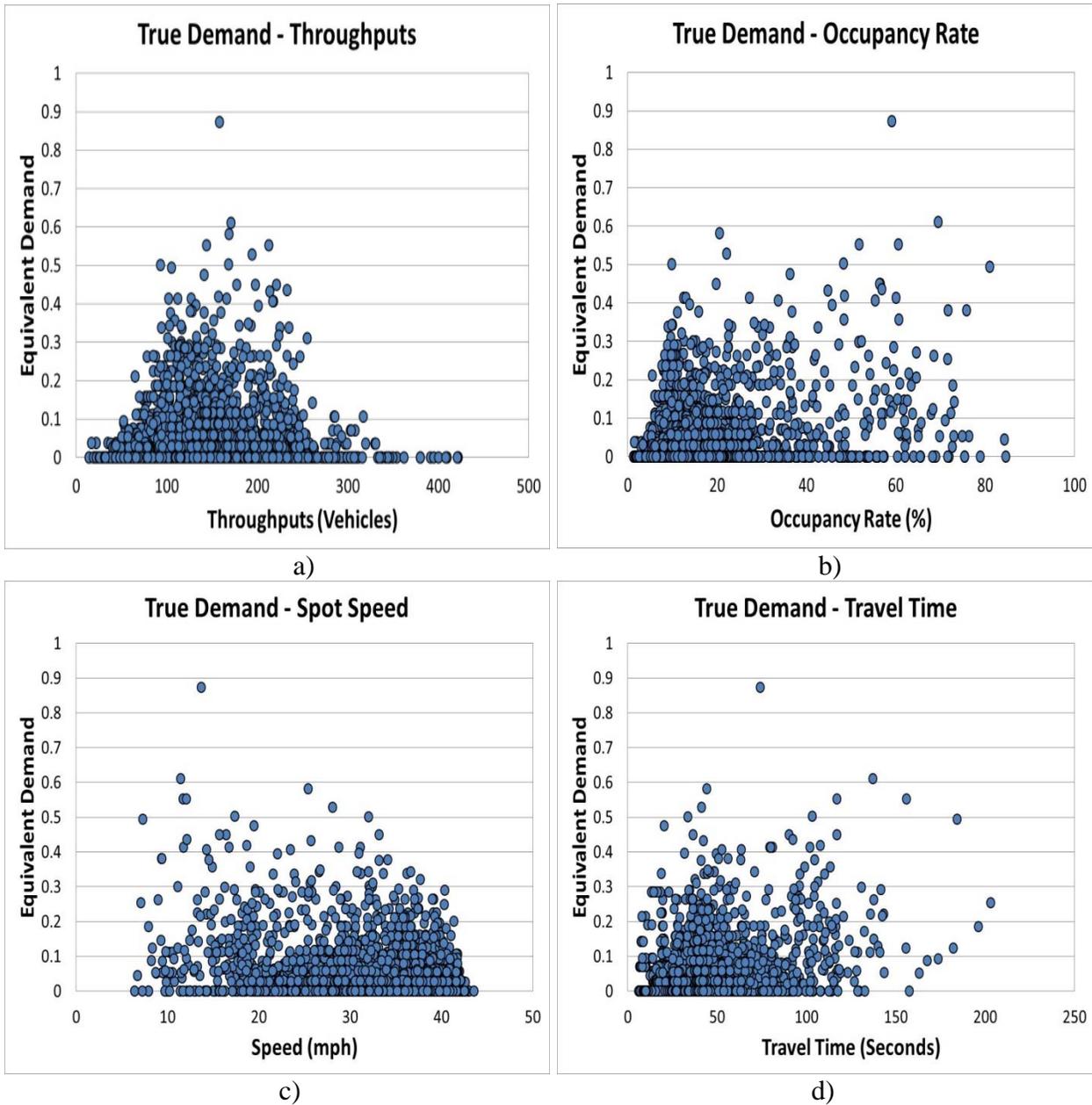
Figure 50- Left-Turn Demand Modeling Plots Utilizing Field Detectors

81
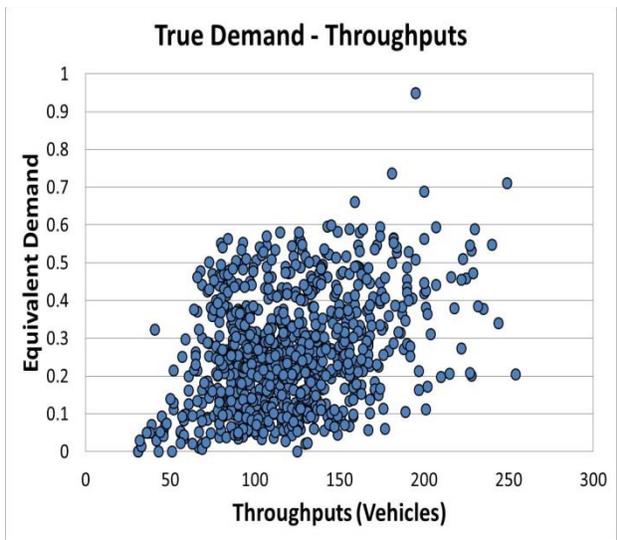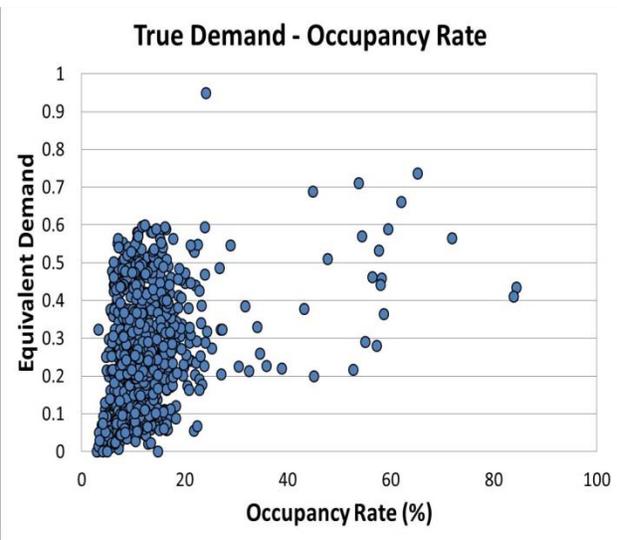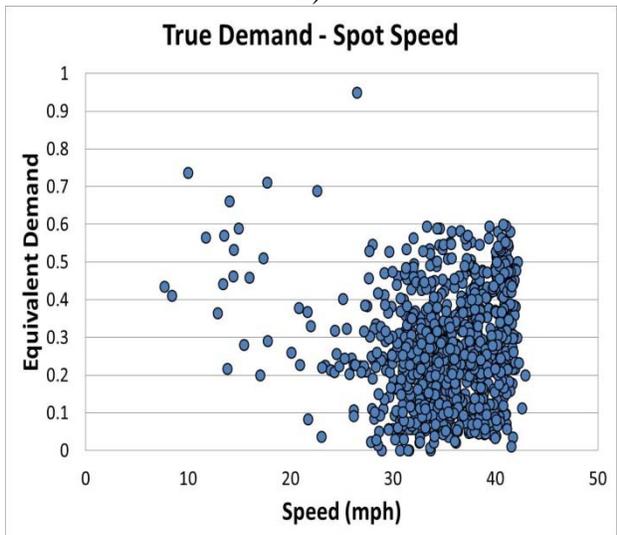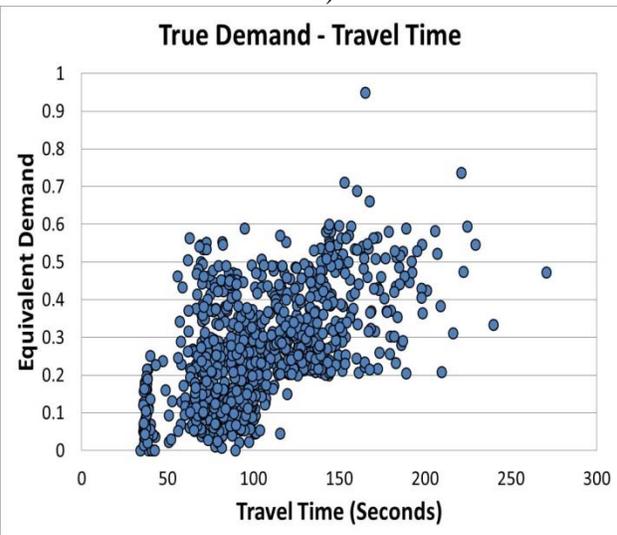
Figure 51- Through Demand Modeling Plots Utilizing Field Detectors
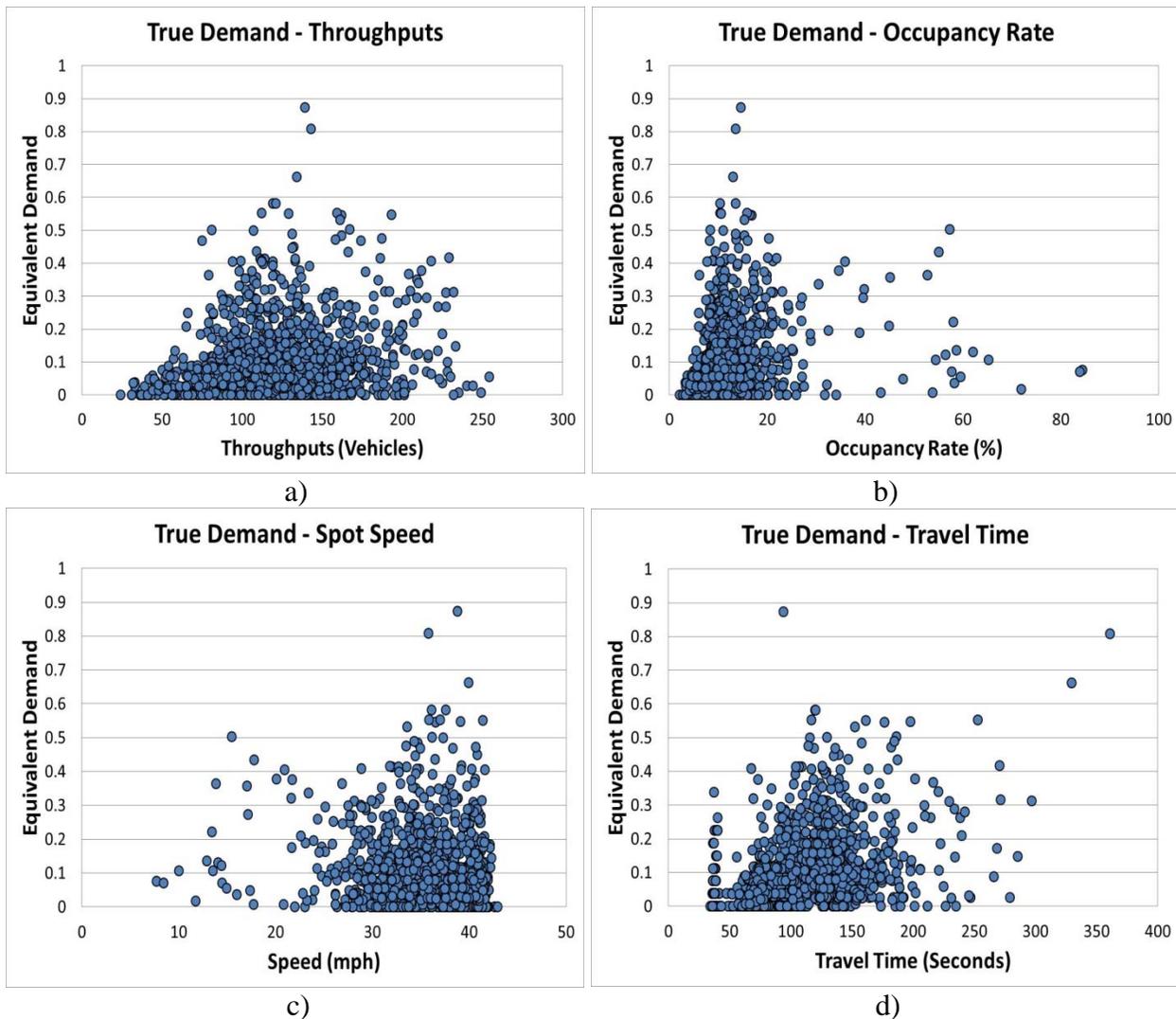
Figure 52- Left-Turn Demand Modeling Plots Utilizing Field Detectors

The visualization of the key performance measures against equivalent demand revealed that there exist a reasonably good linear relationship between performance measures and equivalent demand. This relationship will be further researched during the second phase of this project when such relationship will be validated based on the field data. In summary, the figures 49-52 show that there is a relationship between equivalent demand and field-like traffic performance measures. The relationships show that the equivalent demand is directly proportional to throughput, occupancy, and travel time and inversely proportional to the speed (e.g. the equivalent demand reduces as speed increases).

Link distance, throughput, occupancy rate, and spot speed were selected as significant parameters in demand modeling. The demand models were developed using regression analysis module in MS Excel. Statistical models were developed for different data sets and the model's goodness of fit was evaluated by R-squared values.

Table 14 Demand Modeling Results

Movement	Detection Scenarios	Simulation Detectors		Field Detectors	
		Aggregated Modeling (using equivalent demand)	Average Modeling (using demand)	Aggregated Modeling (using equivalent demand)	Average Modeling (using demand)
Through Demand	All Detection System Available	0.64	0.73	0.72	0.80
	Mid-block Detectors Only	0.63	0.72	0.68	0.75
	Bluetooth Only (linear modeling)	0.48	0.60	0.67	0.78

The demand modeling results are presented in Table 14. In order to better interpret Table 14 consider the following simple example: Suppose that we have three links, which respective statistical models have been developed with R-squared values of 0.75, 0.80, and 0.85. In the average modeling, the calculated R-squared value of three links will be the average of three links, which is 0.80. In aggregated modeling, all the data points in three links will be considered together simultaneously and R-squared value shows the goodness of fit of the single model that is developed for the aggregated data points.

The results show that statistical models developed based on the field detector data provide a better prediction power. Also, it is better to use all detection systems to develop statistical models instead of using either mid-block detectors or Bluetooth detectors. Throughput, occupancy rate, and speed data are acquired from mid-block detectors and travel time data is retrieved from Bluetooth devices. The model coefficients for field detectors are represented in Table 15.

Table 15 Demand Estimation Model Parameters using all of the Field Detectors

a) Eastbound

Detector	1	2	3	4	5
R-Squared	0.65	0.77	0.79	0.89	0.84
Link Distance (ft.)	-0.2435	-0.0034	-0.1677	-0.1727	-0.6012
Throughput (vehicles per 5 minutes)	5.6037	6.239	5.6262	-1.1515	5.1882
Occupancy Rate (%)	0.5079	10.8825	4.0471	25.9677	26.3288
Spot Speed (mph)	-29.4052	-10.5385	-13.6355	-40.9875	-29.3665
Travel Time (Sec)	8.2236	5.0269	4.3568	2.0818	1.9876

b) Westbound

Detectors	1	2	3	4	5
R-Squared	0.71	0.82	0.89	0.87	0.79
Link Distance (ft.)	0.2582	-0.2557	0.7853	-0.3092	-0.2687
Throughput (vehicles per 5 minutes)	6.7789	6.6232	11.4708	11.7542	4.7092
Occupancy Rate (%)	4.8241	8.5044	6.4731	31.4051	2.835
Spot Speed (mph)	-22.7964	-23.3778	-92.7226	-9.5829	-26.1198
Travel Time (Sec)	3.3935	3.0157	9.707	8.8432	7.313

* The numbers in the cells should be multiplied by 10^{-4} to obtain the actual model parameters.

Please refer to Appendix D for full model parameters documentation.

4.3. Scenario Based Analysis

The results of the scenario analyses are presented in this section. The signature of each scenario is captured by monitoring traffic performance measures such as throughput, occupancy rate, speed, and travel time. Appropriate threshold for each performance measure is identified and documented. For each scenario, certain strategies are identified to alleviate the congestion. The effectiveness of the strategies is evaluated using the simulation models. The performance

measures are retrieved from the field and simulation detectors inside simulation model. Table 16 summarizes considered strategies for this study.

Table 16- Summary of Scenarios

#	Congestion Type	Name	Description
1	Recurring	Base	This is a normal condition, which all the links are operating in the undersaturated mode.
2		Saturated	Queue forms and dissipates in some of the intersections sporadically.
3		Oversaturated	Queue spillbacks to the upstream intersection in one or more links.
4	Nonrecurring	Freeway Incidents	Incidents, which occur on freeways and impact the arterial corridors.
5		Left-Turn Spill-Over	Queue on left-turn pocket blocks the through movement and causes congestion.
6		Rail Preemption	Long trains may become problematic and create queues.
7		Arterial Incidents	Incidents, which occur on the arterial corridors.
8		Event Traffic	Special events such as art performances, festivals, and athletic games.

The base scenario represents the normal condition that all the links are operating in the undersaturated condition. This scenario is kept as the base scenario and other scenarios and respective strategies are compared to this scenario. Table 17 presents signal timing pattern in the base scenario. The base scenario signal timing plans are equivalent to existing signal timing plans. The analyses results of other scenarios are presented in this section.

Table 17- Signal Timing Pattern in the Base Scenario

Intersection	SC#	Ph1	Ph2	Ph3	Ph4	Ph5	Ph6	Ph7	Ph8	C.L.*	Offset
SR7	77	26	54	26	48	32	54	26	48	160	88
SW 38th Ave	76	20	79	26	35	20	79			160	84
SW 35th Ave	16		125		35					160	131
SW 34th Ave	15	20	100				120		40	160	151
SW 31st Ave	13	24	70	24	42	24	70	24	42	160	2
Riverland Rd	53	24	77	20	39	24	77	20	39	160	109
SW 24th Ave	87	20	95		45	20	95		45	160	109
I-95 SB/NB	32	20	60		25		55			160	0
SW 18th St	70	15	103		42	15	103		42	160	25
SW 15th Ave	85	25	97				97		38	160	3
SW 14th Ave	99		130		30		130			160	134
NW 11th Ave	82	26	96		38	19	96		38	160	140
Powerline Rd	30		123		37		123		37	160	93
Avenue of the Arts	71	13	71	14	38	21	71	29	38	160	104
NW 5th St	88		106		34	20	106		34	160	78
NW1st Ave	33		84		51	25	84		51	160	51
Andrews Rd	54	23	63	20	43		63	30	43	160	62
NE 3rd Ave	43	20	63	20	47	20	63	30	47	160	129
US1	23	35	47	30	42	25	47	36	42	160	15

* Cycle Length

4.3.1. Saturation and Oversaturation Scenarios

The saturation and oversaturation scenarios were modeled inside the Broward Blvd. model from 8:00 to 9:00 AM. The scope of the scenarios was entire Broward Blvd. corridor. The models were created inside the simulation model by increasing the volume by 20%. The control objective for these scenarios is queue management. The queue management strategy applies only for the main road queues. The field sensors used in this analysis were M-20 (mid-block detector) and B-27 to B-29 (Bluetooth device). Figure 53 shows what field-like simulation measurements were used to develop strategies for scenarios with saturated and oversaturated traffic conditions. In order to collect traffic data for these scenarios, volume, speed, and occupancy were collected from the data collection points that correspond to M-20 field detectors. Similarly, the travel times were collected from travel time sections that emulate section covered by the BlueTOAD devices at SW 14th Ave. and Andrews Blvd.

Figure 53- Saturation and Oversaturation Detection Strategy

For saturation and oversaturation scenarios, two different optimized signal retiming plans were developed using VISGAOST optimizing tool. Table 18 shows optimized timing plan in saturation scenario. Similarly, Table 19 depicts optimized timing plan for the Oversaturated scenario.

Table 18- Optimized Signal Timing Plan in the Saturation Scenario

Intersection	SC#	Ph1	+/-*	Ph2	+/-/	Ph3	+/-	Ph4	+/-	Ph5	+/-	Ph6	+/-	Ph7	+/-	Ph8	+/-	Offset**
SR7	77	27	1	49	-5	59	33	55	7	24	-8	52	-2	30	4	84	36	12
SW 38th Ave.	76	22	2	113	34	14	-12	41	6	80	60	55	-24					81
SW 35th Ave.	16			52	-73			138	103									72
SW 34th Ave.	15	18	-2	88	-12							106	-14			84	44	159
SW 31st. Ave.	13	17	-7	96	26	21	-3	56	14	25	1	88	18	24		53	11	129
Riverland Rd.	53	20	-4	74	-3	20		76	37	50	26	44	-33	32	12	64	25	33
SW 24th Ave.	87	11	-9	64	-31			115	70	40	20	35	-60			115	70	6
I-95 SB/NB	32	20		60				25				55						0
SW 18th St.	70	76	61	72	-31			42		9	-6	139	36			42		81
SW 15th Ave.	85	21	-4	56	-41							77	-20			113	75	180
SW 14th Ave.	99			179	49			11	-19			179	49					147
NW 11th Ave.	82	9	-17	29	-67			152	114	12	-7	26	-70			152	114	3
Powerline Rd.	30			92	-31			98	61			92	-31			98	61	48
Avenue of the Art	71	15	2	50	-21	17	3	108	70	20	-1	45	-26	9	-20	116	78	42
NW 5th St.	88			94	-12			96	62	16	-4	78	-28			96	62	84
NW 1st Ave.	33			66	-18			124	73	10	-15	56	-28			124	73	144
Andrews Rd.	54	10	-13	74	11	71	51	35	-8			84	21	76	46	30	-13	126
NE 3rd Ave.	43	12	-8	100	37	12	-8	66	19	28	8	84	21	26	-4	52	5	3
US1	23	26	-9	57	10	35	5	72	30	18	-7	65	18	42	6	65	23	190

* "(+/-) Column shows the difference (in seconds) between the new and the base timing plans"
** Cycle Length for all intersections is 190 seconds

Table 19- Optimized Signal Timing Plan in the Oversaturation Scenario

Intersection	SC#	Ph1	+/-*	Ph2	+/-	Ph3	+/-	Ph4	+/-	Ph5	+/-	Ph6	+/-	Ph7	+/-	Ph8	+/-	Offset**
SR7	77	19	-7	49	-5	75	49	53	5	18	-14	50	-4	42	16	86	38	77
SW38th Ave	76	16	-4	106	27	13	-13	61	26	10	-10	112	33					112
SW35th Ave	16			141	16			55	20									12
SW34th Ave	15	22	2	107	7							129	9			67	27	34
SW31st Ave	13	31	7	80	10	11	-13	74	32	56	32	55	-15	30	6	55	13	37
Riverland Rd	53	48	24	61	-16	44	24	43	4	39	15	70	-7	54	34	33	-6	87
SW24th Ave	87	14	-6	134	39			48	3	39	19	109	14			48	3	118
I-95 SB/NB	32	20		60				25				55						0
SW18th St	70	34	19	100	-3			62	20	68	53	66	-37			62	20	158
SW15th Ave	85	56	31	70	-27							126	29			70	32	59
SW14th Ave	99			81	-49			115	85			81	-49					68
NW11th Ave	82	48	22	103	7			45	7	82	63	69	-27			45	7	140
Powerline Rd	30			115	-8			81	44			115	-8			81	44	164
Avenue of the Arts	71	46	33	70	-1	17	3	63	25	42	21	74	3	9	-20	71	33	158
NW5th St	88			128	22			68	34	15	-5	113	7			68	34	93
NWNW1st Ave	33			92	8			104	53	36	11	56	-28			104	53	99
Andrews Rd	54	19	-4	65	2	37	17	75	32			84	21	44	14	68	25	102
NE3rd Ave	43	106	86	37	-26	12	-8	41	-6	17	-3	126	63	10	-20	43	-4	140
US1	23	20	-15	39	-8	52	22	85	43	10	-15	49	2	22	-14	115	73	196

* "(+/-) Column shows the difference (in seconds) between the new and the base timing plans"

** Cycle Length for all intersections equals 196 seconds.

The scenarios and their respective strategies were modeled inside the Broward Blvd. simulation model for both simulation and field detectors. It should be noted that the suggested signal timings are developed for the specific saturated and oversaturated conditions, when the network if incrementally and uniformly filled from all entrance links. Thus, this approach creates a couple of scenarios where saturation starts at the weakest bottleneck point in the network and it spreads to the neighboring links thus creating over time a gridlock and oversaturated conditions. The suggested signal timings are introduced all at once (as part of the same signal timing pattern). There is potential that a phased approach of implementing those timings (one at a time or in blocks of intersections/links) could be beneficial too but such experiments were not tested.

Figure 54 shows visualization of the monitored traffic parameters inside the simulation model using field detectors output. The base scenario is represented with a black line and the scenario is shown in a red line. The implemented strategy (optimized signal timing), which is shown in a blue color, improves the mobility of the corridor in terms of observed spot speed, average travel time, and occupancy rate. The chart represents a field-like signature that traffic operators may visualize monitoring TMC data sources. Similarly, Figure 55 shows visualization of the oversaturation scenario traffic parameters obtained from field detectors. The optimized signal timing plan generated by the VISGAOST software improves the traffic mobility in the oversaturation scenario considerably. The strategy reduces the occupancy rate and travel time across the Broward Blvd.
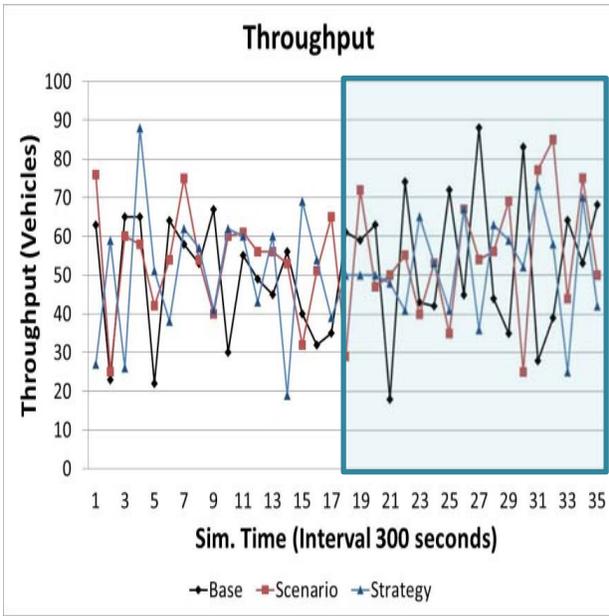
a)
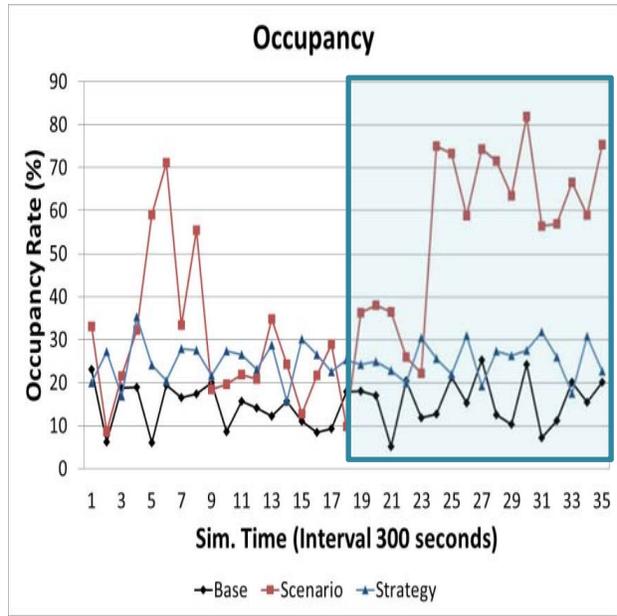
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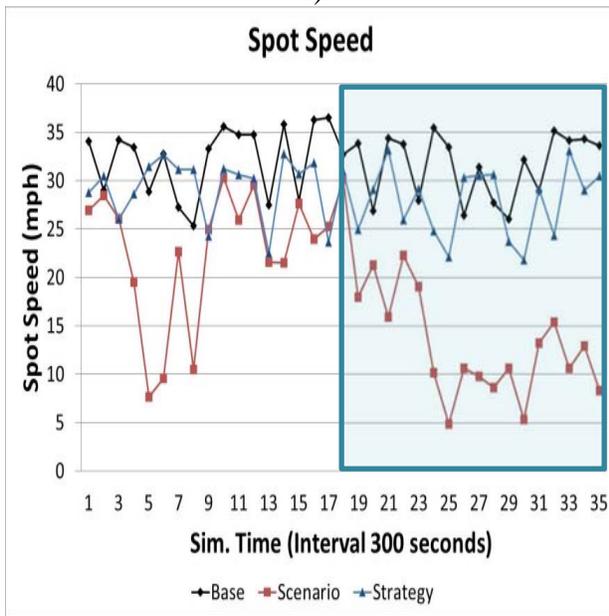
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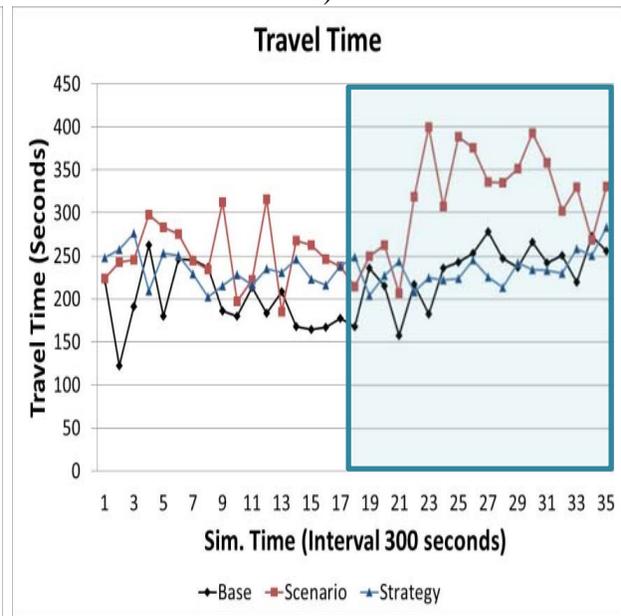
d)

Figure 54- Saturation Traffic Scenario Signature Based on the Field Detectors

The traffic parameters were also monitored utilizing the simulation detectors. Simulation detectors are artificial detectors, which exist only inside the simulation model. They consist of data collection points, which reside at the middle of each intersection and travel time detectors, which are located in the middle of each intersection. Figure 56 shows a sample of simulation detector data visualization for the throughput performance measure. The y-axis on the charts represents Broward Blvd. links from SR7 to US-1 on the eastbound. The x-axis on the charts represents simulation time interval, where each bin represents 300 simulation seconds. In the other words, the x-and y-axes represent spatial and temporal extension of the analysis and the colored scheme represents the value of the performance measure. Figure 56 represents absolute throughput value for the base scenario (a), saturated scenario (b), and the saturated scenario with the implemented strategy (c). The figure also shows relative throughput values, which are compared to the base scenario in charts (d) and (e). Similar charts are developed for other key performance measures of occupancy rate (%), spot speed (mph), and travel time (minutes). The charts provide more detailed information about the impact of the each scenario and its respective strategy on the key performance measures collected from artificial simulation detectors. Similarly, Figure 56 shows true demand performance measure in the base, saturation, and oversaturation scenarios.
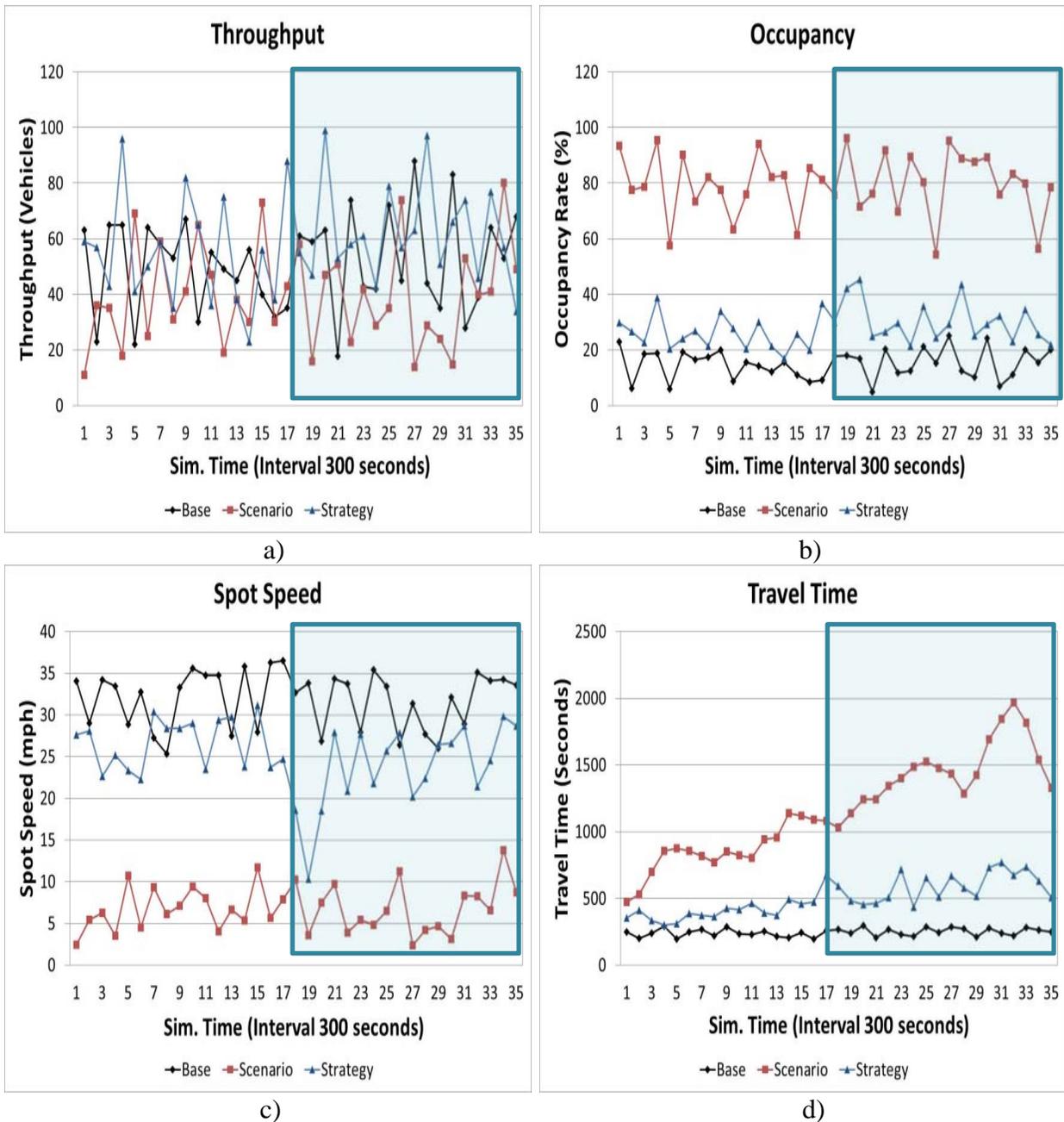
Figure 55- Oversaturation Traffic Scenario Signature Based on the Field Detectors

Appendix E encompasses all charts developed from simulation detectors for the key traffic performance measure of throughput, occupancy rate, spot speed, and travel time. The charts are developed for each recurring and nonrecurring scenario.

a) Base   b) Scenario   c) Strategy-Applied

d) Scenario Compared to Base   e) Strategy Compared to Base
Figure 56- Visualization of the Throughput Performance Measure in Saturation Scenario

| a) Base | b) Scenario |

Figure 57- True Demand in Saturation Scenario

When monitoring key traffic performance measures, appropriate thresholds for each performance measure are determined. It should be noted that in this study, 5-minutes time interval for monitoring traffic parameters.

Table 20- Saturation and Oversaturation Scenario Thresholds

Parameters	Thresholds (Saturated)	Thresholds (Over-saturated)	Available Sensor
True Demand (vehicles per 5 minutes)	Higher than 100 with a few (two or three) intersections	Higher than 100 in multiple intersections	
Throughput (vehicles per 5 minutes)	Increases more than 30%	Decreases more than 30%	M-20
Occupancy rate (%)	Slightly increases by 10%	Increases more than 100%	M-20
Spot speed (mph)	Slightly decreases by 10%	Decreases more than 50%	M-20
Travel time (seconds)	Slightly increases by 10%	Increases more than 100%	B-27 to B-29

If link throughputs get close to link capacity while other MOEs show small changes, the current condition is likely saturated condition. Also, if throughput and speed considerably decease while occupancy and travel time considerably increase, the traffic condition is likely the oversaturation condition. Signal retiming strategies improve the traffic mobility. In the saturation scenario, the occupancy rate decreases nearly 7% and average travel time reduces by nearly 16% when the strategy is applied. Also, implementation of the strategy increases the average speed by 11.7%. In the oversaturation scenario, the signal retiming strategy increases the throughput and speed by 15.9% and 25.6% respectively. Also, the implemented strategy reduces the average travel time and occupancy rate by near 34.1% and 20.2% respectively. Table 21 summarizes mobility

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impact of traffic strategies in the saturation scenario and Table 22 shows mobility impact of traffic strategies in the oversaturation scenario.

Table 21- Mobility Impact of Traffic Strategy in Saturation Scenario

Performance Measures	Saturation			
	Base	Scenario	Strategy-applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	50.6	56.4	58.6	3.9%
Occupancy (%)	16.8	26.3	24.5	-6.8%
Speed (mph)	35.2	26.5	29.6	11.7%
Travel Time (seconds)	34.6	54.2	45.6	-15.9%

Table 22- Mobility Impact of Traffic Strategy in Oversaturation Scenario

Performance Measures	Oversaturation			
	Base	Scenario	Strategy-applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	50.6	41.6	48.2	15.9%
Occupancy (%)	16.8	49.5	39.5	-20.2%
Speed (mph)	35.2	19.5	24.5	25.6%
Travel Time (seconds)	34.6	120.6	79.5	-34.1%

4.3.2. Freeway Incident Scenario

The freeway incident scenario was modeled inside the network simulation model. The duration of the scenario was determined at 60 minutes from 4:30 PM to 5:30 PM. The incident location was selected right after Broward Blvd. onramp. The freeway incident was emulated by parking lots in VISSIM simulation model. Also, reduce speed areas were created to make the situation more realistic. The duration of the freeway incident scenario was modified using dwelling time parameter of the parking lots. The field sensors of M-21 (mid-block detector) and B-27 to B-29 (travel time detector) were used to extract the data from the simulation model. Figure 58 shows freeway incidents field detector location.

Figure 58- Freeway Incidents Field Detectors Location

To mitigate the congestion caused by the freeway incident scenario, traffic was rerouted to the parallel arterial streets on both directions. The traffic diversion was implemented using two DMS on both east and westbound. The DMS message signs were changed to the route guidance information as shown in Table 23 and Table 24.

Table 23- Westbound Broward Blvd. DMS Message during Freeway Incident

Number	Route	Travel Time (min)
1	Broward - I95(NB) (BASE)	25
2	Broward - NW6th - Sunrise - I95(NB) (Alt.1)	15
3	Broward - NW6th - NW27th - Sunrise - I95(NB) (Alt.2)	17
4	Broward - NW27th - Sunrise - I95(NB) (Alt.3)	18

Table 24- Eastbound Broward Blvd. DMS Message during Freeway Incident

Number	Route	Travel Time (min)
1	Broward - I95(NB) (BASE)	25
2	Broward – NW27th. - Sunrise - I95(NB)	15
3	Broward – NW31st. - Sunrise - I95(NB) (NB)	15

Figure 59 shows rerouting strategy on both directions for freeway incident scenario. The main direction of travel is highlighted in red and other alternative routes are shown in different colors. The route numbers are selected based on Table 23 and Table 24 data.

a) Westbound

b) Eastbound

Figure 59- Rerouting Traffic in Freeway Incident Scenario

The signature of the freeway incident scenario was captured using M-21 (mid-block detector) and B-27 to B-29 (Bluetooth) travel time detector. Throughput, occupancy, and spot speed were retrieved from the mid-block detector and the travel time data was acquired from the travel time detector. It is assumed that 20% of the traffic is rerouted by applying the suggested strategies at each direction.

99
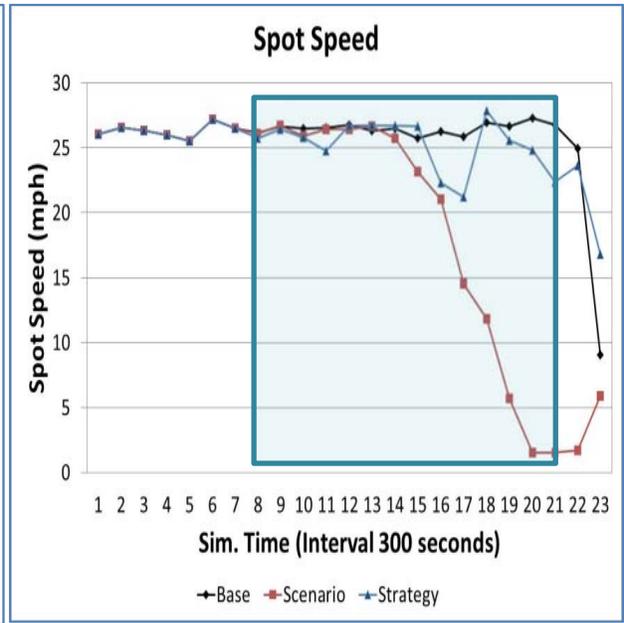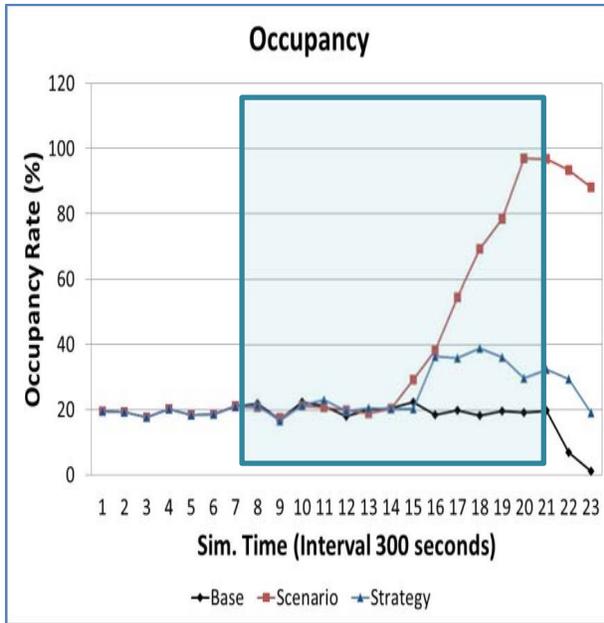
a)

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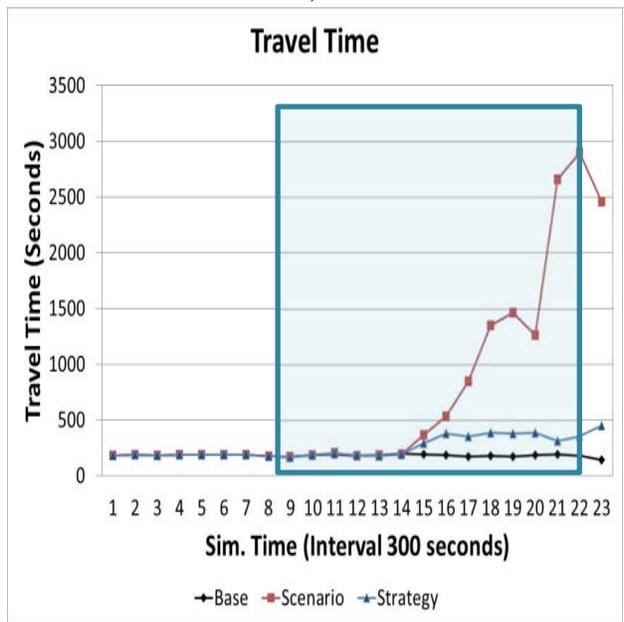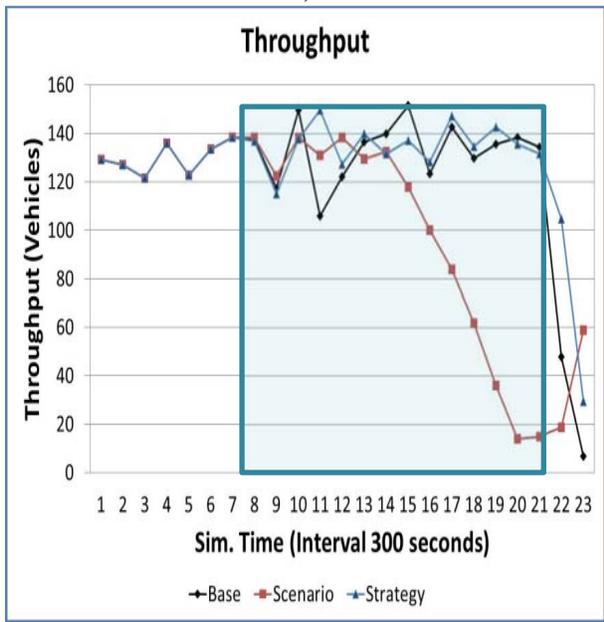
c)

d)

Figure 60- Freeway Incident Traffic Scenario Signature based on the Field Detectors

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The rerouting strategy utilizing DMS devices mitigates the congestion caused by the freeway incident considerably. The visualization of the freeway incident scenario using the simulation detectors is provided in Appendix E at the end of this report.

Table 25- Freeway Incident Traffic Thresholds

Parameters	Thresholds	Detector
Throughput (vehicles per 5 minutes)	Decreased more than 30%	M-20
Occupancy rate (%)	Higher than 30%	M-20
Spot speed (mph)	Decreases more than 30%	M-20
Travel time (seconds)	Increases more than 30%	B-27 to B-29

To identify freeway incident scenario, it is necessary to monitor the links adjacent to I-95 freeway. If throughput and spot speed decrease and occupancy rate and travel time increase in multiple sections adjacent to I-95 freeway, then the scenario is likely a freeway incident. The traffic rerouting strategy implemented by DMS mitigates the traffic congestion caused by freeway incident scenarios.

Table 26- Mobility Impact of Traffic Strategy in Freeway Incident Scenario

Performance Measures	Freeway Incident – 60 min. duration			
	Base	Scenario	Strategy-applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	116.5	103.3	113.1	9.5%
Occupancy (%)	24.8	35.2	32.5	-7.6%
Speed (mph)	28.7	21.7	23.8	9.7%
Travel Time (seconds)	41.4	120.3	68.6	-42.9%

The strategy evaluation results show that throughput and speed increase by 9.5% and 9.7% respectively while occupancy and travel time reduce by 7.6% and 42.9%.

4.3.3. Left Turn Spillover Scenario

The left-turn spillover scenario was modeled inside the Broward Blvd. simulation model in the morning peak. The scenario starts at 8:00 AM and it lasts for either 30 or 60 minutes based on the sub-scenario. The location of the scenario was selected at the intersection of the Broward Blvd. and SW 24th Ave. in the westbound direction. The scenario was implemented is VISSIM software by rerouting 600 vehicles per hour from I-95 freeway to create the left-turn spillover congestion. The control objective in this scenario was to clear the queue that was created due to the left-turn spillover.

Signals timing pattern should be changed by the operator in-the-loop. The left-turn phase was extended by employing the phase duration from the other phase, which has relatively fewer traffic. Therefore, the cycle length and the phase sequence remained unchanged. The signal retiming was implemented at SW 24th Ave in the westbound direction. Under this pattern, left-turn signal phase in the westbound direction. Table 27 shows signal retiming strategy proposed for this scenario.

Table 27- Left Turn Spillover Signal Retiming Strategy

Intersection	SC#	Ph1	Ph2	Ph3	Ph4	Ph5	Ph6	Ph7	Ph8	C.L.	Offset
SW24th Ave	87	20	95->85		45->35	20->40	95->85		45->35	160	109
(+/-)*	87	0	-10		-10	20	-10		-10	0	0

*"(+/-) Row shows the difference (in seconds) between the new and the base timing plans"

The field detectors of M-19 (mid-block detector) and B-25 to B-26 (travel time detector) were used to collect traffic data from the simulation model.
Figure 61 shows left-turn spillover scenario detector location.

Figure 61- Left Turn Spillover Scenario Detectors Location

The signature of the scenario is captured using the field detectors and are shown in Figure 62.
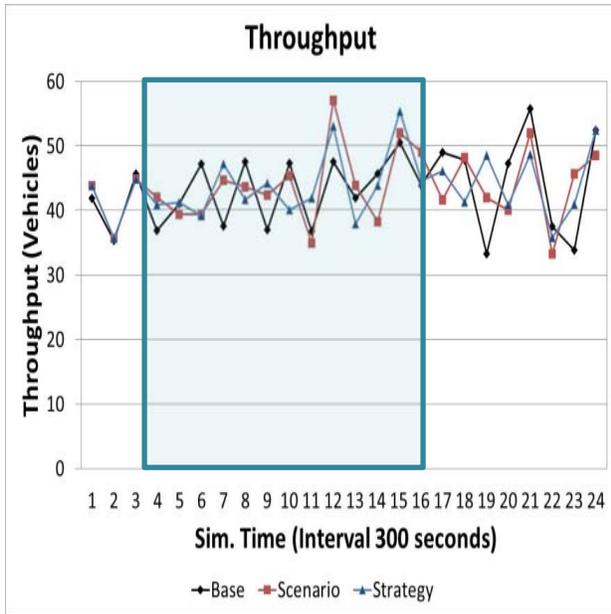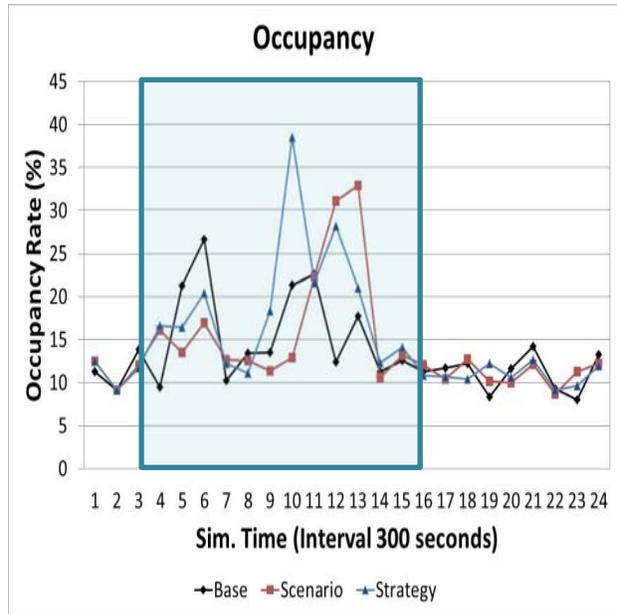
a)   b)
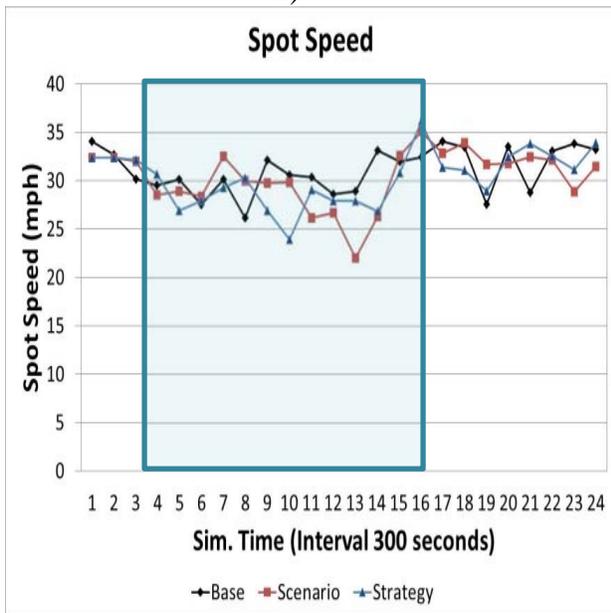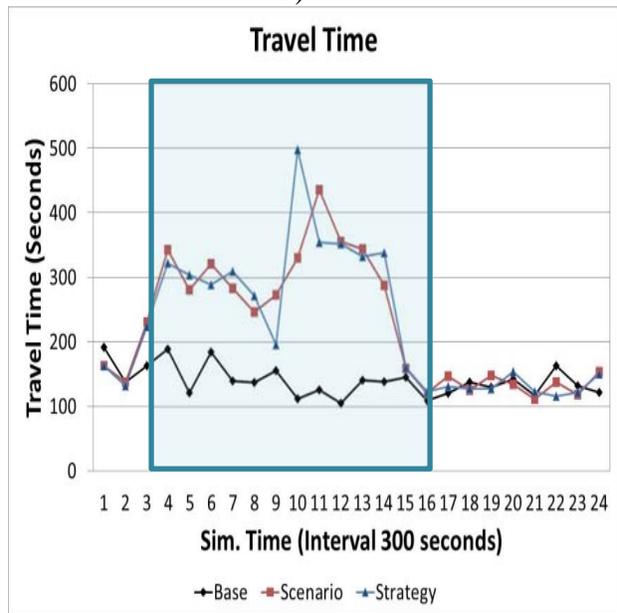
c)   d)

Figure 62- Left Turn Spillover Traffic Scenario Signature Based on the Field Detectors

The left-turn spillover scenario does not have a strong signature compared to other scenarios. This fact can be justified as the left-turn spillover scenario does not cause a considerable congestion as compared to other scenarios. The scenario signature based on the simulation detectors is presented in the Appendix E of this final report. The performance measures thresholds are also determined based on the field detector observations.

Table 28- Left Turn Spillover Thresholds

Parameters	Thresholds	Detector
True Demand (vehicles per 5 minutes)	Higher than 30	M-19
Throughput (vehicles per 5 minutes)	Increases more than 20%	M-19
Occupancy rate (%)	Higher than 20%	M-19
Spot speed (mph)	Decreases less than 20%	M-19
Travel time (seconds)	No significant changes	B-25 to B-26

To identify left-turn spillover scenario, it is recommended to monitor two consecutive sections. If the throughput and occupancy in the upstream section increases by near 20% while there is no change in the downstream section, then the scenario is likely the left-turn spillover scenario. It should be noted that travel time does not change significantly in both downstream and upstream sections. The suggested strategy slightly improves the mobility of the traffic under this condition. Table 29 shows the impact of applies strategy for left-turn spillover scenario for 30 minutes duration (a) and 60 minutes duration (b).

Table 29- Mobility Impact of Traffic Strategy in Left Turn Spillover Scenario

a) 30 minutes duration

Performance Measures	Base	Scenario	Strategy-applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	113.5	103.5	105.0	1.4%
Occupancy (%)	12.5	13.2	12.9	-2.3%
Speed (mph)	31.5	30.7	31.0	1.0%
Travel Time (seconds)	34.0	35.3	34.9	-1.1%

b) 60 minutes duration

Performance Measures	Base	Scenario	Strategy-applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	113.5	108.1	109.6	1.4%
Occupancy (%)	12.5	13.5	13.3	-1.5%
Speed (mph)	31.5	30.6	30.9	0.8%
Travel Time (seconds)	34.0	36.9	36.2	-1.9%

The percent change in various traffic parameters is low compared to the other traffic congestion scenarios. This result comes from the fact that a left-turn spillover at this location does not create severe traffic congestion on the arterial, when compared to the other scenarios (e.g. rail preemption or incidents). A potential change in the location of this scenario (e.g. a left-turn spillover at another intersection) could yield different results but this location was selected due to proximity to field devices (BlueToad and mid-block sensors) which can be used to capture such an impact of the left-turn spillover.

4.3.4. Rail Preemption Scenario

The rail preemption scenario was modeled for the morning peak starting at 8:00 AM. The scenario has two sub-scenarios, which are both different in duration. The first sub-scenario has duration of 300 seconds and the second sub-scenario has duration of 700 seconds. The location of the scenario was selected at Broward Blvd. between SW 2nd Ave. and SW 1st Ave. The rail preemption was emulated in VISSIM simulation model by adding multiple carts to the existing trains. There are sensors placed on the rail before the intersection to detect trains and turn the signal light into red.

The control objective under this scenario is queue clearance. In order to mitigate the impact of the rail preemption quickly, the signal retiming strategy is applied after the train passes. In the

new signal retiming plan, the cycle length increases by 20%; this includes the increase of the phase duration of EB/WB through movement. Regular signal timing is recovered when the traffic condition is moderate. Table 30 shows recommended signal retiming strategy for the rail preemption scenario. The signal retiming is suggested in the east side of I-95 freeway.

Table 30- Signal Retiming Strategy for Rail Preemption Scenario

Intersection	SC#	Ph2	+/- *	Ph6	+/-	C.L.
I-95 SB/NB	32	100	40	95	40	200
SW18th St	70	143	40	143	40	200
SW15th Ave	85	137	40	137	40	200
SW14th Ave	99	170	40	170	40	200
NW11th Ave	82	136	40	136	40	200
Powerline Rd	30	163	40	163	40	200
Avenue of the Arts	71	111	40	111	40	200
NW5th St	88	146	40	146	40	200
NWNW1st Ave	33	124	40	124	40	200
Andrews Rd	54	103	40	103	40	200
NE3rd Ave	43	103	40	103	40	200
US1	23	87	40	87	40	200

*(+/-) Column shows the difference (in seconds) between the new and the base timing plans

The field detectors of M-21 (mid-block detector) were used to collect simulation data of throughput, occupancy rate, and spot speed from the simulation model. Also, travel time data was acquired using Bluetooth devise of B-27 and B-29.

Figure 63- Rail Preemption Scenario Detectors Location

The signature of the scenario is captured using these detectors and are shown in Figure 64.
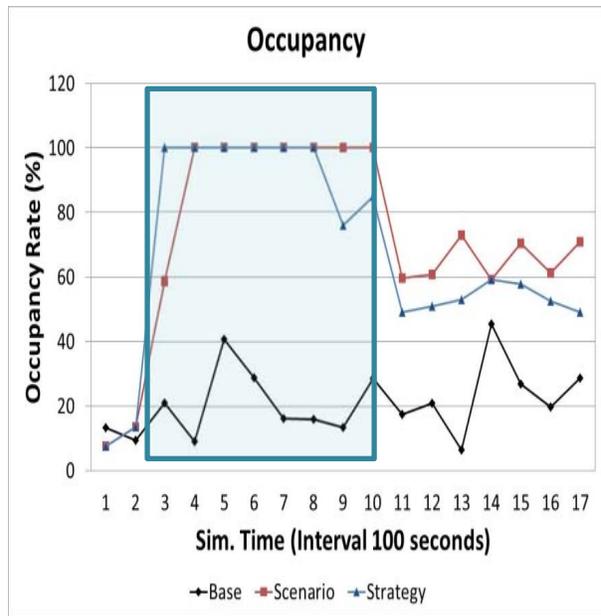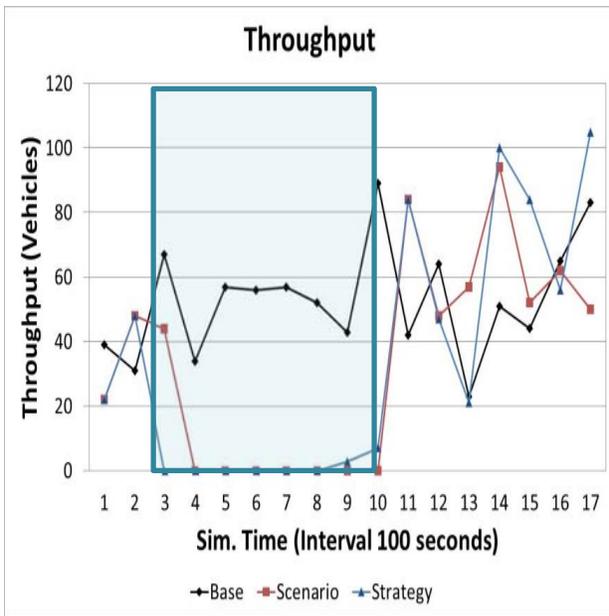
a)

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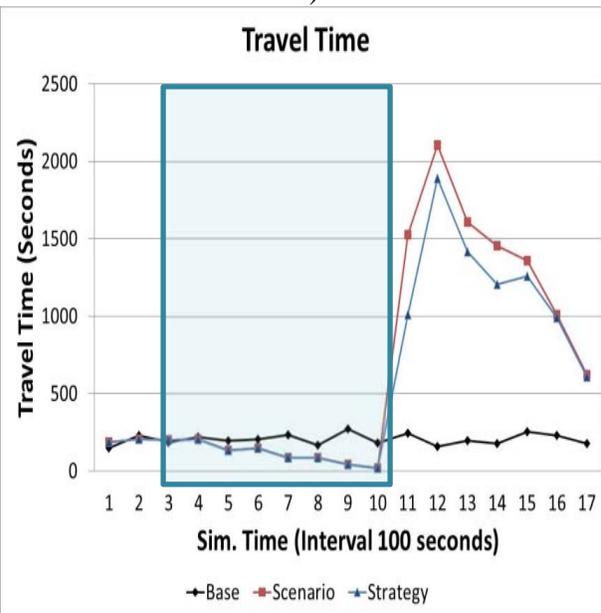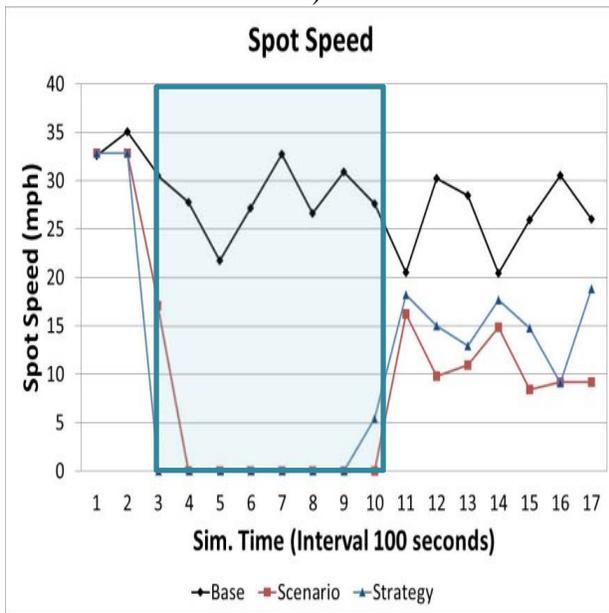
c)

d)

Figure 64- Rail Preemption Traffic Scenario Signature Based on the Field Detectors

The rail preemption scenario has a strong signature as shown on Figure 64. The rail preemption totally blocks the traffic for some time. In this situation, spot speed and throughput reduce significantly and occupancy and travel time increase significantly. The traffic parameters are also retrieved from field detectors. These parameters are shown in Table 31. The visualization of the rail preemption scenario using the simulation detectors is provided in Appendix E at the end of this report.

Table 31- Rail Preemption Thresholds

Parameters	Thresholds	Detectors
True Demand (vehicles per 5 minutes)	Higher than 100	M-21
Throughput (vehicles per 5 minutes)	Lower than 10 vehicles	M-21
Occupancy rate (%)	Higher than 90%	M-21
Spot speed (mph)	Lower than 5 mph	M-21
Travel time (seconds)	Increases more than 500%	B-27 to B-29

The recommended strategy improves the mobility of the traffic in this condition. Scenario shows the mobility impact of the recommended traffic strategy in the rail preemption scenario for 300 seconds sub-scenario (a) and 700 seconds sub-scenarios (b).

Table 32- Mobility Impact of Traffic Strategy in Rail Preemption Scenario

a) 300 seconds duration

Performance Measures	Base	Scenario	Strategy-Applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	54.6	52.3	53.9	3.1%
Occupancy (%)	22.3	25.9	25.0	-3.4%
Speed (mph)	29.6	26.8	27.6	3.0%
Travel Time (seconds)	39.5	47.6	44.6	-6.3%

b) 700 seconds duration

Performance Measures	Base	Scenario	Strategy-applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	54.6	49.8	52.3	5.0%
Occupancy (%)	22.3	35.6	32.6	-8.4%
Speed (mph)	29.6	22.9	25.1	9.6%
Travel Time (seconds)	39.5	67.8	61.6	-9.1%

The recommended signal retiming strategy slightly improves the traffic condition impacted by the rail preemption scenario. The throughput increases from 3.1% to 5.0%, and speed increases from 3.0% to 9.6%. Also, travel time reduces from 6.3% to 9.1% while occupancy reduces by 3.4% to 8.4%.

4.3.5. Arterial Incident Scenario

The arterial incident scenario is modeled in the morning peak starting at 8:00 AM. The scenario is modeled in two different duration time of 30 minutes and 60 minutes. The intersection of Broward Blvd. and Powerline Rd. has been selected to model this scenario. The control objective in this scenario is queue management and incident clearing. The applied strategy should mitigate the impact of incident quickly. For this purpose, a signal retiming strategy is proposed. The cycle length of nearby intersections are increased by 20% including the increase of the phase duration of EB/WB through movement. Signal retiming is recovered back to normal when traffic condition is moderate. Table 33 shows the recommended signal retiming strategy for the arterial incident scenario.

Table 33- Signal Retiming Strategy for Arterial Incident Scenario

Intersection	SC#	Ph2	+/-*	Ph6	+/-	C.L.
I-95 SB/NB	32	100	40	95	40	200
SW18th St	70	143	40	143	40	200
SW15th Ave	85	137	40	137	40	200
SW14th Ave	99	170	40	170	40	200
NW11th Ave	82	136	40	136	40	200
Powerline Rd	30	163	40	163	40	200
Avenue of the Arts	71	111	40	111	40	200
NW5th St	88	146	40	146	40	200
NWNW1st Ave	33	124	40	124	40	200
Andrews Rd	54	103	40	103	40	200
NE3rd Ave	43	103	40	103	40	200
US1	23	87	40	87	40	200

(+/-) Column shows the difference (in seconds) between the new and the base timing plans

The arterial incident traffic parameters such as throughput, occupancy rate, and spot speed are acquired using M-20 (mid-block) detector and travel time data is retrieved from a pair of Bluetooth sensors (B-27 and B-29).

Figure 65- Arterial Incident Scenario Detectors Location

The detection system is used to capture the signature of the arterial incident scenario. The arterial incident scenario signature is showed in Figure 64.

a)

b)

c)

d)
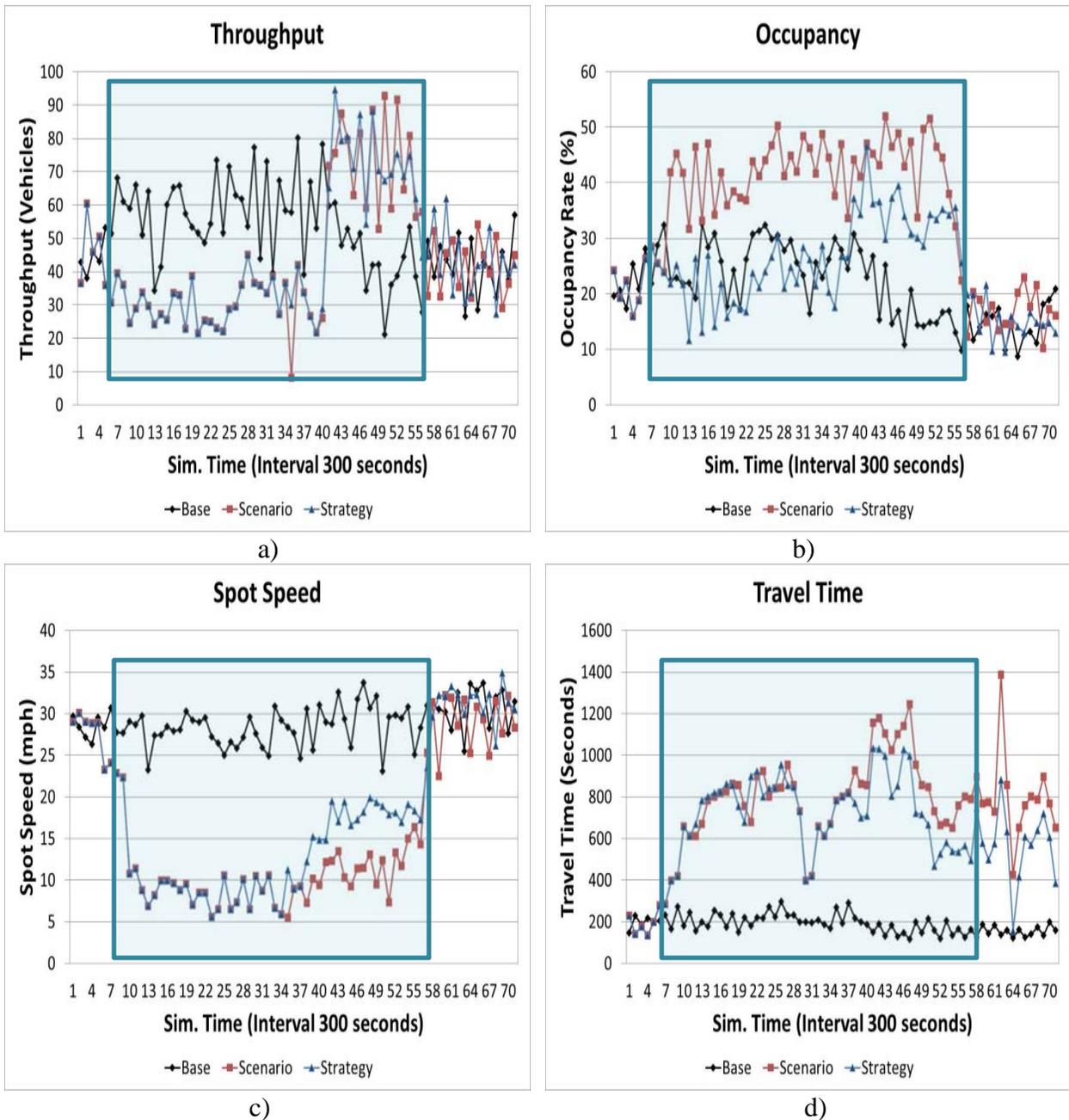
Figure 66- Arterial Incident Traffic Scenario Signature Based on the Field Detectors

The arterial incident has a strong signature in all traffic parameters. The recommended strategy alleviates the traffic congestion accordingly. The visualization of the simulation detectors for this scenario is available in Appendix E of this report. The traffic parameters' thresholds are also identified for arterial incident scenario. These thresholds are shown in Table 34.

Table 34- Arterial Incident Thresholds

Parameters	Thresholds	Detector
True Demand (vehicles per 5 minutes)	Higher than 100	M-20
Throughput (vehicles per 5 minutes)	Decreases more than 50%	M-20
Occupancy rate (%)	Higher than 50%	M-20
Spot speed (mph)	Decreases more than 50%	M-20
Travel time (seconds)	Increases more than 200%	B-27 to B-29

The recommended traffic strategy slightly improves the traffic mobility under arterial incident scenario.

Table 35- Mobility Impact of Traffic Strategy in Arterial Incident Scenario
a) 30 Minutes Duration

Performance Measures	Base	Scenario	Strategy-applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	149.5	141.6	142.5	0.6%
Occupancy (%)	18.9	24.5	22.1	-9.8%
Speed (mph)	31.2	26.5	27.5	3.8%
Travel Time (seconds)	36.5	53.6	50.6	-5.6%

b) 60 Minutes Duration

Performance Measures	Base	Scenario	Strategy-applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	149.5	132.5	135.6	2.3%
Occupancy (%)	18.9	31.8	28.3	-11.0%
Speed (mph)	31.2	23.9	24.5	2.5%
Travel Time (seconds)	36.5	96.8	89.9	-7.1%

The signal retiming strategy for arterial incident scenario increases throughput and speed from 0.6% to 2.3% and 2.5% to 3.8% respectively. The strategy also reduces occupancy and travel time from 9.8% to 11.0% and 5.6% to 7.1% respectively.

4.3.6. Event Traffic Scenario

The event traffic scenario was modeled for the Discovery and Science Museum in Broward Blvd. The museum hosts art performances and cultural events regularly which impose considerable additional traffic demand to the adjacent arterial streets. The museum is located at the intersection of Broward Blvd. and NW5th Ave. The scenario was modeled for an hour from 6:00 PM. It was assumed that the museum is the attraction destination for near 2,000 additional vehicles. Additional vehicles were rerouted from I-95 SB, I-95 NB, and the adjacent arterial streets of NW 5th Ave. and Broward Ave. Traffic were guided into the parking lot of museum. The control objective under this scenario was queue management. In order to mitigate the impact of event traffic, the signal retiming strategy is applied during the event traffic duration. Regular signal retiming is recovered when the traffic condition is moderate. Table 36 shows signal retiming strategy for arterial incident scenario. Table 36 shows signal retiming strategy for arterial incident scenario.

Table 36- Signal Retiming Strategy for Event Traffic Scenario

Intersection	SC#	Ph2	+/-*	Ph6	+/-	C.L.
I-95 SB/NB	32	100	40	95	40	200
SW18th St	70	143	40	143	40	200
SW15th Ave	85	137	40	137	40	200
SW14th Ave	99	170	40	170	40	200
NW11th Ave	82	136	40	136	40	200
Powerline Rd	30	163	40	163	40	200
Avenue of the Arts	71	111	40	111	40	200
NW5th St	88	146	40	146	40	200
NWNW1st Ave	33	124	40	124	40	200
Andrews Rd	54	103	40	103	40	200
NE3rd Ave	43	103	40	103	40	200
US1	23	87	40	87	40	200

* (+/-) Column shows the difference (in seconds) between the new and the base timing plans

The traffic parameters in the simulation model were detected utilizing M-21 (mid-block detector) and B-27 and B-29 Bluetooth device pair.

Figure 67- Event Traffic Scenario Detectors Location

Figure 67 shows the detectors that were used to capture the signature of the scenario.
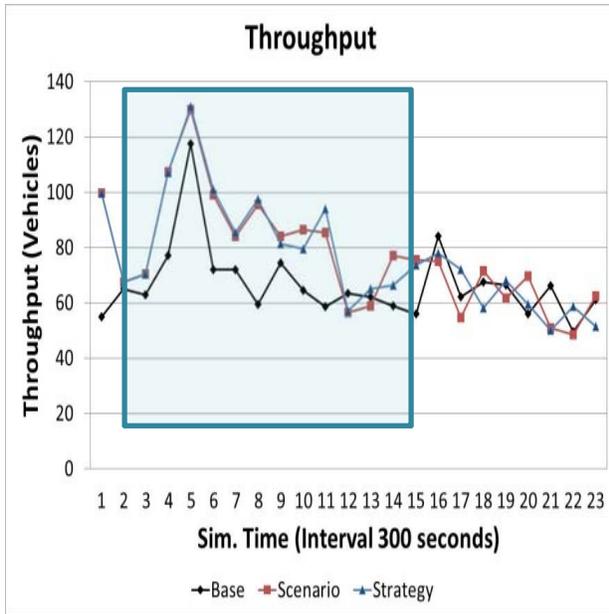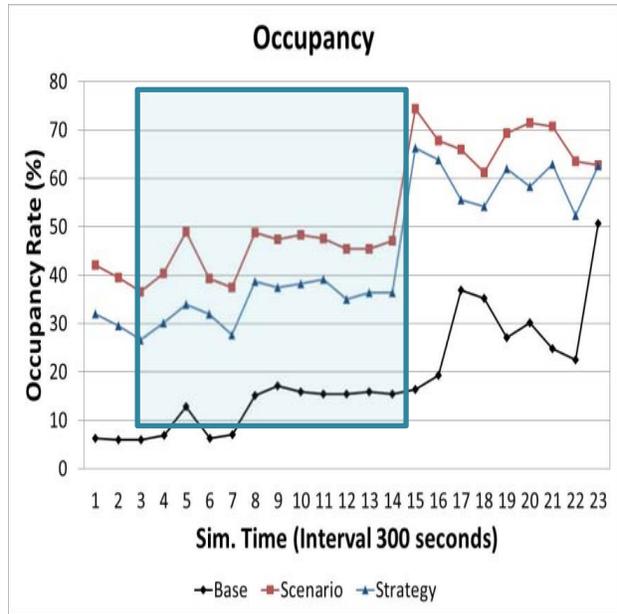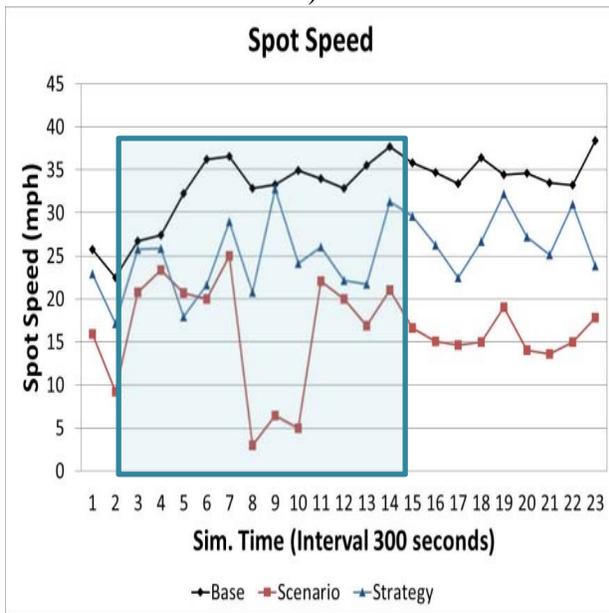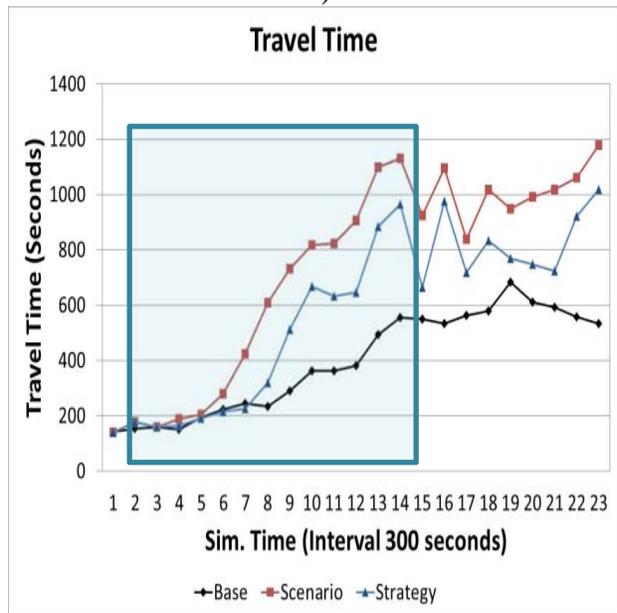
Figure 68- Event Traffic Scenario Signature Based on the Field Detectors

The captured scenario signature shows that there is a sudden drop in the spot speed during event. Also, travel time increases constantly. The occupancy also increases considerably but there is no strong signature in the throughput value. The traffic parameters thresholds are summarized in Table 37.

Table 37- Event Traffic Thresholds

Parameters	Thresholds	Detector
True Demand (vehicles per 5 minutes)	Higher than 30	Multiple intersections adjacent to the point of interests
Throughput (vehicles per 5 minutes)	Increases more than 50%	M-21
Occupancy rate (%)	Higher than 50%	M-21
Spot speed (mph)	Decreases more than 50%	M-21
Travel time (seconds)	Increases more than 100%	B-27 to B-29

In essence, traffic operators need to monitor consecutive sections in the traffic network. If all of the traffic parameters get worse near the attraction location after 5:00 PM then it is likely event traffic. It is also recommended to provide the traffic operators with event schedule beforehand. The applied traffic signal retiming strategy reduces travel time and occupancy by approximately 8%. Respectively, spot increases by approximately 10% when the strategy is applied. The event traffic scenario analyzed conditions for the traffic arriving to the event. The after-event scenario may be covered in the Phase 2 of the project.

Table 38- Mobility Impact of Traffic Strategy in Event Traffic Scenario

Performance Measures	Base	Scenario	Strategy-applied	Percent Changed (%)
Throughput (vehicles per 5 minutes)	91.6	116.3	117.1	0.7%
Occupancy (%)	13.5	23.5	21.6	-8.1%
Speed (mph)	31.0	22.3	24.5	9.9%
Travel Time (seconds)	29.8	51.6	47.5	-7.9%

The visualization of the freeway incident scenario using the simulation detectors is provided in Appendix E at the end of this report.

5. Conclusions

Traffic congestion is an inevitable part of the transportation network. With a constant increase in number of drivers, the roadway infrastructure is not able to keep its pace. Recurring and nonrecurring traffic congestions cause oversaturation in the transportation network. One of the major requirements to deal with oversaturation and congested traffic network is the ability to predict and measure the traffic demand in the transportation network. However, traffic demand cannot be measured directly from the field sensors. Therefore, there is a need to develop a methodology to measure traffic demand from the field sensors. The objective of this research was to develop a method that can be implemented by signal maintaining agency in Florida for measuring and reporting demand measures in both real-time and predicted modes. The thresholds are used to identify network traffic condition. A key deliverable of this research is a guideline, which helps traffic operators to manage and control different traffic scenarios effectively. In order to reach this objective, several tasks were defined and implemented. The following section summarizes research project tasks addressed in this project.

5.1. Summary of Project Tasks

This section provides a brief description of the project tasks addressed in this research study. Nine tasks were considered for this research project:

1. Build, calibrate, and validate a microsimulation model
2. Identify types and formats of traffic data from the field sensors
3. Identify performance measures for traffic demand
4. Develop methods to derive traffic demand from available field data
5. Identify traffic demand thresholds to activate strategies
6. Develop strategies to improve traffic condition
7. Identify and model a variety of traffic demand scenarios
8. Evaluate the impact of the selected strategies on the road network.
9. Develop and evaluate TMC operating guidelines.

5.1.1 Build, Calibrate, and Validate a Microsimulation Model

The analysis platforms of this research are two high fidelity microsimulation models built in VISSIM software. The microsimulation models are as follows:

1. Network Model: this model encompasses six major corridors in the study area. The scope of the model covers the CBD of the city of Fort Lauderdale, which is located between SR -7 and US-1, from east to west, and between Davie Blvd. and Oakland Blvd., from south to north. The area also includes the Fort Lauderdale downtown area of Broward Blvd. and Sunrise Blvd. Six major corridors are present in the scope of the project as follows:

1. Oakland Park Blvd.
2. Sunrise Blvd.
3. Broward Blvd.
4. Davie Blvd.
5. SR-7

6. US-1

The FAU research team used VISSIM microsimulation software to model the study area because VISSIM offers a variety of options and programming flexibility that will ensure successful modeling outputs. A considerable amount of available resources of the FAU research team (staff time, data collection trips, meetings, etc.) was devoted to building a microsimulation model that closely resembles field conditions of the study area. The model includes nearly 200 signalized intersections and thousands of traffic links. The model simulates traffic from 4:00 PM to 6:00 PM with a warm up period of 45 minutes.

2. Broward Blvd. Model: This model includes the primary corridors of the study area. Broward Blvd. represents the heart of Fort Lauderdale and is the center to many businesses, entertainment, and attraction areas, which was developed for the PM peak (4:00-6:00 PM). The Broward Blvd. model was extracted and filled with the traffic data of an entire day (6:00AM-Midnight) with 45 minutes of warm up period. The imported data for building the models include:

1. Traffic counts obtained from FDOT, Broward County and an online interactive map available at official FDOT website (FDOT Traffic Online, 2013).
2. Signal timings and signal patterns for weekdays obtained from BCTED
3. School zone areas
4. Time schedule for public transportation such as the Tri-Rail and FEC rail

When the models were completely developed, the FAU research team put a significant amount of effort into calibrating and validating the simulation model. The models were calibrated using the field traffic counts and validated against probe data. The calibration and validation tasks were implemented iteratively to make sure that the models represent the real work traffic condition with acceptable accuracy. At the end of this task, the FAU team developed two models that were fully calibrated and validated against the field data.

Table 39 depicts the final calibration results when the validation task was completed for the network model. Note that the R-squared value for both calibration and validation tasks were between 0.80 and 0.96, which is acceptable. The calibration and validation of a network level microsimulation model is a challenging task because major arterials and freeways interact dynamically. The FAU research team devoted a significant amount of time to fulfill these tasks. The final results presented in Table 39 and Table 40 shows an acceptable point where both calibration and validation results are in an acceptable range. Appendix A encompasses detail calibration and validation chart of the network model.

Table 39- Network Model Calibration Results for Different Corridors

	Oakland	Sunrise	Broward	Davie	SR7	US1
R^2	0.90	0.92	0.91	0.96	0.92	0.94

Table 40- Network Model Validation Results for Different Corridors

R^2	Oakland	Sunrise	Broward	Davie	SR7	US1
EB	0.86	0.82	0.89	0.85	0.83	0.90
WB	0.80	0.84	0.83	0.92	0.89	0.84

The Broward Blvd. model was calibrated based on the turning movement and traffic counts data. The simulation data were compared against the field detectors. A total of five traffic detectors are present on Broward Blvd., which have been used for model calibration purposes. The name and location of the traffic detectors are represented below:

1. M-17 (NW 38th Ave.)
2. M-18 (NW 27th Ave.)
3. M-19 (NW-31st Ave.)
4. M-20 (NW-9th Ave.)
5. M-21 (NW 7th Ave.)

Hourly traffic volume was obtained from 6:00 AM to 23:00 PM from the simulation model and was compared to the field traffic counts. Table 41 shows an entire day of calibration results for different traffic detectors.

Table 41- Broward Blvd. Detail Calibration Result for Different Intersections

	M-17 (NW 38th Ave.)	M-18 (NW 27th Ave.)	M-19 (NW-31st Ave.)	M-20 (NW 9th Ave.)	M-21 (NW 7th Ave.)	Overall
R^2	0.34	0.84	0.74	0.89	0.96	0.76

The R-squared value is slightly lower compared to the network model. This discrepancy can be explained considering that the Broward Blvd. microsimulation model was developed for an entire day (18 hours) compared to the network model (two hours). Appendix B includes calibration and validation charts of the Broward Blvd. model.

5.1.2. Identify Types and Formats of Traffic Data from the Field Sensors

The TSM&O program enhances the existing ITS infrastructure in Broward County. The program will install and use the existing ITS infrastructure, which includes data collection and communication devices to facilitate traffic monitoring and management in the central Broward County major arterials. In this task, the FAU research team investigated available data sources in the study area. The team also used literature to select appropriate performance measures. The following ATMS data sources were identified as useful in the area:

1. Bluetooth BlueTOAD (Traffic Cast): the BlueTOAD devices detect anonymous Bluetooth signal from mobile devices (cell phones, tablets, laptops, etc.) inside vehicles. The devices can collect travel time, speed, and OD data from the field.

2. Microwave Detector Stations (Wavetronix): two types of Wavetronix sensors of Smart Sensor V and Smart Sensor HD have been installed in the Broward County. Smart Sensor V can accurately monitor up to eight lanes of traffic and can collect volume, speed,

occupancy, and vehicle classification from the field. Smart Sensor HD can monitor up to 22 lanes of traffic. They can record volume, average speed, occupancy, 85th percentile, average headway, average gap, speed bin counts, direction counts, and classification counts.

3. Video Detection Systems (ITERIS and Traficon): the video detection systems (VDS) are used to detect vehicles and actuate traffic signals operations. Broward County uses VDS from two vendors of ITERIS and TRAFICON. TRAFICON video cameras are more frequent in the area. The systems can collect turning movement counts and speed data but their accuracy depends on their location. Vehicle counts, speed, occupancy, density, headway, gap time, vehicle classification can be retrieved from VDS.

4. Automated Vehicle Identification (SIRIT): the systems are usually used in in toll or high occupancy lanes to read license plates numbers. The AVI systems can be utilized to determine travel habits, frequency of travel, origin and destination points, and travel time data. The detectors can also provide information for congestion or variable rate tolling based on travel time or land load.

5. INRIX: a traffic information system that is being used on national level and covers nearly 260,000 miles of roads in real-time. The website covers major arterials and city streets in 52 cities with population over one million people. The information system provides real-time, historical and predictive travel time and speed in a user-friendly interactive user interface. Also, link free-flow speed, congestion alerts, incident data, and traffic maps can be acquired from the website.

6. SunGuide (Florida Intelligent Transportation System): an ATMS software that helps FDOT to control and monitor roadside equipment and vehicle resources. The software facilitates traffic and incident management in the state of Florida. It also disseminates traveler information to the monitoring public. The software communicates with Road Rangers and supports I-95 express lane pricing. SunGuide controls multiple traffic control and management devices such as dynamic message signs, variable speed limit signs, toll message signs, and ramp signals.

7. ATMS.now (Trafficware): is a central management system used by the Broward County TMC to control and manage traffic Nazdec traffic controllers remotely and enable traffic operators to change the signal timing in real-time. The systems also enable operators to provide CCTV surveillance footage. Also, CMS are controlled using the software. Broward County has about 1,300 signal controllers, which almost half of them have been transferred to the new ATMS.now system. Table 42 summarizes available data sources and performance measures that can be retrieved from the traffic databases respectively.

Table 42- Summary of Data Sources and Available Traffic Data

Output Data Source	O – D data	Speed	Travel Time	Volume	Occupancy	Headway	Traffic Counts	Gap	Density	VMT
BlueTOAD	x	x	x							
VDS		x			x	x	x		x	
MVDS		x		x	x	x	x	x		
AVI		x	x							
INRIX		x	x							
SunGuide		x	x	x	x	x	x	x	x	x
ATMS.now					x					

5.1.3. Identify Performance Measures for Demand

Using the insight from the previous research studies in identifying performance measured for demand modeling, the following performance measures were selected for demand modeling:

1. Volume (vehicles per 5 minutes): total number of vehicles travelling a particular link
2. Occupancy (%): percent time when a sensor is in the detection mode.
3. Spot speed (mph): average speed of vehicles at certain location.
4. Travel Time (minutes): elapsed time to traverse a link or road segment.
5. Travel Speed (mph): average speed of vehicles travelling a particular link.
6. Lane Group Demand: total number of vehicles, which desire to select a particular lane group of an intersection.

Also, geometrical factors that can also impact traffic demand were also considered in demand modeling. The factors are listed as follows:

1. Link length (ft.): the length of a link in feet.
2. Left turn pocket y/n: a Boolean variable, which indicates whether a left-turn pocket exists on the road segment or not.
3. Left-turn pocket length (ft.): the length of the left-turn pocket in feet.

5.1.4. Develop Methods to Derive Traffic Demand from Available Field Data

In this task, the FAU research team developed a methodology to estimate virtual traffic demand (through a set of meaningful relationships between available data in the field and real traffic demand in the VISSIM microsimulation model). The relationship between traffic demand and field like performance measures is determined using the microsimulation output data in the form

of statistical models. The generated statistical models will be used to estimate traffic demand in the field as well.

To this end, the FAU research team developed a set of simulation tools to determine link-based true traffic demand at each signalized approach. The link-based true traffic demand is measured in the microsimulation model at the upstream entrance of the link, representing true traffic demand consisting of vehicles that require a green light at the downstream intersection. Most specifically this demand includes: Delay-Queue vs. Time diagrams, which depict arrival and departure curves at each signalized approach; Time-Distance diagrams with individual vehicular trajectories; and MOE reporting dashboard, which shows real-time changes in simulated MOEs. The tools determine traffic demand and provide database that can be measured in the field.

The general form of the model is showed in the following Equation:

$$Demand \; (vehicles \; per \; 5 \; minutes) = a_1X_1 + a_2X_2 + \cdots . + a_iX_i \quad (1)$$

Where,

X_i : ith MOE;
a_i : ith MOE coefficient;
$i = 1$ to n;
n= number of performance measures in demand modeling

The simulation model output, which is in text file format, is handled through a C#-based data handling module. The output includes multiple MOEs. On the other hand, another tool captures the true demand values of each link from the simulation model.

Several statistical analyses were conducted with different time intervals to check if performance measures' time interval is significant contributor to demand estimation modeling. In these experiments, the demand was modeled utilizing all of the selected performance measures with variable time intervals. The analysis revealed that the performance measures' time interval is not a significant contributor to the model prediction power. Therefore, a default time interval of five minutes (300 seconds) was selected for the remaining analyses.

The demand models were developed using regression analysis module in MS Excel. Statistical models were developed for different data sets and the model's goodness of fit was evaluated by R-squared values. Please refer to Appendix D for full demand modeling parameters.

Table 43- Demand Modeling Results

Movement	Detection Scenarios	Simulation Detectors		Field Detectors	
		Aggregated Modeling (using equivalent demand)	Average Modeling (using demand)	Aggregated Modeling (using equivalent demand)	Average Modeling (using demand)
Through Demand	All Detection System Available	0.64	0.73	0.72	0.80
	Mid-block Detectors Only	0.63	0.72	0.68	0.75
	Bluetooth Only (linear modeling)	0.48	0.61	0.67	0.78

The demand modeling results is presented in Table 43. The results show that statistical models developed based on the field detector data provide a better prediction power. Also, it is better to use all detection systems to develop statistical models instead of using either mid-block detectors or Bluetooth detectors. Throughput, occupancy rate, and speed data are acquired from mid-block detectors and travel time data is retrieved from Bluetooth devices.

5.1.5. Defining Scenarios, Identifying Demand Thresholds, and Develop and Evaluate Strategies

There is a high correlation between identifying traffic demand thresholds to activate strategies, developing strategies to improve traffic condition, identifying and modeling a variety of traffic demand scenarios, and evaluating the impact of the selected strategies on the road network. Therefore, the findings of these tasks are summarized in a single section. Figure 32 shows the correlation between project key tasks.
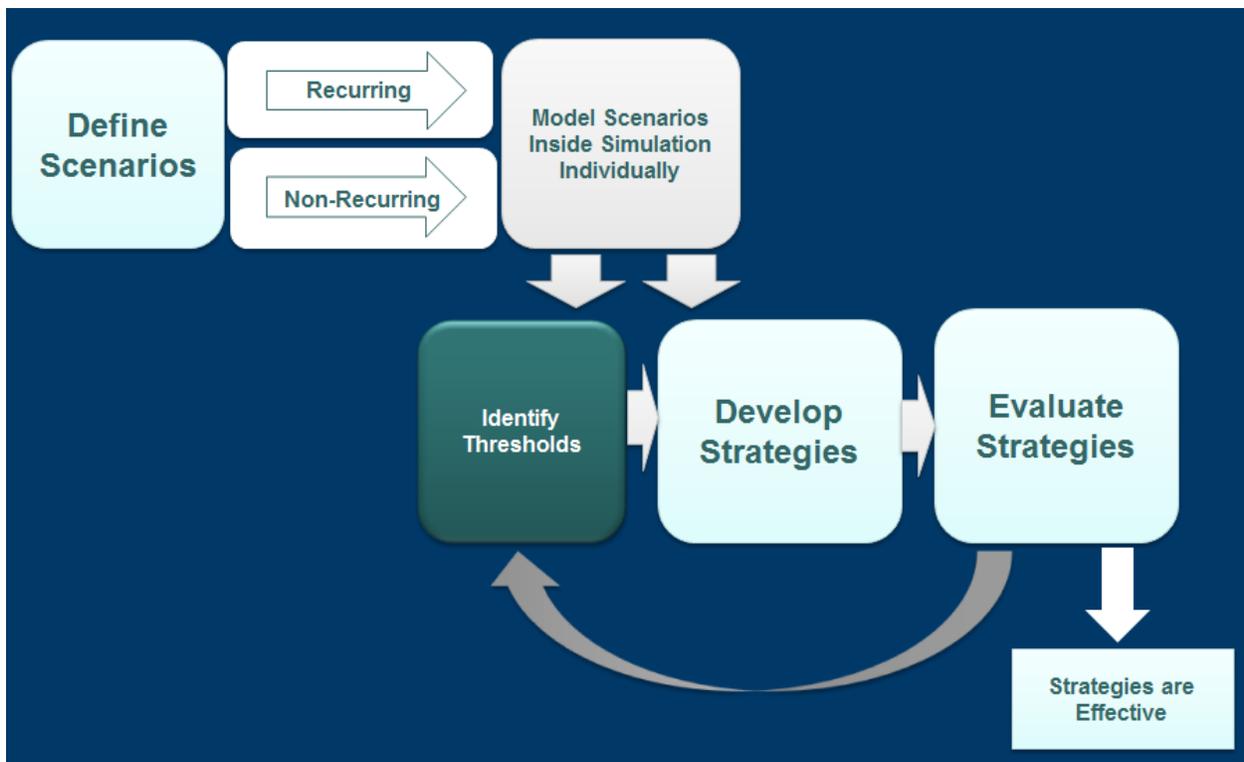
Figure 69- Correlation between Project Key Tasks

In the first step, multiple traffic scenarios were identified as recurring and nonrecurring scenarios. The recurring scenario are identified as normal, saturated, and oversaturated scenarios while the nonrecurring scenarios are defined as freeway incidents, left-turn spillover, rail preemption, arterial incidents, and event traffic. When the scenario identification task is finished, each scenario was modeled inside appropriate microsimulation model. All scenarios, except for freeway incident scenario, were modeled in the Broward Blvd. model. The freeway incident scenario was modeled inside the network VISSIM model. For each defined traffic scenario, traffic conditions are captured by monitoring selected performance measures of throughput, occupancy rate, spot speed, and travel time. Each scenario was controlled by either SIL or OIL simulation. Table 44 summarizes characteristics of defined scenarios in this research study.

Table 45 shows more detail about modeling scenarios in the simulation models. Table 46 depicts a summary of performance measures' thresholds and Table 47 shows mobility impact of traffic strategies for each scenario. The following tables provide a summary of scenario analyses in a tabular format.

Table 44- Scenario Characteristics Summary

#		Name	Description	Sim. Run #	Simulation Duration	Network	OIL/SIL*	Management Objectives	Strategy
1	Recurring	Normal	This is a normal condition, which all the links are operating in the undersaturated mode.	1	6 AM to12 AM /off-peak	Broward	SIL	Max Progression	
2		Saturated	Queue forms and dissipates in some of the intersections sporadically.	2	6 AM to12 AM / peak	Broward	SIL	Max Throughput	Optimized Signal Retiming
3		Oversaturated	Queue spillbacks to the upstream intersection in one or more links.	2	6 AM to12 AM / peak	Broward	OIL	Queue Management	Optimized Signal Retiming
4	Nonrecurring	Freeway Incidents	Incidents, which occur on freeways and impact the arterial corridors.	3	4 PM to 6 PM / peak	Network	OIL	Incident Clearing/Queue Management	DMS
5		Left-Turn Spill-Over	Queue on left-turn pocket blocks the through movement and causes congestion.	4	6 AM to 12 AM / Peak	Broward	OIL	Queue Clearance for Left Turn	Signal Retiming
6		Rail Preemption	Long trains may become problematic and create queues.	5	6 AM to 12 AM / Off Peak	Broward	OIL	Queue Clearance	Signal Retiming
7		Arterial Incidents	Incidents, which occur on the arterial corridors.	6	6 AM to 12 AM/Off Peak	Broward	OIL	Incident Clearing/Queue Management	Signal Retiming
8		Event Traffic	Special events such as art performances, festivals, and athletic games.	7	6 AM-12 PM / peak	Broward	OIL	Queue Management	Signal Retiming

* OIL=Operator in the Loop, SIL= Simulation in the Loop

Table 45- Modeling Scenarios in Simulation

Scenarios	Duration	Time	Simulation Time	Location	Implementation
Base	-	-	-	-	Calibrated and validated with the field-collected traffic count data
Saturation and Over-Saturation	-	8:00-9:00 AM	8,100-11,700	Entire network	Volume increases by 120%
Freeway Incident	60 min.	4:30-5:30 PM	4,500-8,100	Broward I-95 NB off ramp	Blocked 2 most right lanes with parking spaces
Left-turn Spillover	30 min.	8:00-8:30 AM	8,100-9,900	Broward Ave & NW 24th Ave WB	Re-routed the traffic (300-600 vehicles/hour) from I-95 to fill left pocket on NW 24th Ave
	60 min.	8:00-9:00 AM	8,100-11,700		
Rail Preemption	300 sec.	7:58-8:03 AM	8,000-8,300	Broward Ave. between SW 2nd Ave and SW 1st Ave	Added more cars to the train for making it longer
	700 sec.	7:58-8:09 PM	8,000-8,700		
Arterial Incident	30 min.	8:00 – 8:30 AM	8,100-9,900	Broward Ave. & Powerline Rd.	Blocked single lane using a parking space
	60 min.	8:00 – 9:00 AM	8,100-11,700		
Event Traffic	60 min.	6:00-7:00 PM	44,100-47,700	Broward Ave & NW 5th St	Added more traffic from I-95 NB, I-95 SB, Broward WB, and NE 3rd Ave WB

Table 46- Performance Measures' Threshold of Scenarios

Scenario	MOE*	Thresholds	Detector
Saturated	True Demand	Higher than 100 with a few (2-3) intersections	NA
	Throughput	Increases more than 30%	M-20
	Occupancy	Slightly increases by 10%	M-20
	Spot Speed	Slightly decreased by 10%	M-20
	Travel Time	Slightly increase by 10%	B-27 to 29
Oversaturated	True Demand	Higher than 100 in multiple intersections	NA
	Throughput	Decreases more than 30%	M-20
	Occupancy	Increases more than 100%	M-20
	Spot Speed	Decreases more than 50%	M-20
	Travel Time	Increases more than 100%	B-27 to 29
Freeway Incident	True Demand	NA	NA
	Throughput	Decreased more than 30%	M-20
	Occupancy	Higher than 30%	M-20
	Spot Speed	Decreases more than 30%	M-20
	Travel Time	Increases more than 30%	B-27 to 29
Left Turn Spillover	True Demand	Higher than 30	NA
	Throughput	Increases more than 20%	M-19
	Occupancy	Higher than 20%	M-19
	Spot Speed	Decreases less than 20%	M-19
	Travel Time	No significant changes	B-25 to 26
Rail Preemption	True Demand	Higher than 100	NA
	Throughput	Lower than 10 vehicles	M-21
	Occupancy	Higher than 90%	M-21
	Spot Speed	Lower than 5 mph	M-21
	Travel Time	Increases than 500% after the rail duration	B-27 to 29
Arterial Incidents	True Demand	Higher than 100	NA
	Throughput	Decreases more than 50%	M-20
	Occupancy	Higher than 50%	M-20
	Spot Speed	Decreases more than 50%	M-20
	Travel Time	Increases more than 200%	B-27 to 29
Event Traffic	True Demand	Higher than 30	NA
	Throughput	Increases more than 50%	M-21
	Occupancy	Higher than 50%	M-21
	Spot Speed	Decreases more than 50%	M-21
	Travel Time	Increases more than 100%	B-27 to 29

*MOE's units are:
   Throughput (vehicles per 5 minutes)
   Occupancy (%)
   Spot Speed (mph)
   Travel Time (seconds)

Table 47- Mobility Impact of Traffic Strategies on Scenarios

Scenario	Duration	MOE*	Base	Before Strategy	After Strategy	Percent Changed
Saturation	60 Minutes	Throughput	50.6	56.4	58.6	3.9%
		Occupancy	16.8	26.3	24.5	-6.8%
		Spot Speed	35.2	26.5	29.6	11.7%
		Travel Time	34.6	54.2	45.6	-15.9%
Oversaturation	60 Minutes	Throughput	50.6	41.6	48.2	15.9%
		Occupancy	16.8	49.5	39.5	-20.2%
		Spot Speed	35.2	19.5	24.5	25.6%
		Travel Time	34.6	120.6	79.5	-34.1%
Freeway Incident	60 Minutes	Throughput	116.5	103.3	113.1	9.5%
		Occupancy	24.8	35.2	32.5	-7.6%
		Spot Speed	28.7	21.7	23.8	9.7%
		Travel Time	41.4	120.3	68.6	-42.9%
Left Turn Spillover	30 Minutes	Throughput	113.5	103.5	105.0	1.4%
		Occupancy	12.5	13.2	12.9	-2.3%
		Spot Speed	31.5	30.7	31.0	1.0%
		Travel Time	34.0	35.3	34.9	-1.1%
	60 Minutes	Throughput	113.5	108.1	109.6	1.4%
		Occupancy	12.5	13.5	13.3	-1.5%
		Spot Speed	31.5	30.6	30.9	0.8%
		Travel Time	34.0	36.9	36.2	-1.9%
Rail Preemption	300 seconds	Throughput	54.6	52.3	53.9	3.1%
		Occupancy	22.3	25.9	25.0	-3.4%
		Spot Speed	29.6	26.8	27.6	3.0%
		Travel Time	39.5	47.6	44.6	-6.3%
	700 seconds	Throughput	54.6	49.8	52.3	5.0%
		Occupancy	22.3	35.6	32.6	-8.4%
		Spot Speed	29.6	22.9	25.1	9.6%
		Travel Time	39.5	67.8	61.6	-9.1%

*MOE's units are:

Throughput (vehicles per 5 minutes)
Occupancy (%)
Spot Speed (mph)
Travel Time (seconds)

Table 47- Mobility Impact of Traffic Strategies on Scenarios (Continued.)

Scenario	Sub	MOE*	Base	Before Strategy	After Strategy	Percent Changed
Arterial Incident	30 Minutes	Throughput	149.5	141.6	142.5	0.6%
		Occupancy	18.9	24.5	22.1	-9.8%
		Spot Speed	31.2	26.5	27.5	3.8%
		Travel Time	36.5	53.6	50.6	-5.6%
	60 Minutes	Throughput	149.5	132.5	135.6	2.3%
		Occupancy	18.9	31.8	28.3	-11.0%
		Spot Speed	31.2	23.9	24.5	2.5%
		Travel Time	36.5	96.8	89.9	-7.1%
Event Traffic	60 Minutes	Throughput	91.6	116.3	117.1	0.7%
		Occupancy	13.5	23.5	21.6	-8.1%
		Spot Speed	31.0	22.3	24.5	9.9%
		Travel Time	29.8	51.6	47.5	-7.9%

* MOE's units are:

> Throughput (vehicles per 5 minutes)
> Occupancy (%)
> Spot Speed (mph)
> Travel Time (seconds)
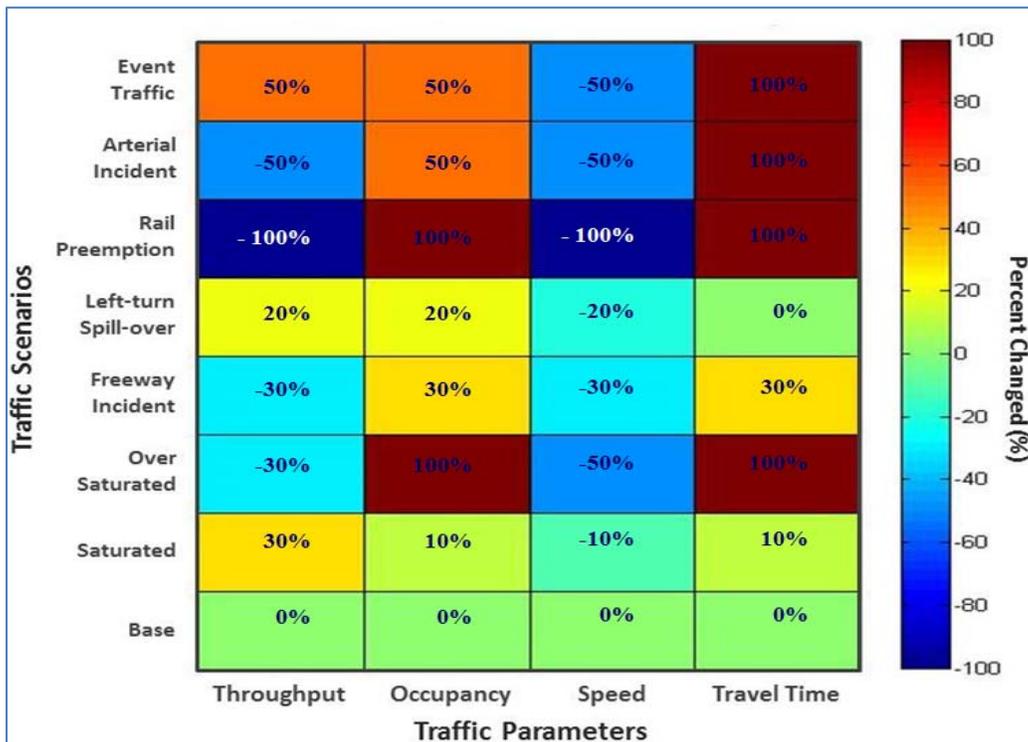
Figure 70- Percent Changes in Scenario Thresholds Compared to Base Scenario

Figure 70 visualizes relative traffic parameters thresholds compared to the base scenario. The rail preemption scenario has a clear signature as it was expected. All of the traffic parameters under this scenario vary by almost 100%. Oversaturated, event traffic, arterial incident also have a

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relatively strong and clear signature as the traffic parameters under such scenarios vary from 50% to 100%. Freeway incident and saturated scenario have moderate signature as their traffic parameter thresholds vary from 10% to 30%. However, identifying left-turn spillover scenario is not easy, as the scenario does not have a clear and strong signature. The traffic parameters under this scenario vary only from 0% to 20%. Figure 71 shows the absolute values of the traffic parameters in different scenarios.
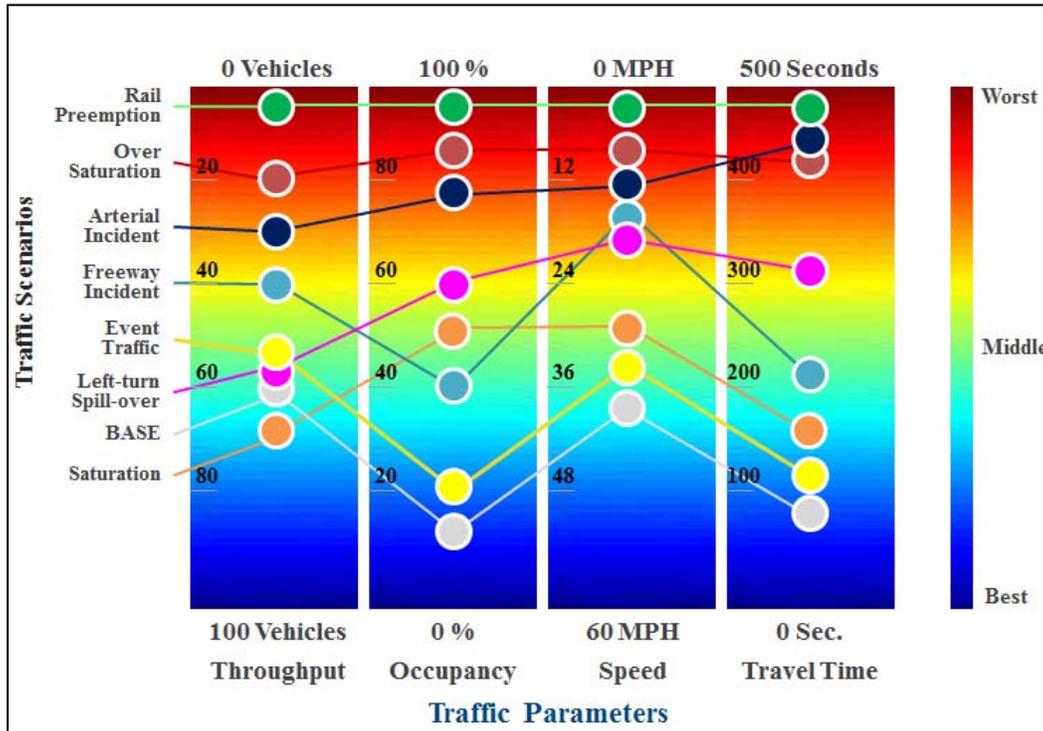
Figure 71- Traffic Scenarios Rank Based on Traffic Parameters
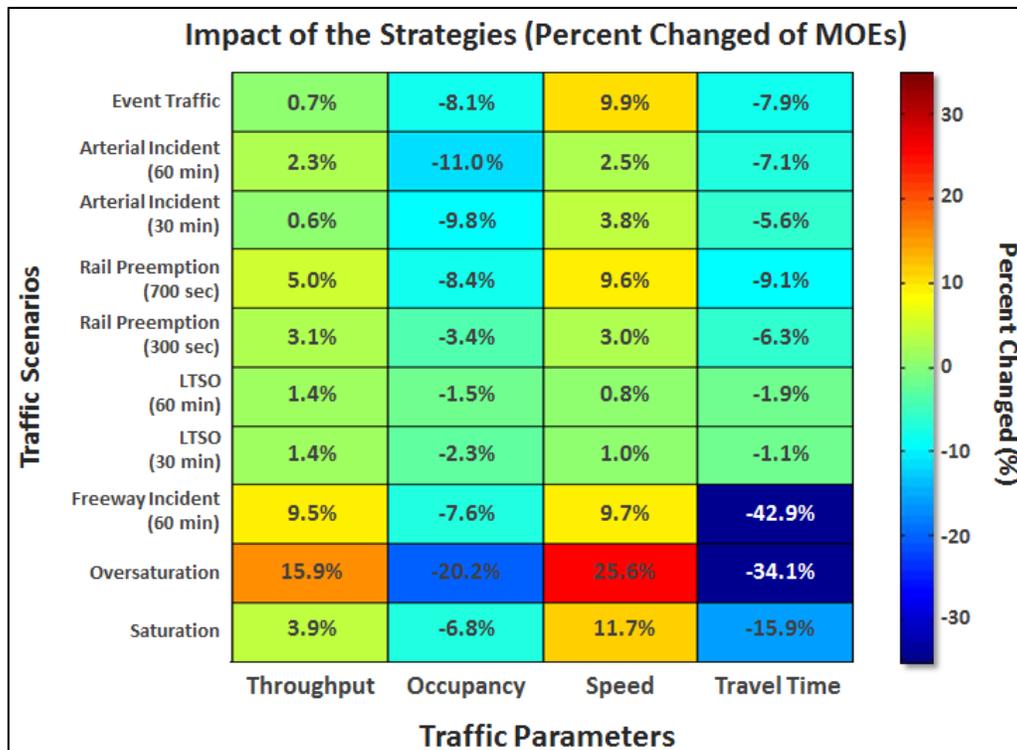
Figure 72- Impact of the Strategies on Different Traffic Scenarios

Figure 72 shows the relative impact of the selected strategies on each scenario. The implemented strategies alleviate the congestion in freeway incident, oversaturation, and saturation scenarios. Rerouting traffic utilizing DMS improves the traffic under freeway incident scenario considerably. The travel time reduces by 43% and throughput improves by nearly 10%. The optimized timing plan generated by the VISGAOST improves the mobility of the transportation network significantly. The optimized signal retiming plan reduces oversaturation and saturation scenario's travel time by approximately 34% and 16%.

The strategies implemented in the other scenarios are also effective. The average travel time improves by nearly 8% in the event traffic scenario. In arterial incident scenario, the occupancy reduces by nearly 10% on average after strategy implementation. Travel time improves by 6.3% to 9.1% in the rail preemption scenario and the throughput improves by 3.1% to 5.0%. The implemented strategy under left-turn spillover scenario has some positive impacts but they are not significant. This conclusion is justified by the fact that a left-turn spillover scenario creates less traffic congestion than the other tested scenarios.

A robust analysis platform was developed in this research project. Multiple data sources are identified to monitor traffic conditions. A methodology to estimate traffic demand from the field data was developed and evaluated. Several recurring and nonrecurring scenarios were defined and modeled inside appropriate microsimulation models and appropriate strategies were implemented to mitigate the congestion caused by each specific scenario. The recommended strategies are evaluated in the simulation model and after several iterations, an appropriate strategy is recommended for each traffic scenario. Also, traffic parameters thresholds are determined based on the multiple analysis conducted in this research. The scenario information,

strategies, and thresholds are combined in a single document as traffic operator's guideline. The guideline is intended to help traffic operators to manage and control the traffic condition effectively.

5.2. Future Research Implementation Plans

The outcome of this research opens door for multiple innovative research trends to apply ATMS features to better control and manage traffic congestion in Broward and Palm Beach Counties. There is a need to implement results of the Phase 1 of Demand Based Signal Retiming (DBSR) project in the field and extend the proposed methodology on the areas that do not have access to a lot of data from traffic detectors. The problem with Flagler Bridge reconstruction in West Palm Beach, where reconstruction activities (due to lane restrictions) will worsen traffic congestion, is an excellent environment to extend the methodology developed in Phase 1. Unlike central Broward County, which is expected to benefit from many traffic data sensors recently deployed within the Advanced Traffic Management System, Palm Beach County can only rely, like many other places around the country, on basic traffic detection inputs, which usually include feeds from local detectors at signalized intersections and relatively new traffic information services from web applications (Google, Bing, INRIX, etc.). This project represents an extension (Phase 2) of the DBSR project whose primary objective is to implement methodologies and procedures developed in Phase 1. The following research objectives and tasks will be pursued in the phase 2 of the project:

- Implement and refine the signal retiming and traffic demand prediction methods and procedures (developed in Phase 1 of the project) in the Traffic Management Center (TMC) environment for Broward County. This implementation includes assistance to the FDOT District 4 to assess feasibility and suitability of the proposed approach for inclusion in the first arterial operations contract.

- Extend the methodology developed under Phase 1, for traffic-data-rich environments such as Central Broward, to areas like West Palm Beach downtown where there is a common level of traffic sensors deployed in the field. This objective included assistance to FDOT, Palm Beach County traffic division (and other participants) on methods and strategies to monitor traffic in congested downtown West Palm Beach during the reconstruction of the new Flagler Memorial Bridge and the numerous special events that occur.

- There is a variety of traffic data sources that are available right now in West Palm Beach TMC. Those include traffic videos from traffic signal video detection systems, CCTV cameras, and others. Other available data include traffic information systems, which are either available to broader public (Google Traffic, Bing Traffic) or available to FDOT such as INRIX and TrafficCast. The FAU research team should investigate whether it should be feasible to use existing data sources to develop a set of traffic indicators (e.g. congestion or travel time contour maps), which could be used by PBC TMC operators to effectively monitor traffic conditions in the West Palm Beach network. This effort includes minor software development projects if the team finds that it is feasible to integrate traffic data from existing sources into a coherent platform that can efficiently

(without expensive investments) report traffic conditions to TMC operators. Also indicators/measures that would trigger an operator's attention would be investigated along with how the trends of these measures would be determined and the thresholds for a traffic event.

- The impact of the recurring and non-recurring congestion scenarios were analyzed for major streets only in the Phase 1 of the project. There is no sensor data installed in the side streets and it makes it difficult to conduct traffic impact analysis on the side streets. However, FAU research team will analyze side-street performance measures, as applicable, in Phase 2 of the project.

- The event traffic scenario considered only conditions for the traffic arriving to the event. The after-event conditions should also be considered in future research efforts. At that time an appropriate strategy should also be developed to alleviate the traffic congestion for the traffic that leaves an event.

- Future research should also address development of a benefit/cost analysis for the proposed strategies for each recurring and non-recurring congestion scenario. To estimate the benefit to cost ratio it is necessary to convert the mobility measures into the monetary values and to develop a comprehensive and accurate approach to estimate costs associated with each of the proposed strategies."

- The FAU research team will develop predictive methods to improve monitoring of traffic conditions and execution of traffic operation strategies to ease congestion during recurring and nonrecurring congestion in areas like West Palm Beach. While the methods will be based, to the extent possible, on a quantitative analysis it is expected that FAU team will primarily work on the development of estimation techniques based on literature review (of similar techniques developed elsewhere), historic data and inputs from Palm Beach County and FDOT staff. The purpose of this task is to qualitatively assess management of available data to improve traffic operations without large investments. For example, the FAU team will be investigating trends in traffic volumes, emergency calls, and crashes to identify potential locations/time periods where it is possible that these three data feeds have significant correlations. This will help FAU team to derive certain quantitative information from the past which can serve to qualitatively assess what may happen in the future. Strategies defined in previous tasks and new strategies will be identified to address any negative trends in performance.

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Appendix A: Network Microsimulation Model Calibration and Validation Visualization Results
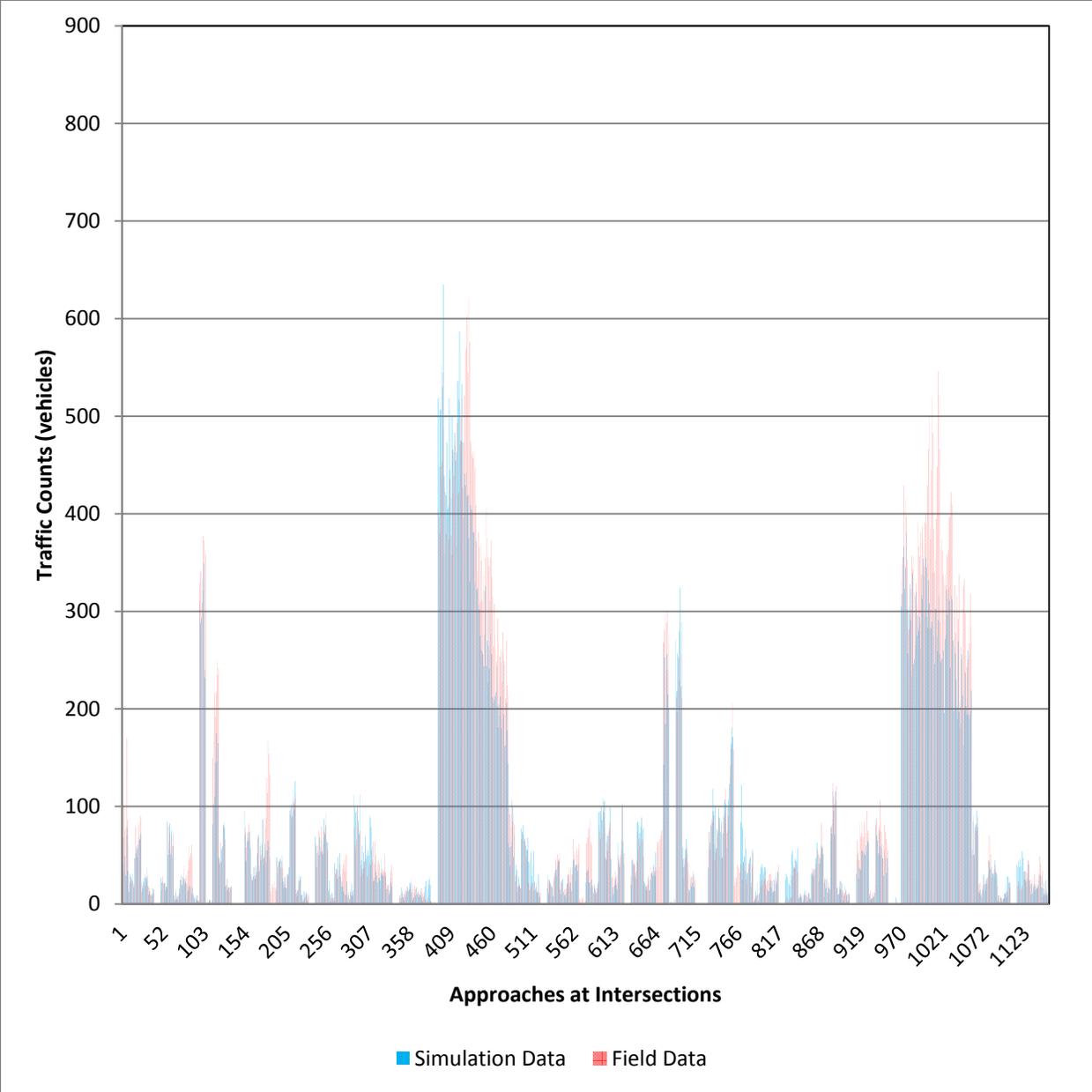
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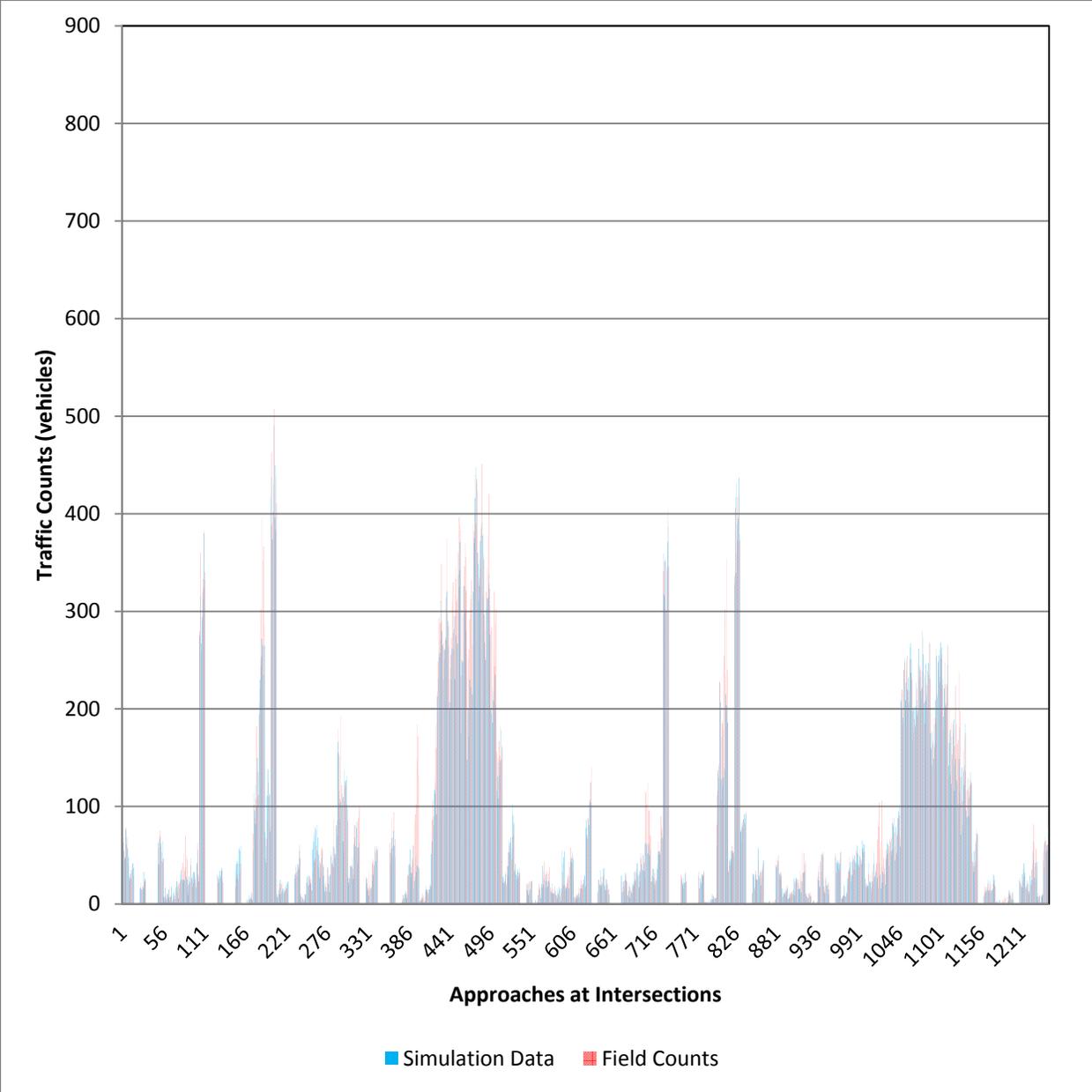
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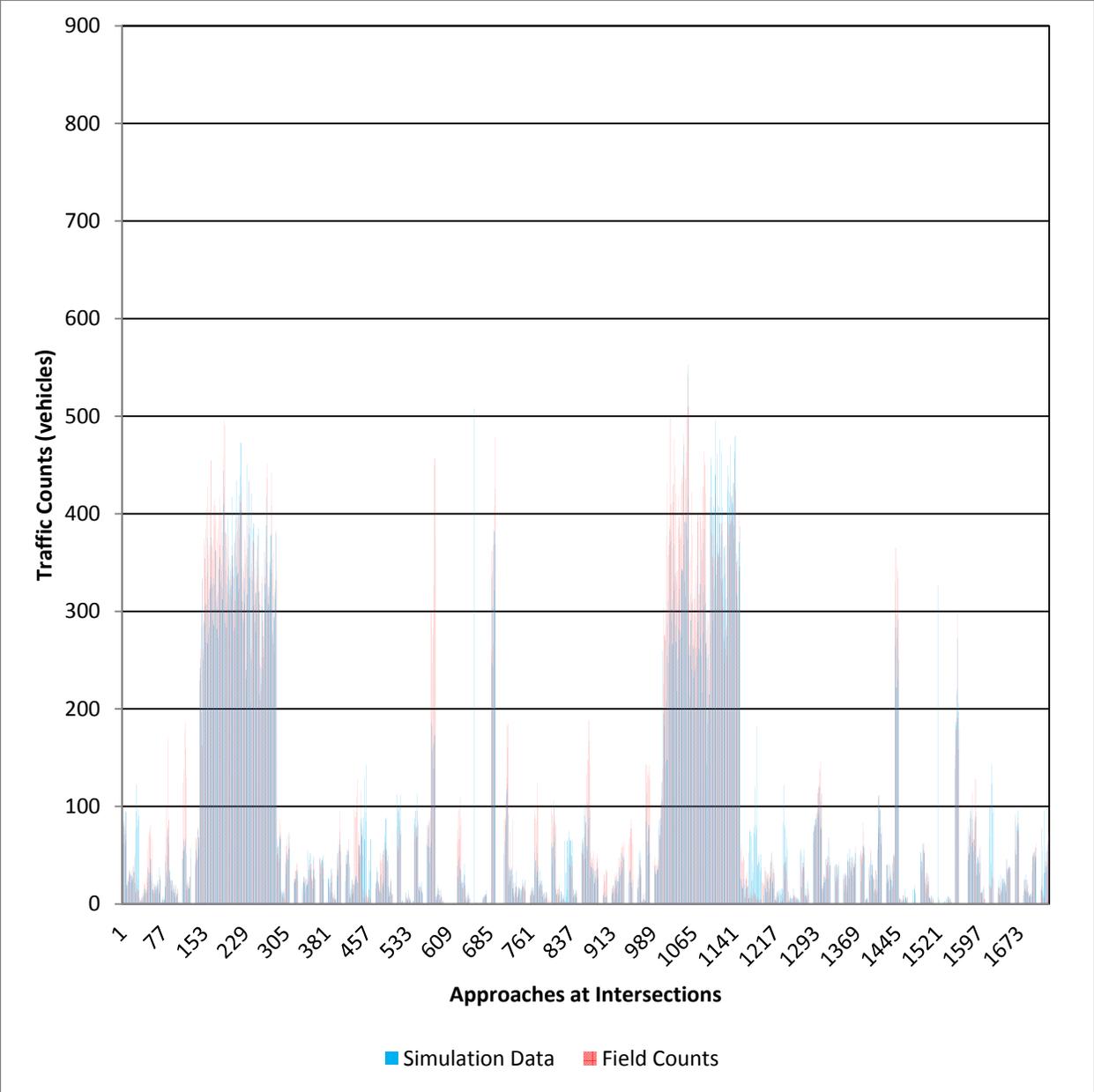
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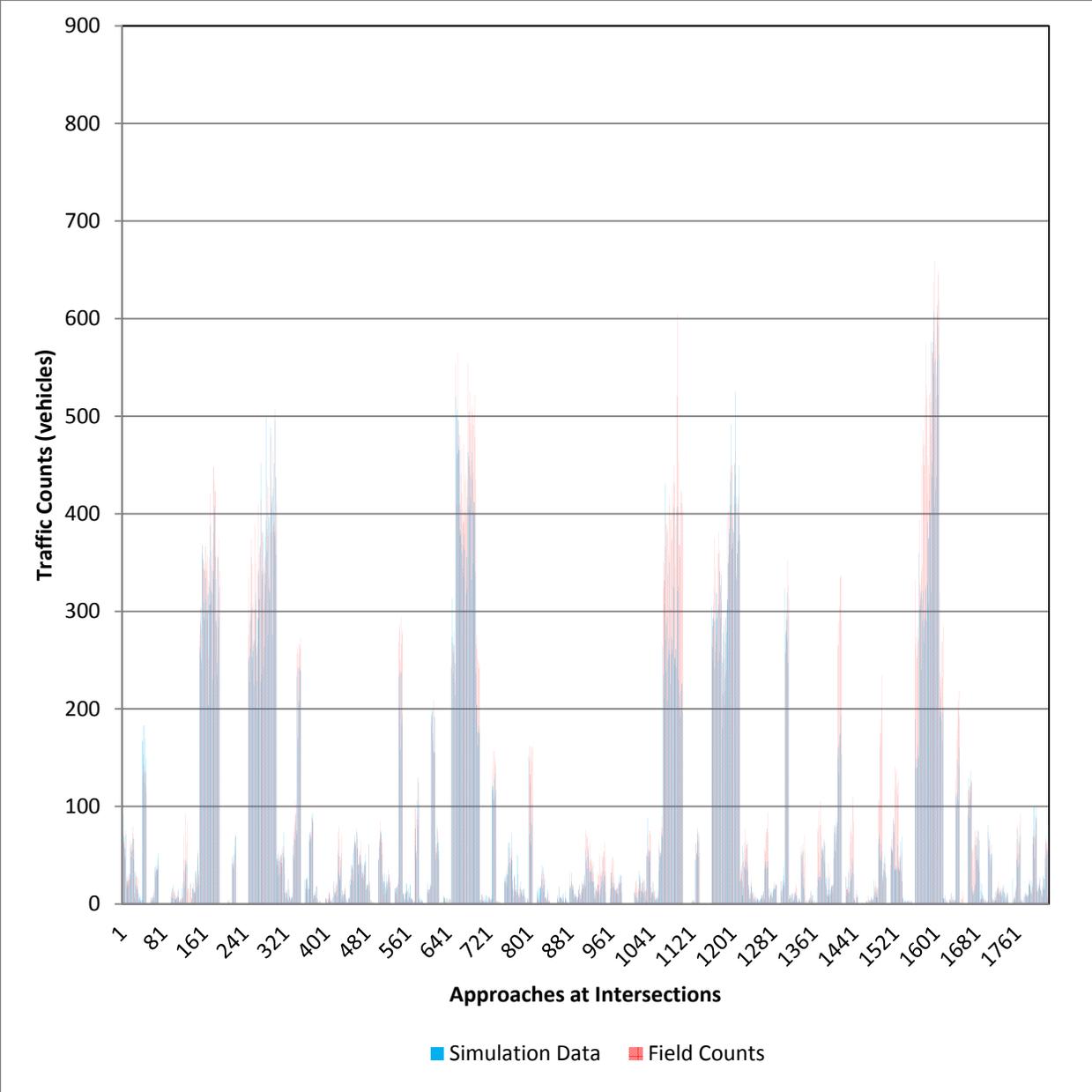
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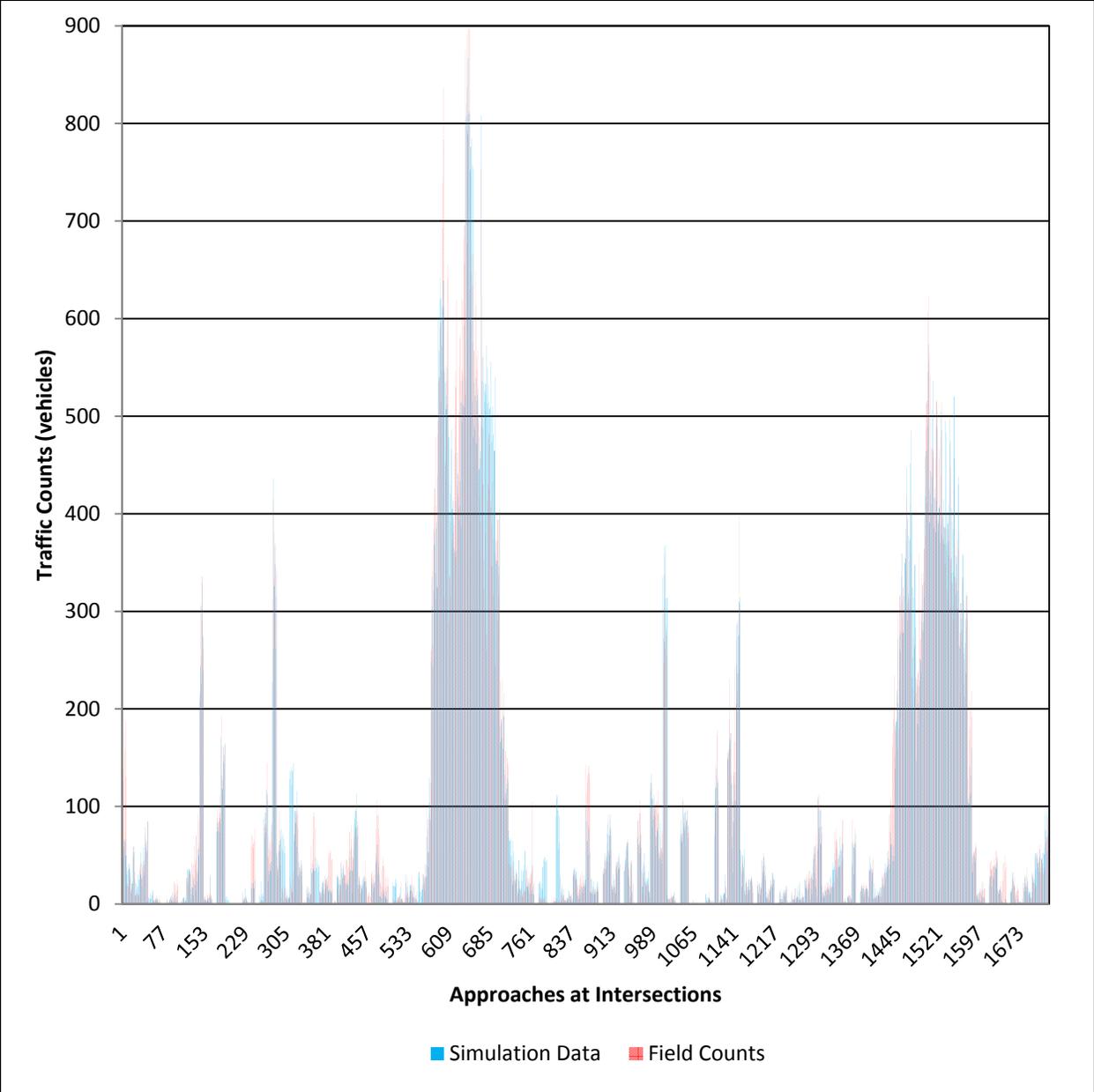
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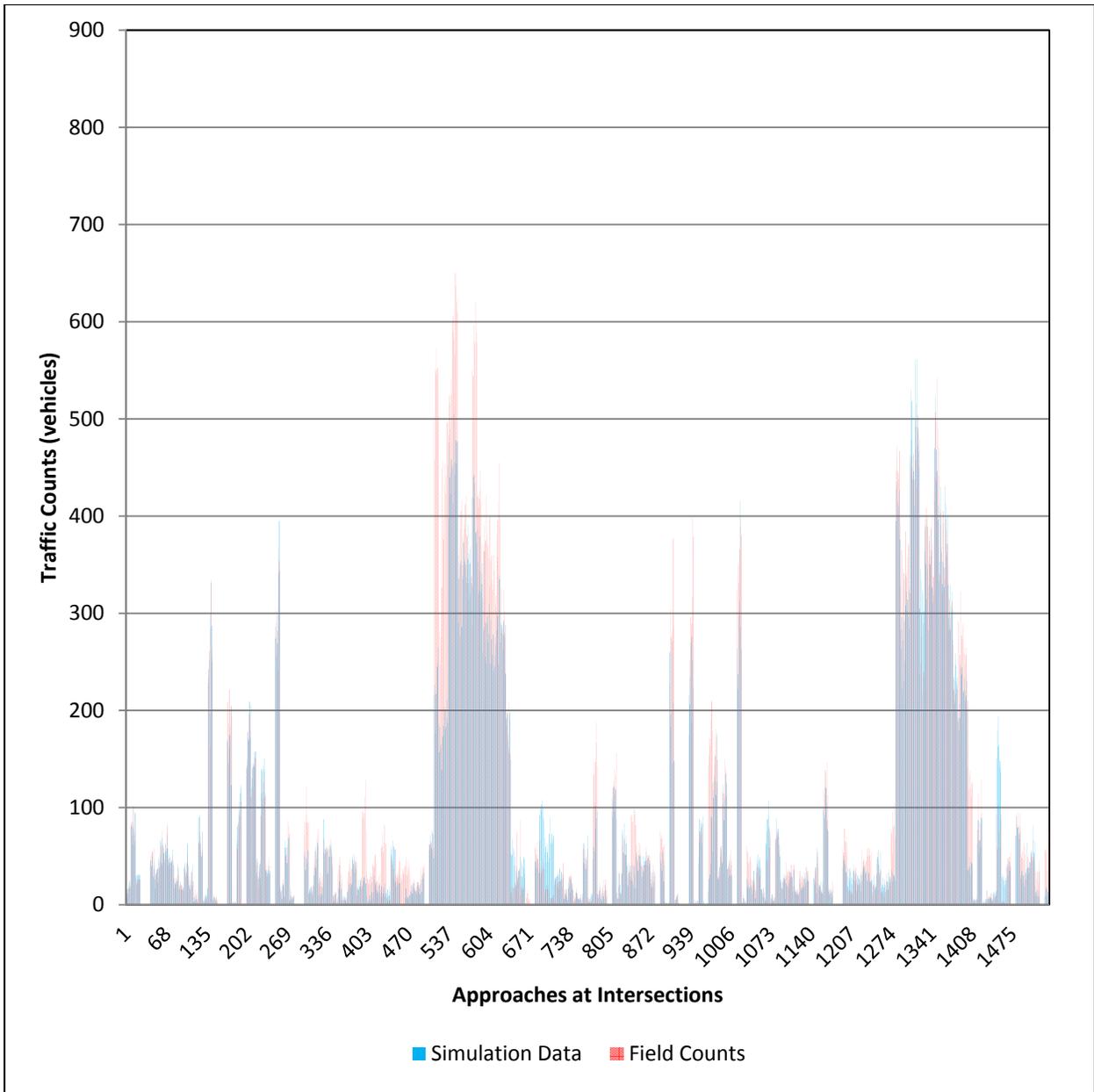
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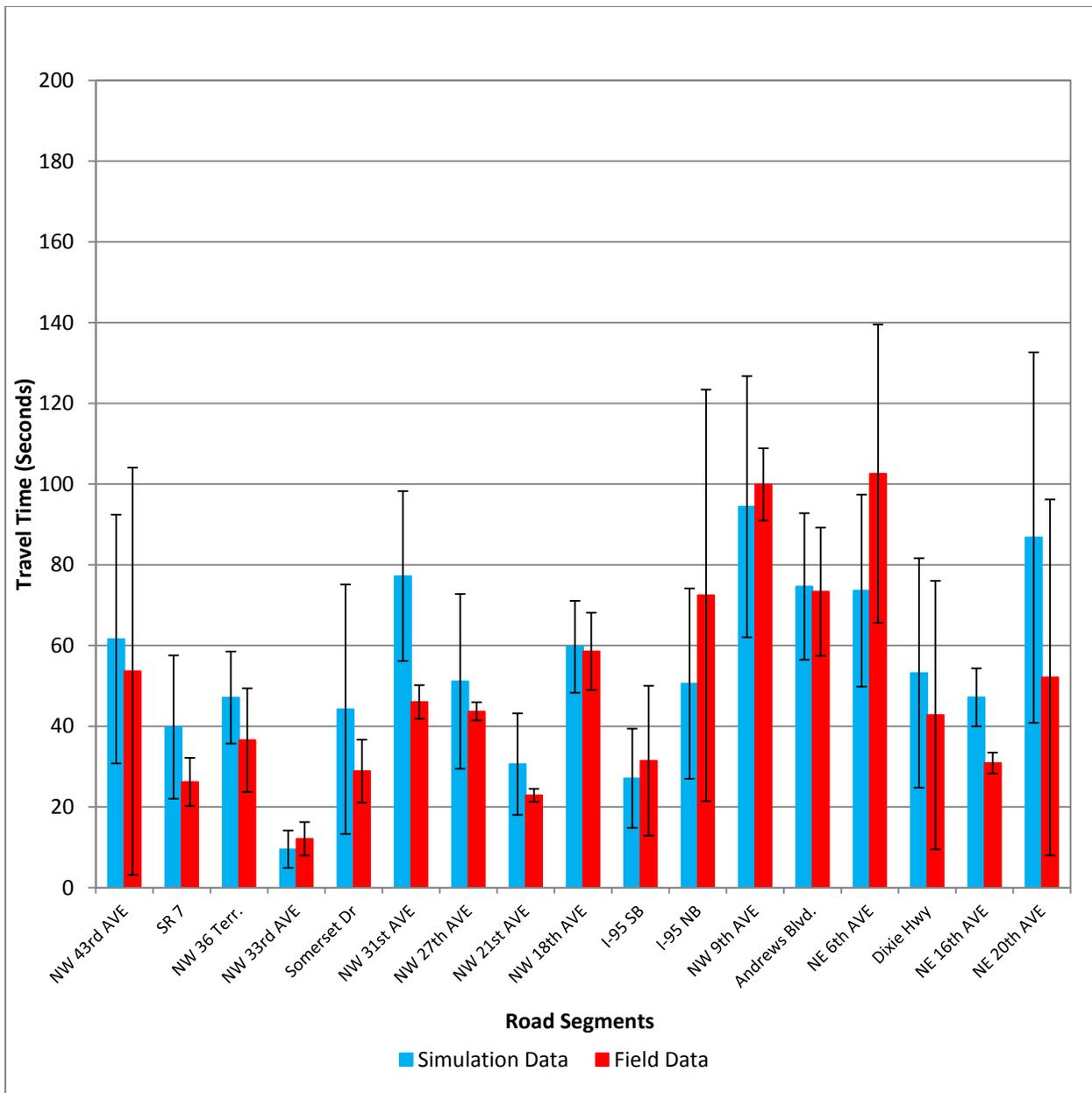
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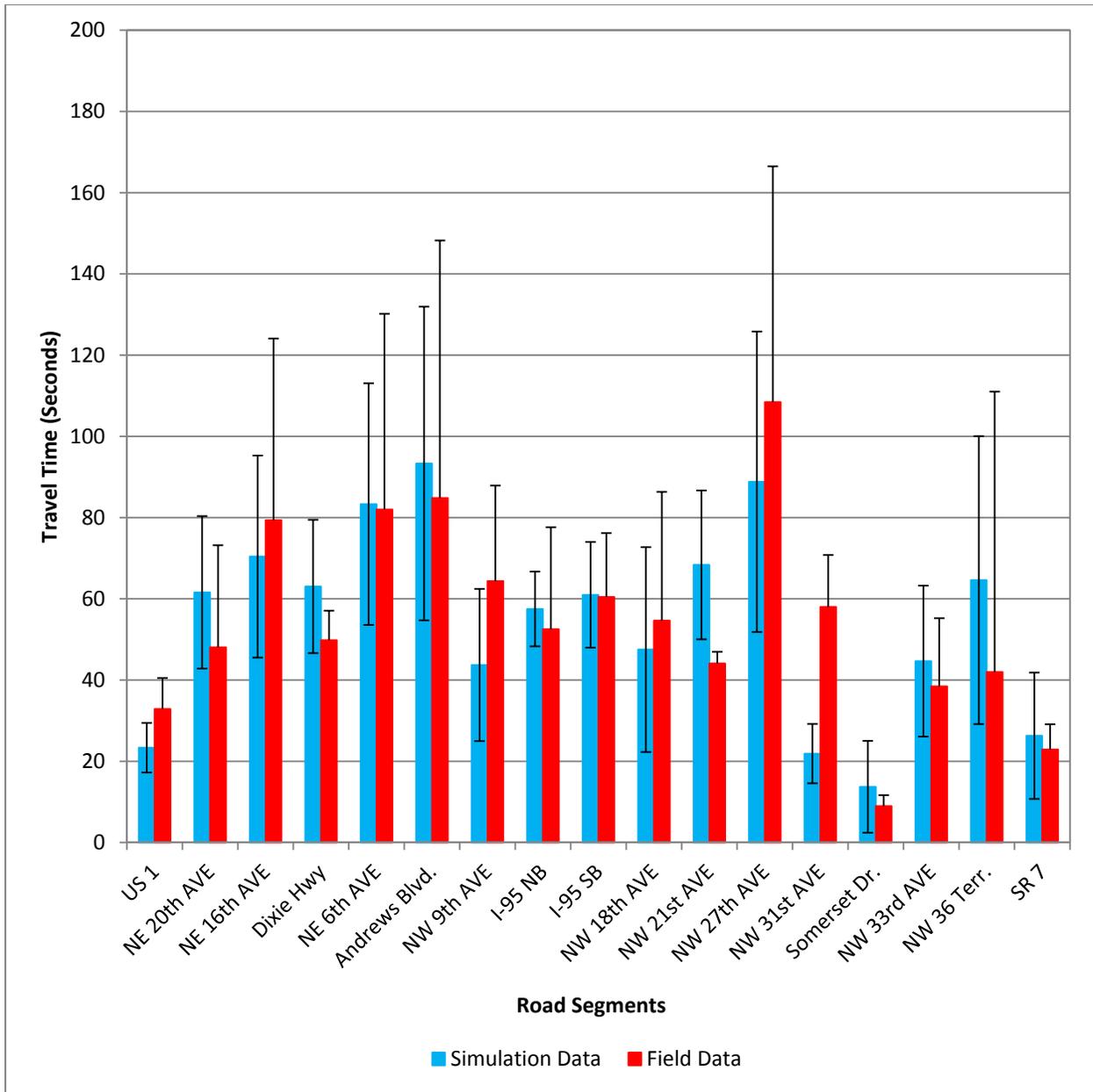
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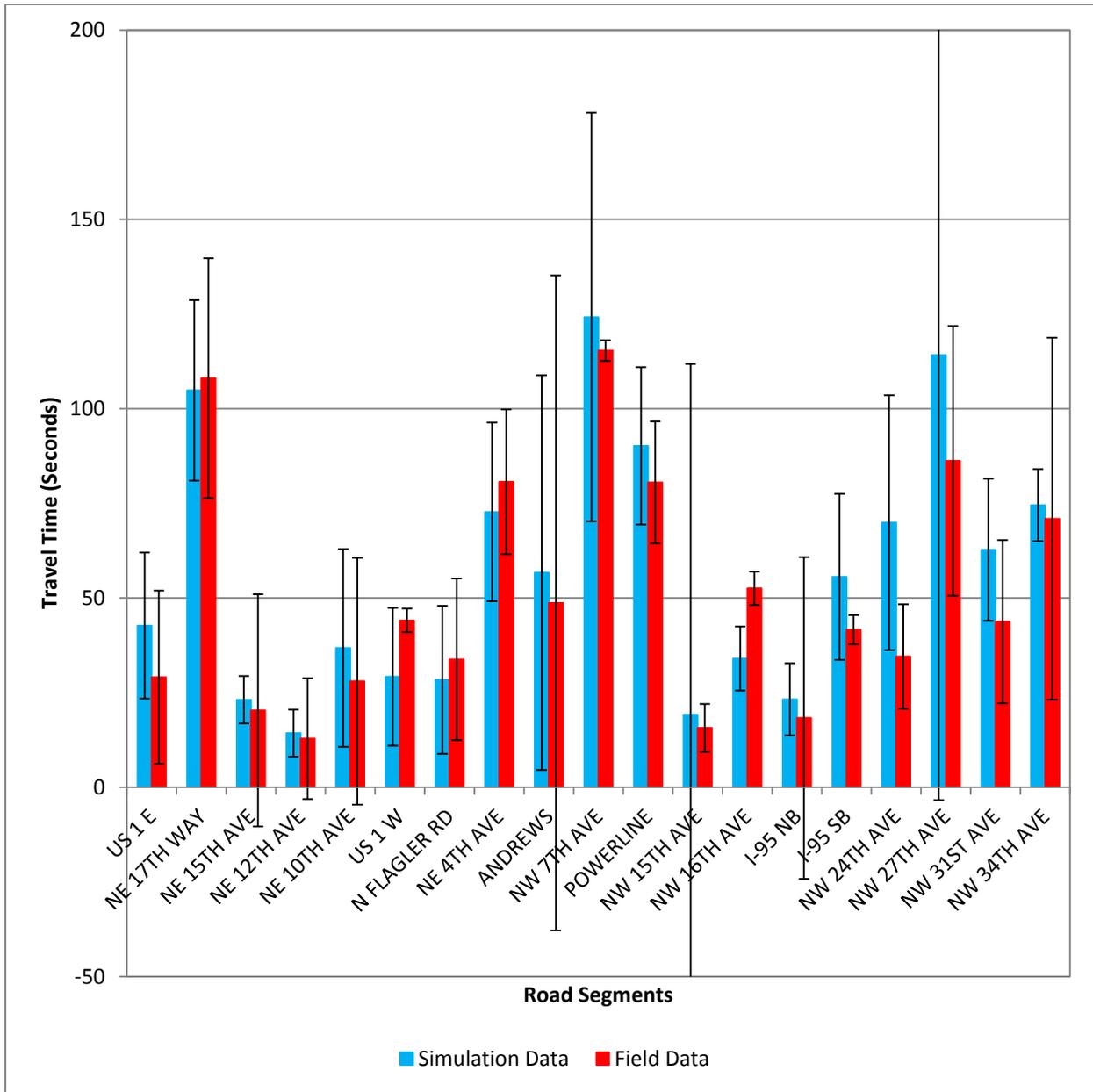
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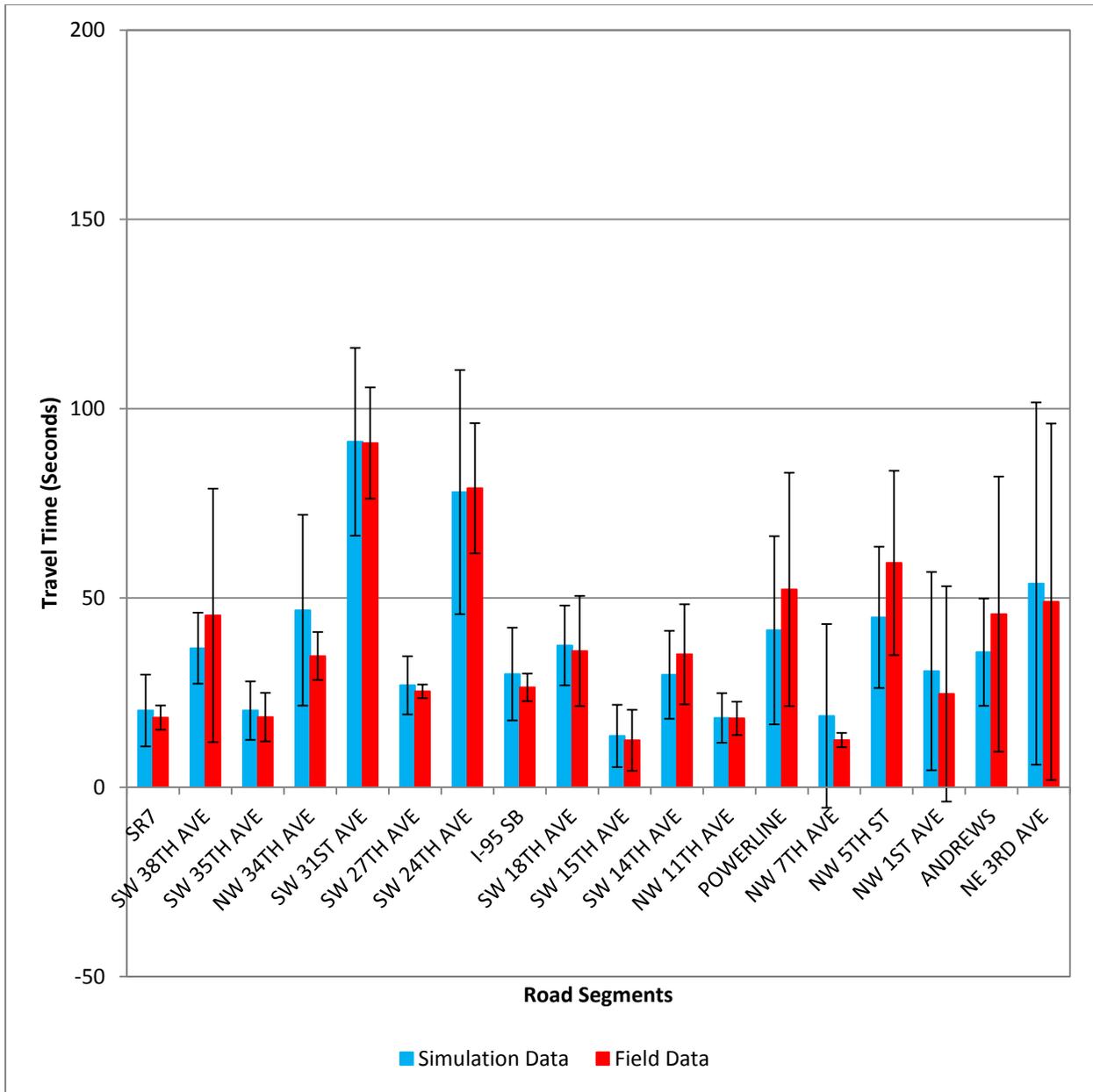
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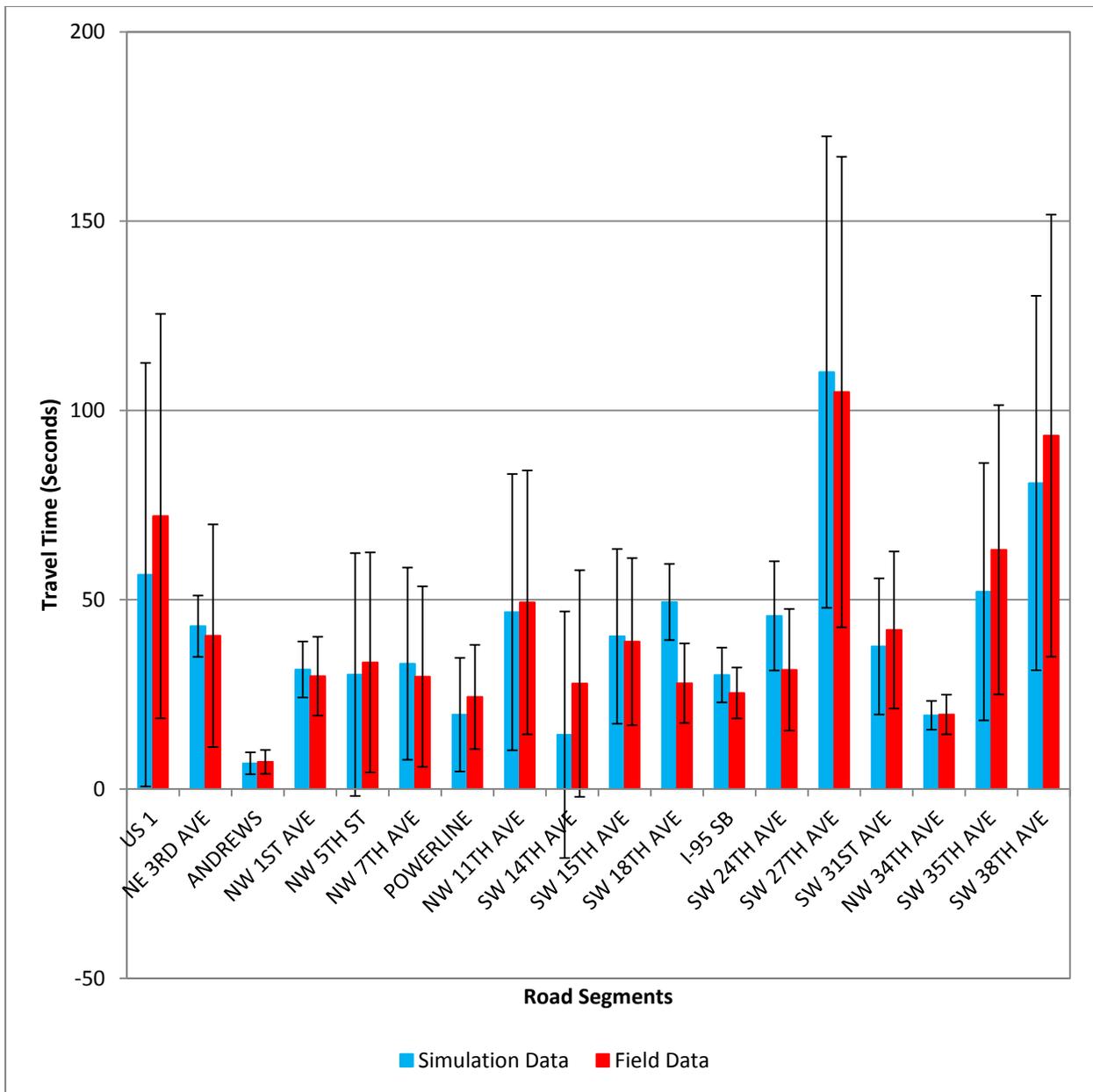
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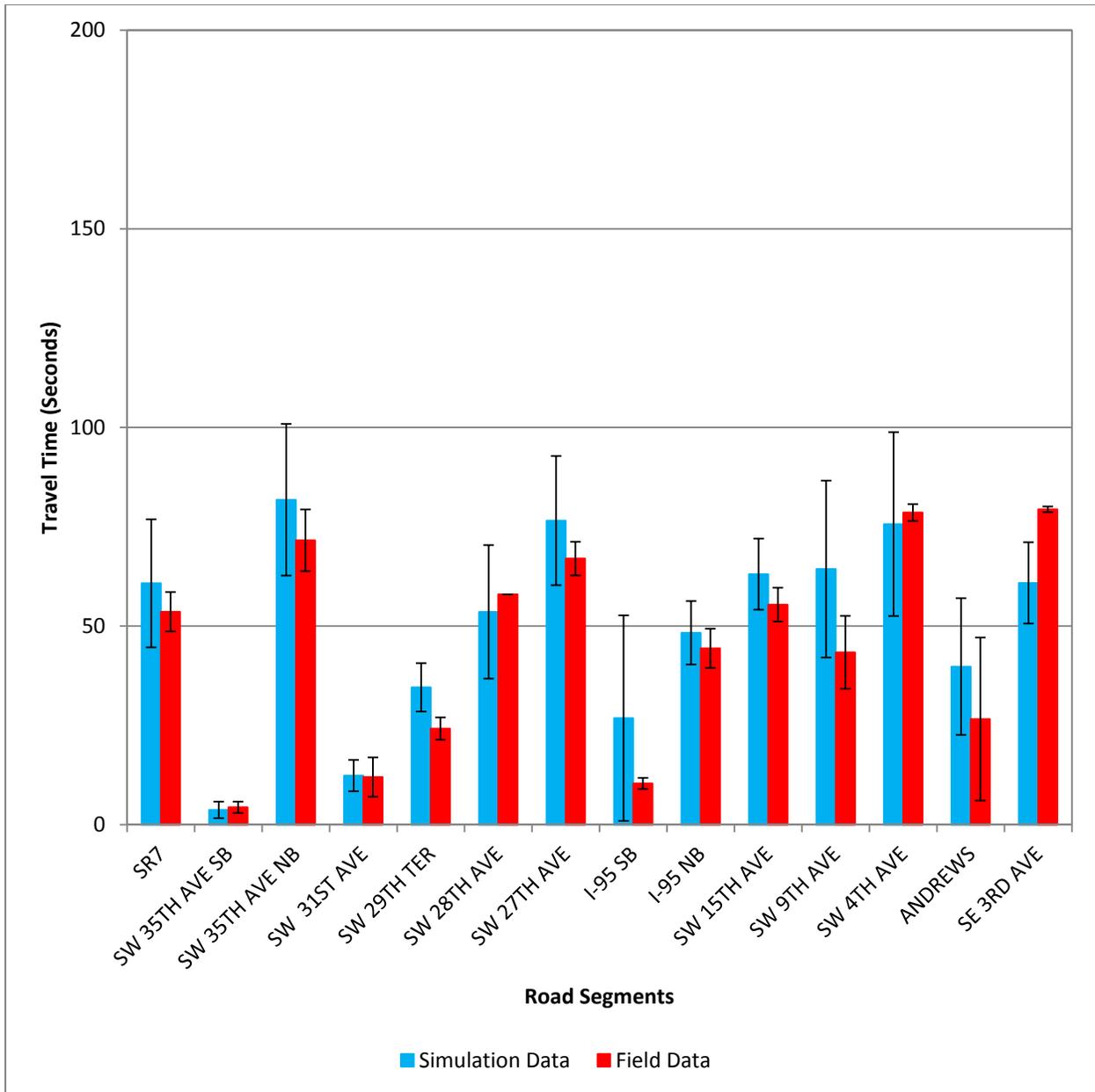
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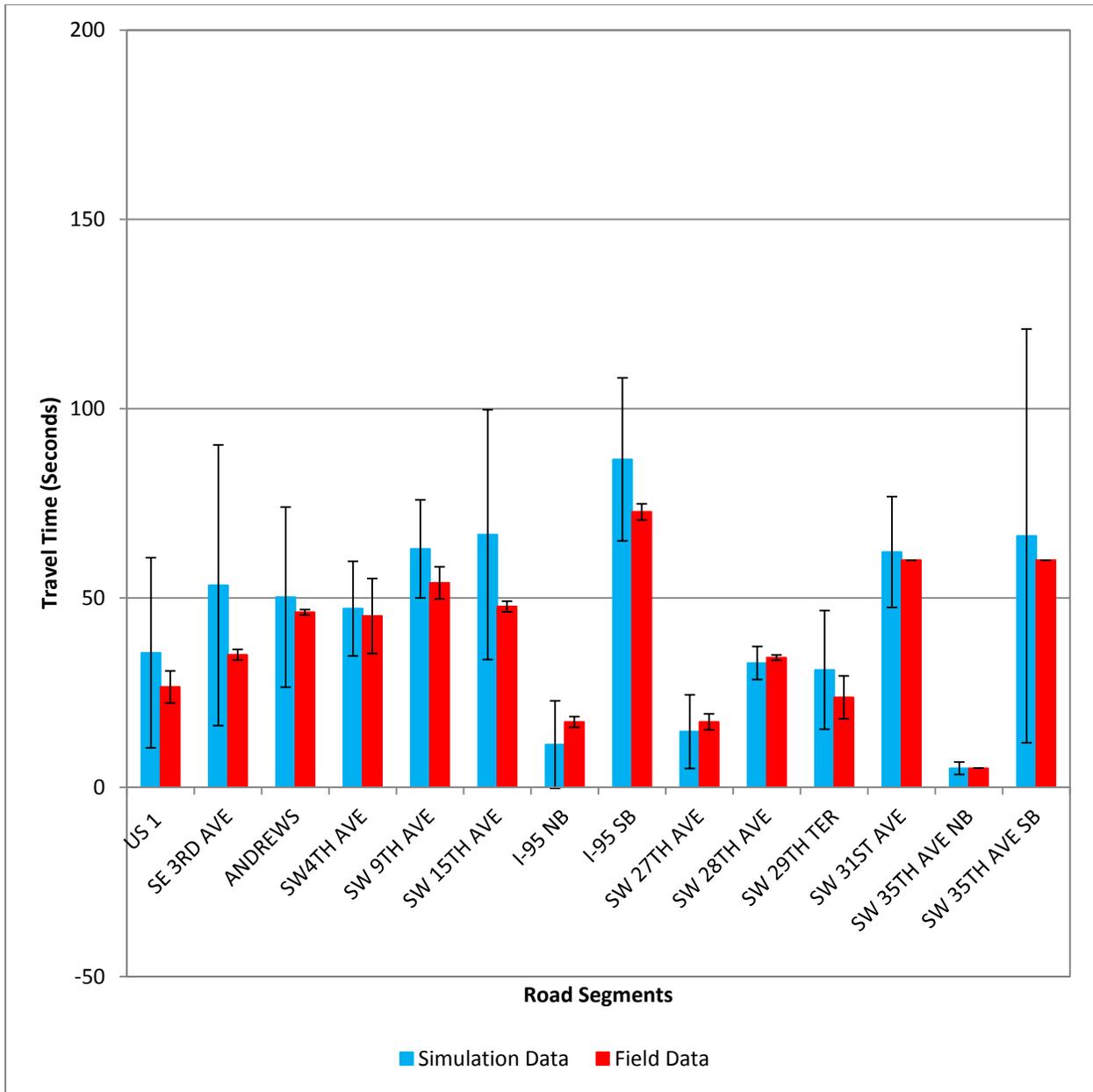
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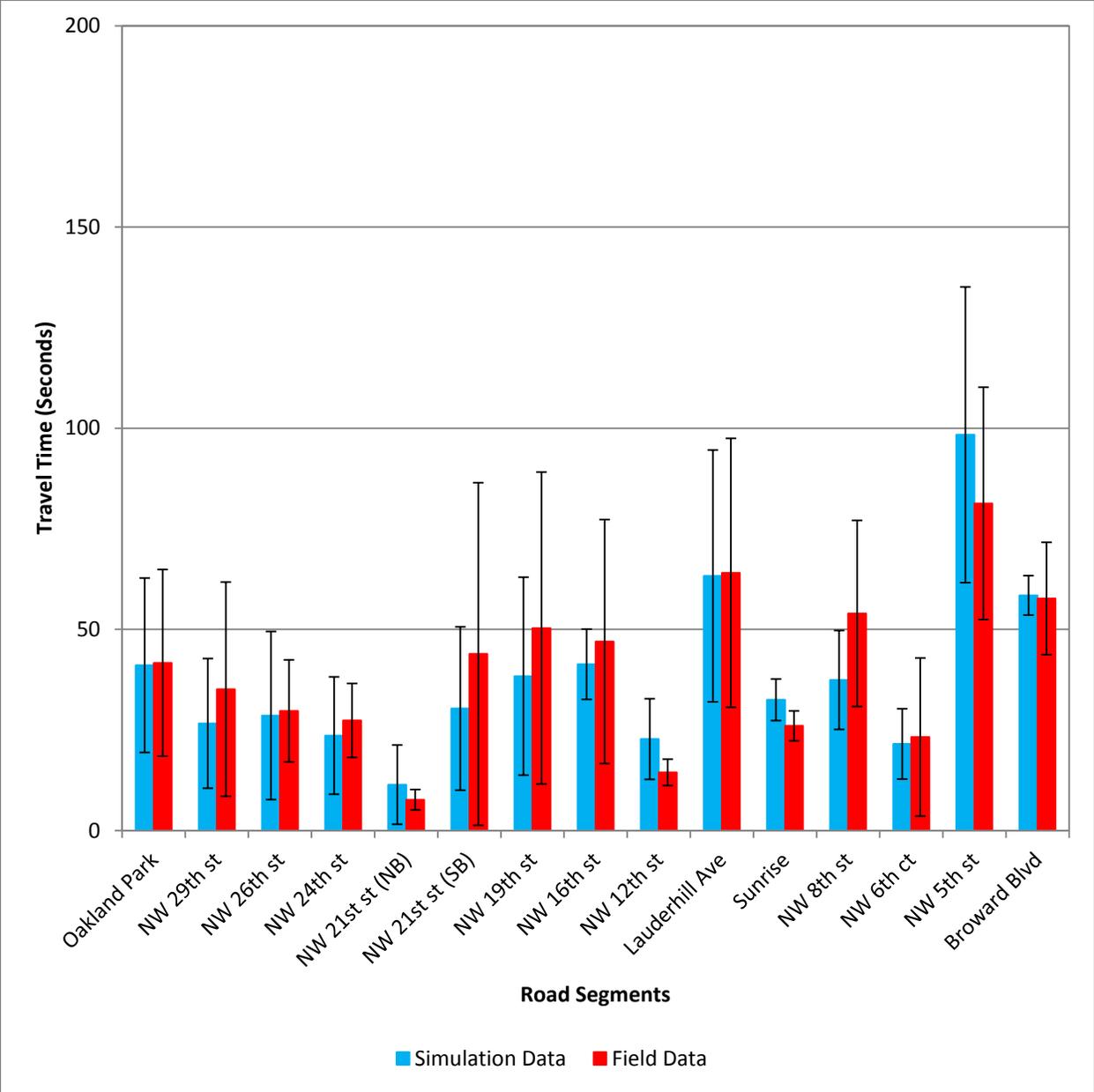
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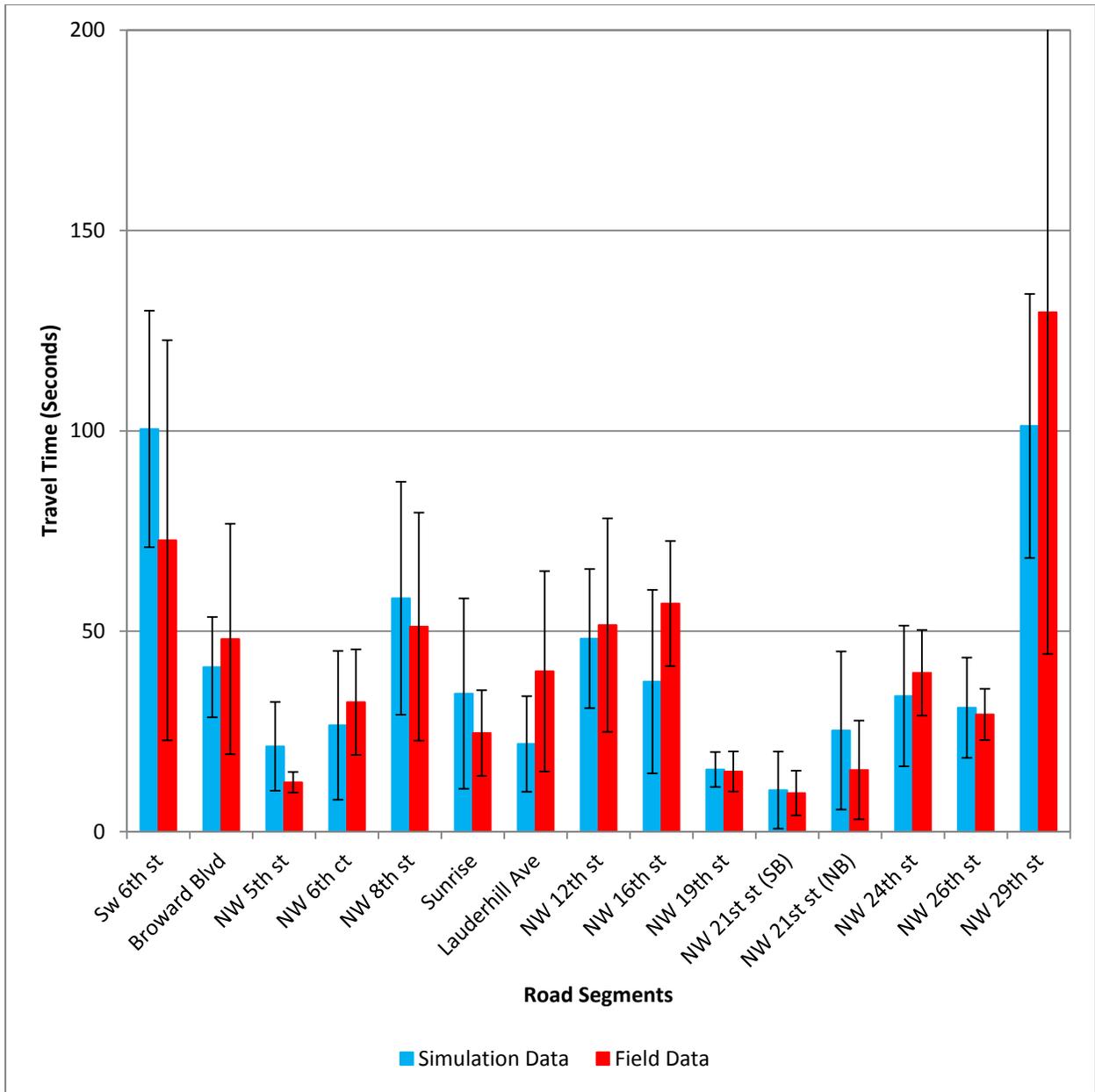
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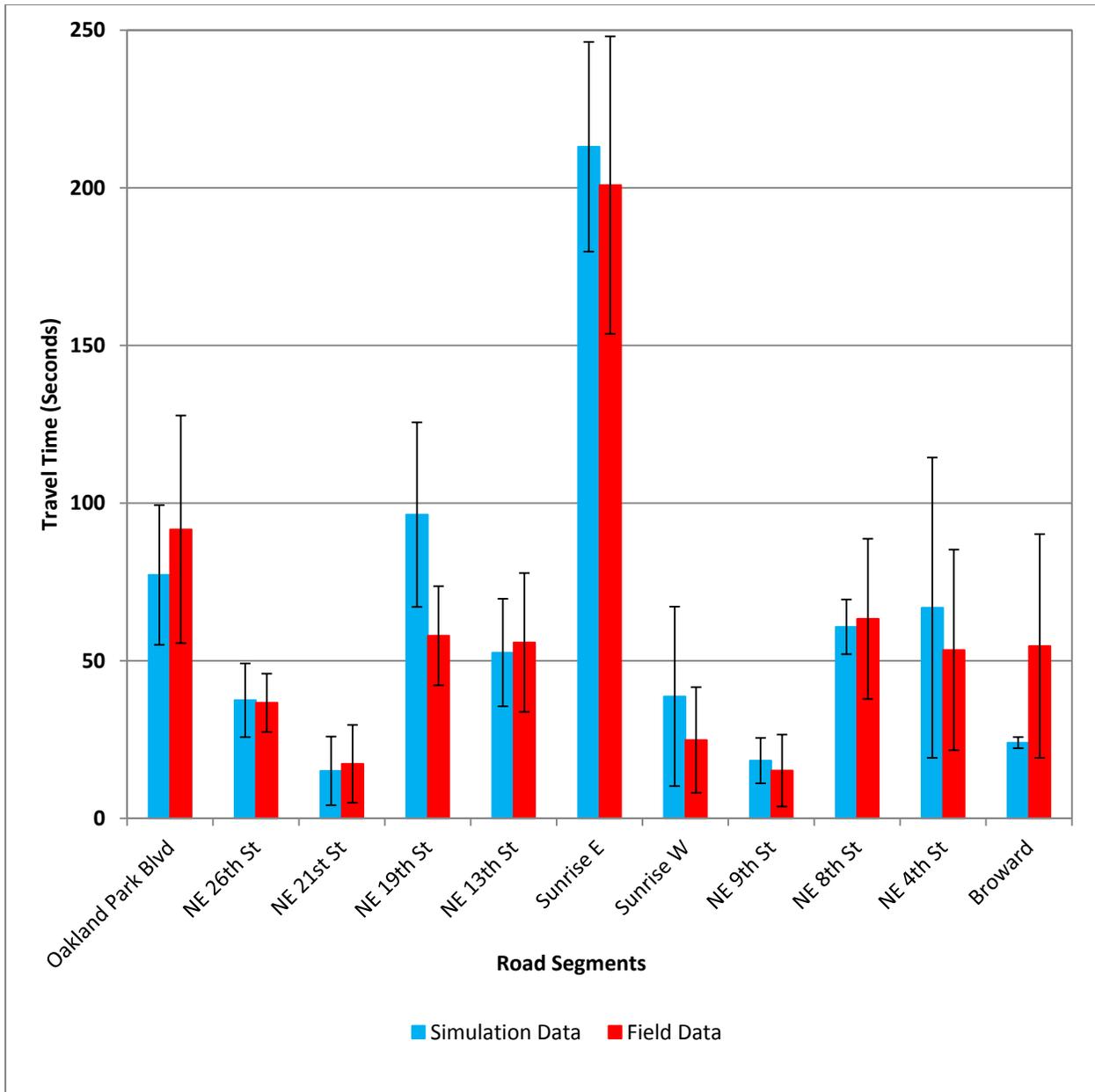
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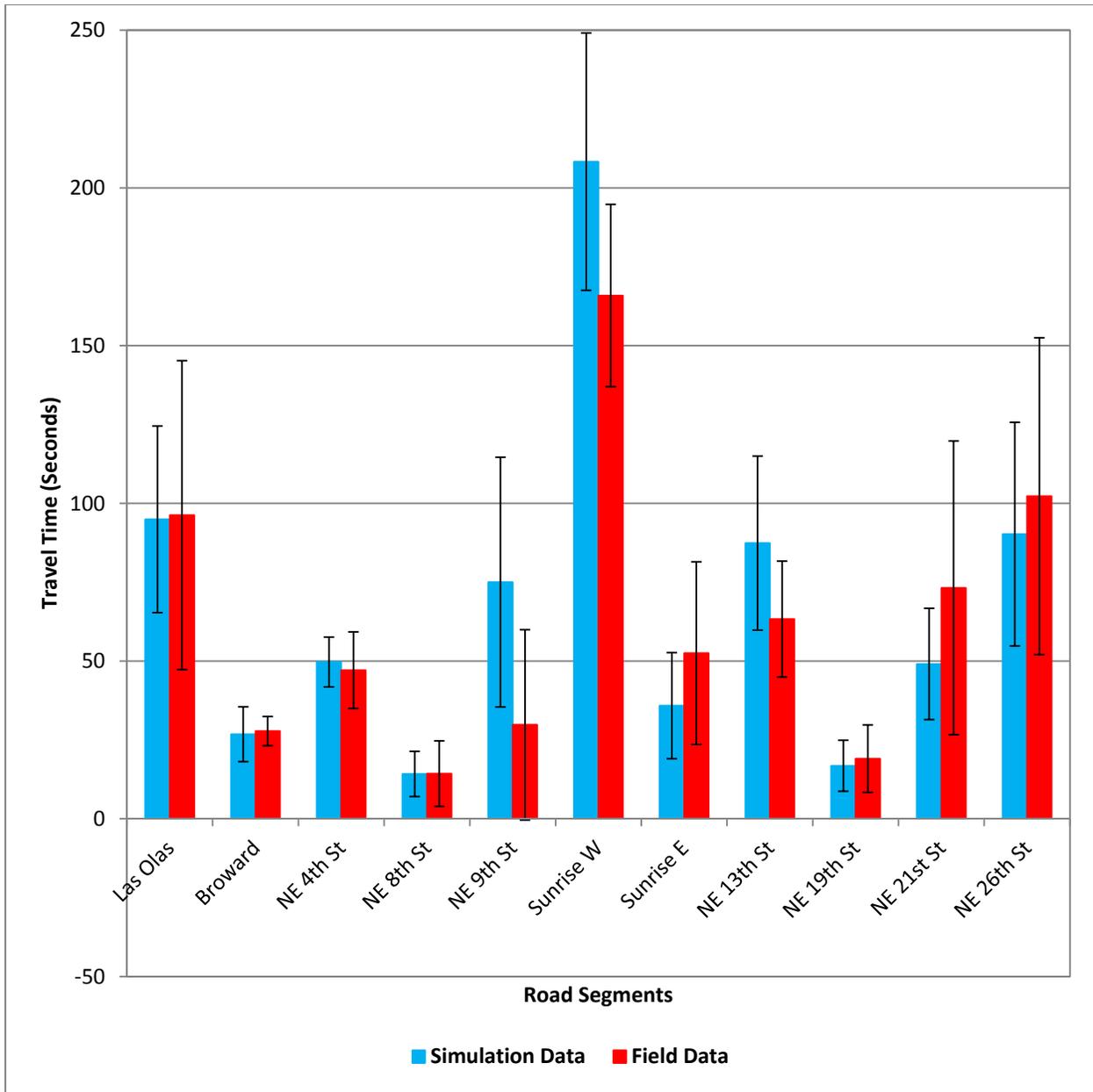
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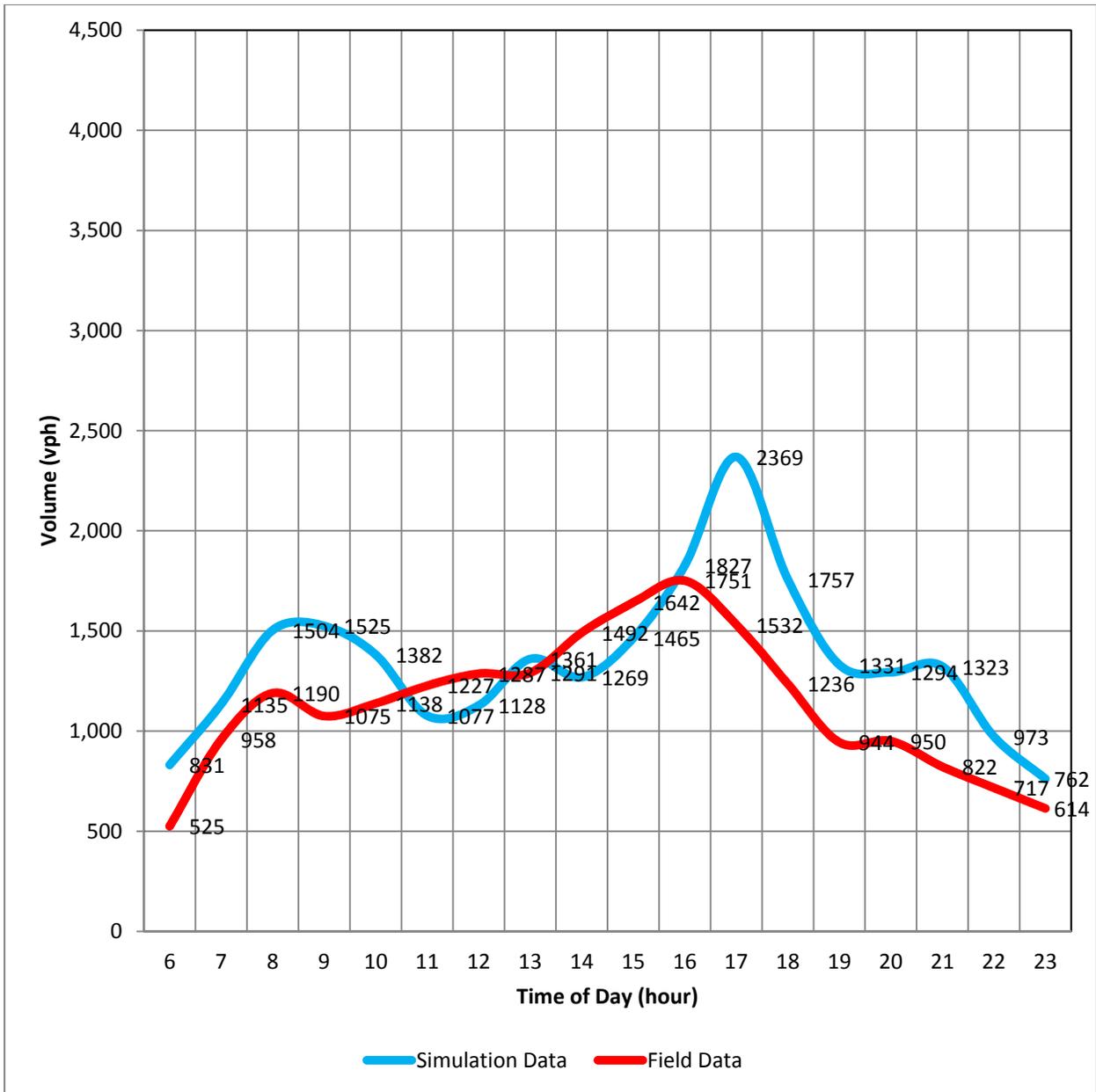
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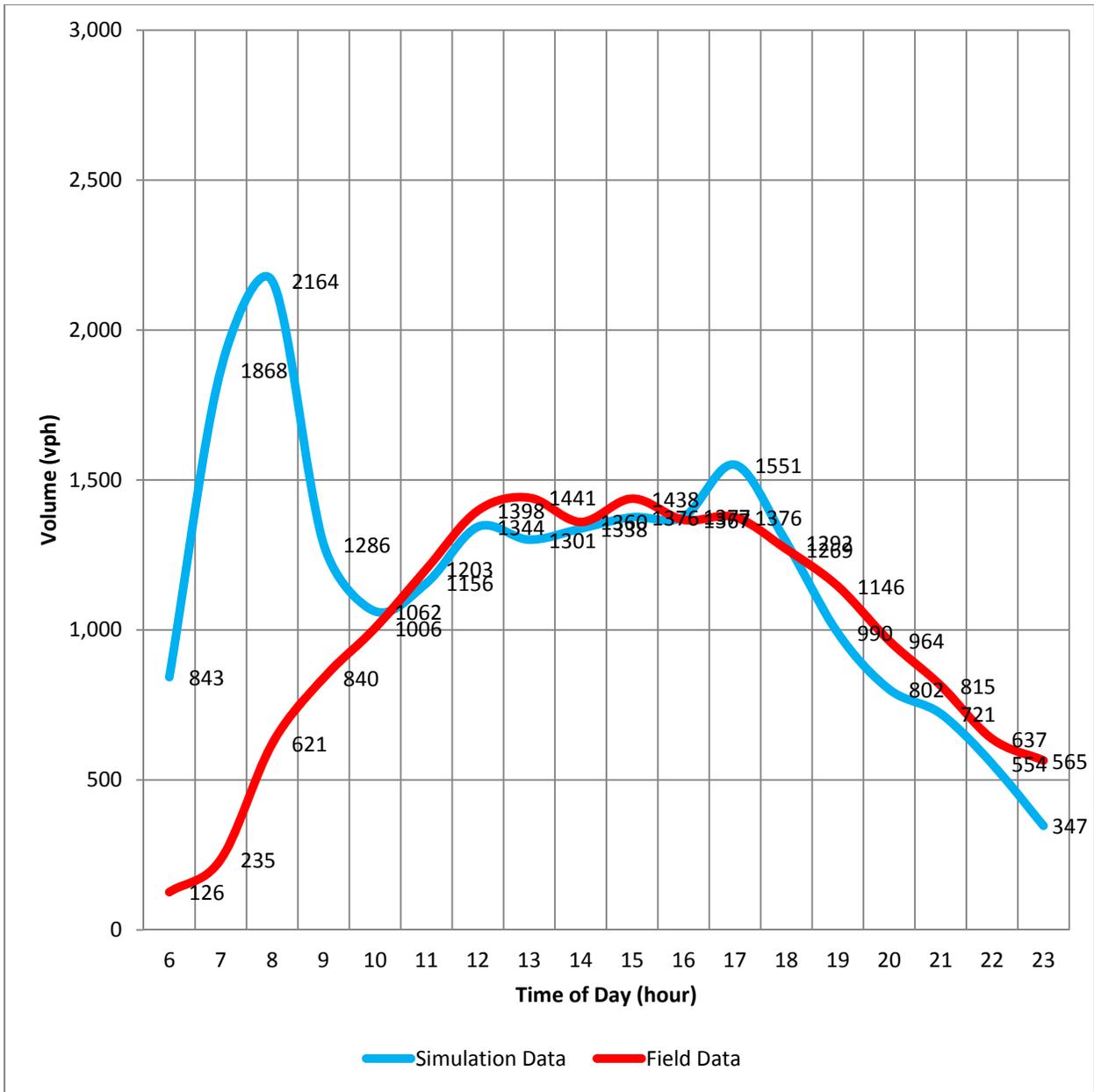
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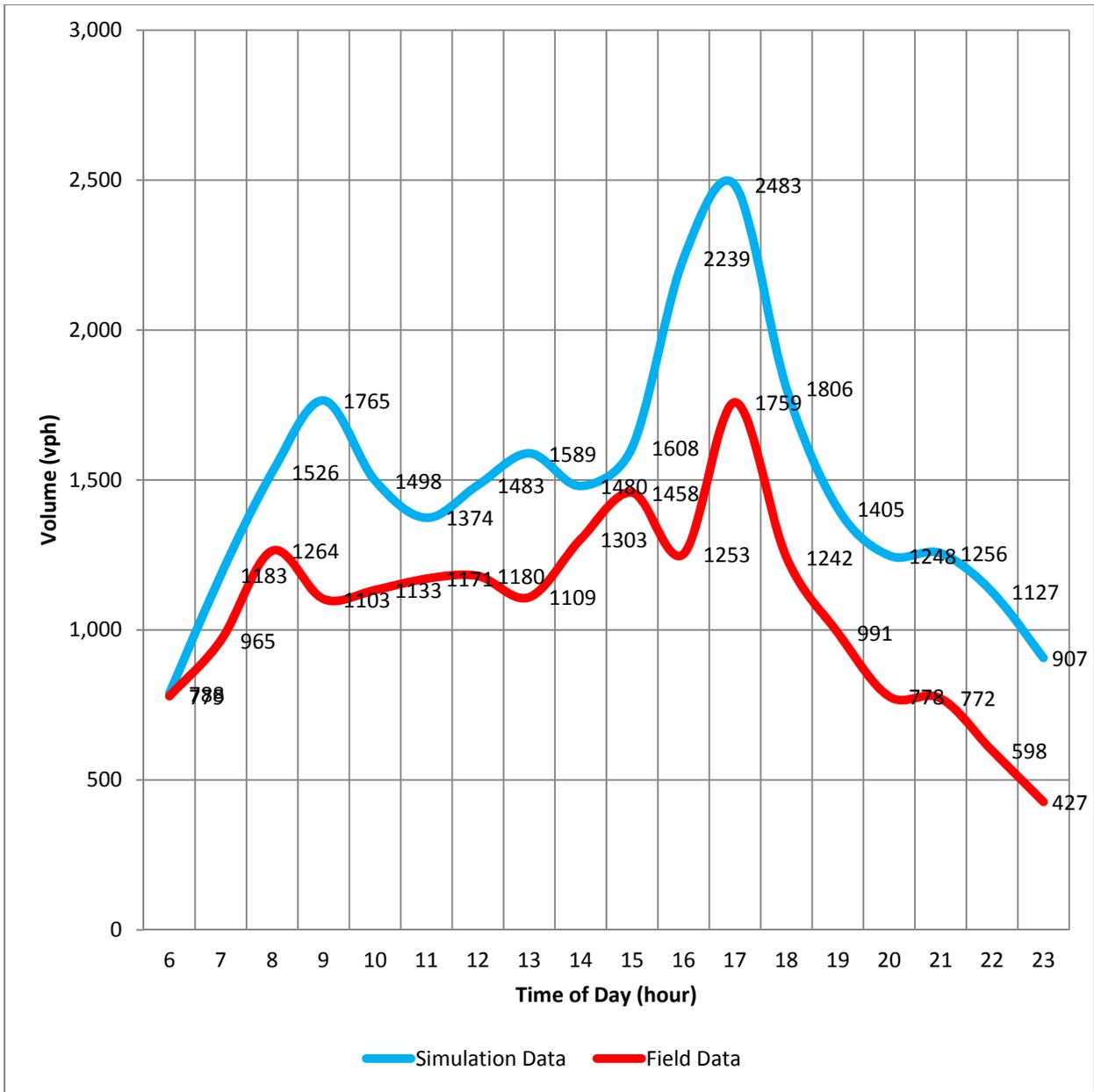
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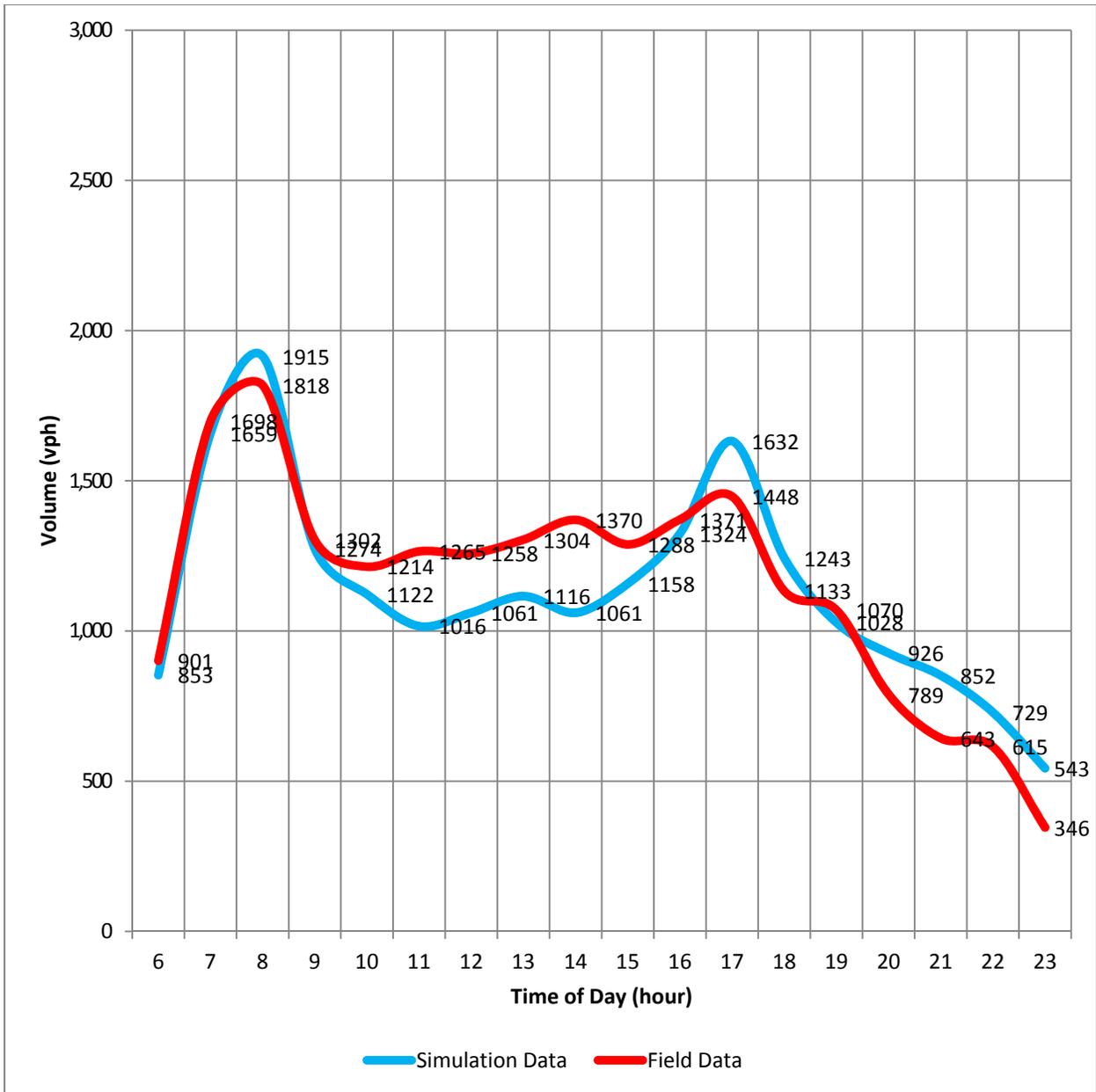
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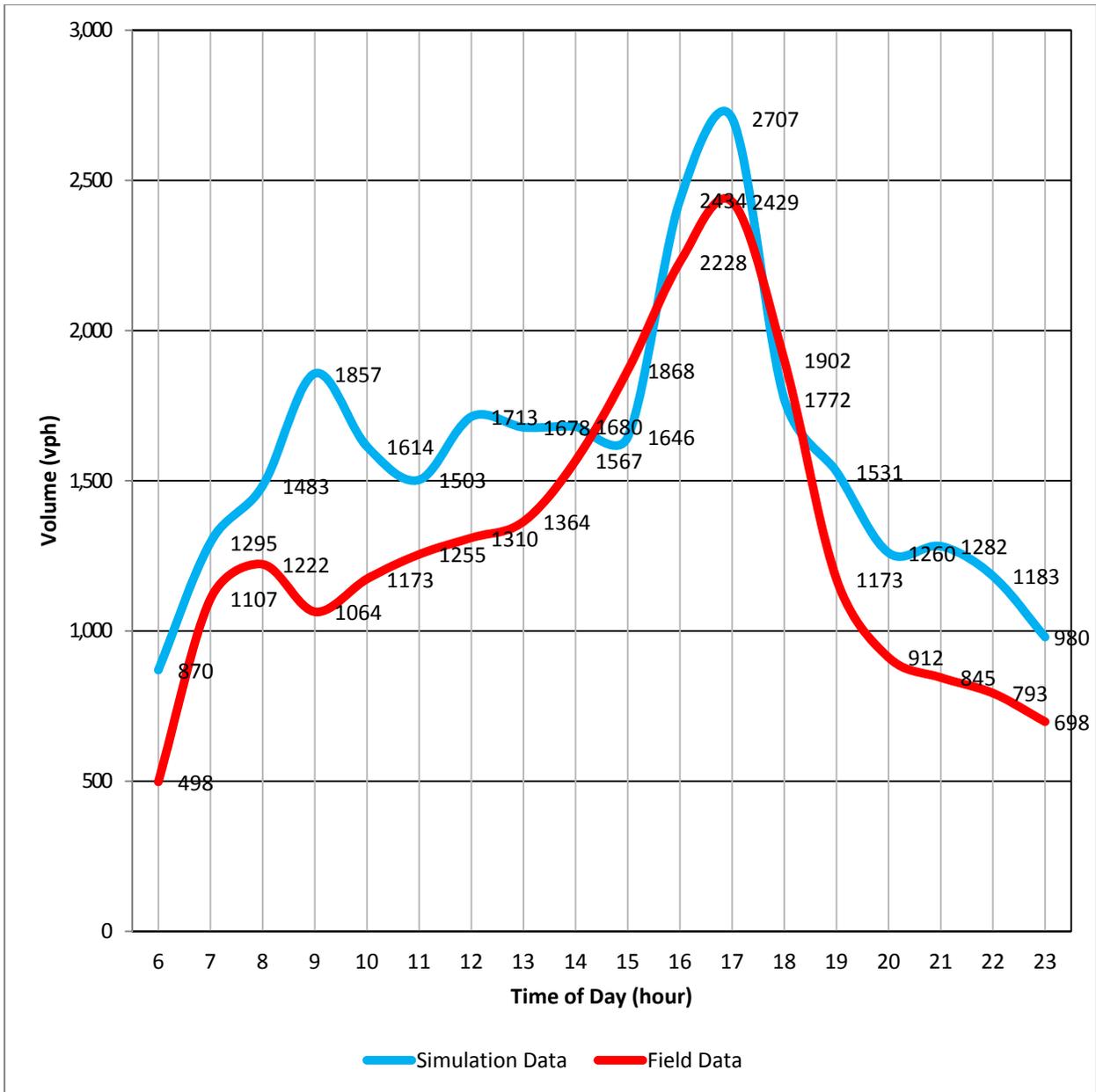
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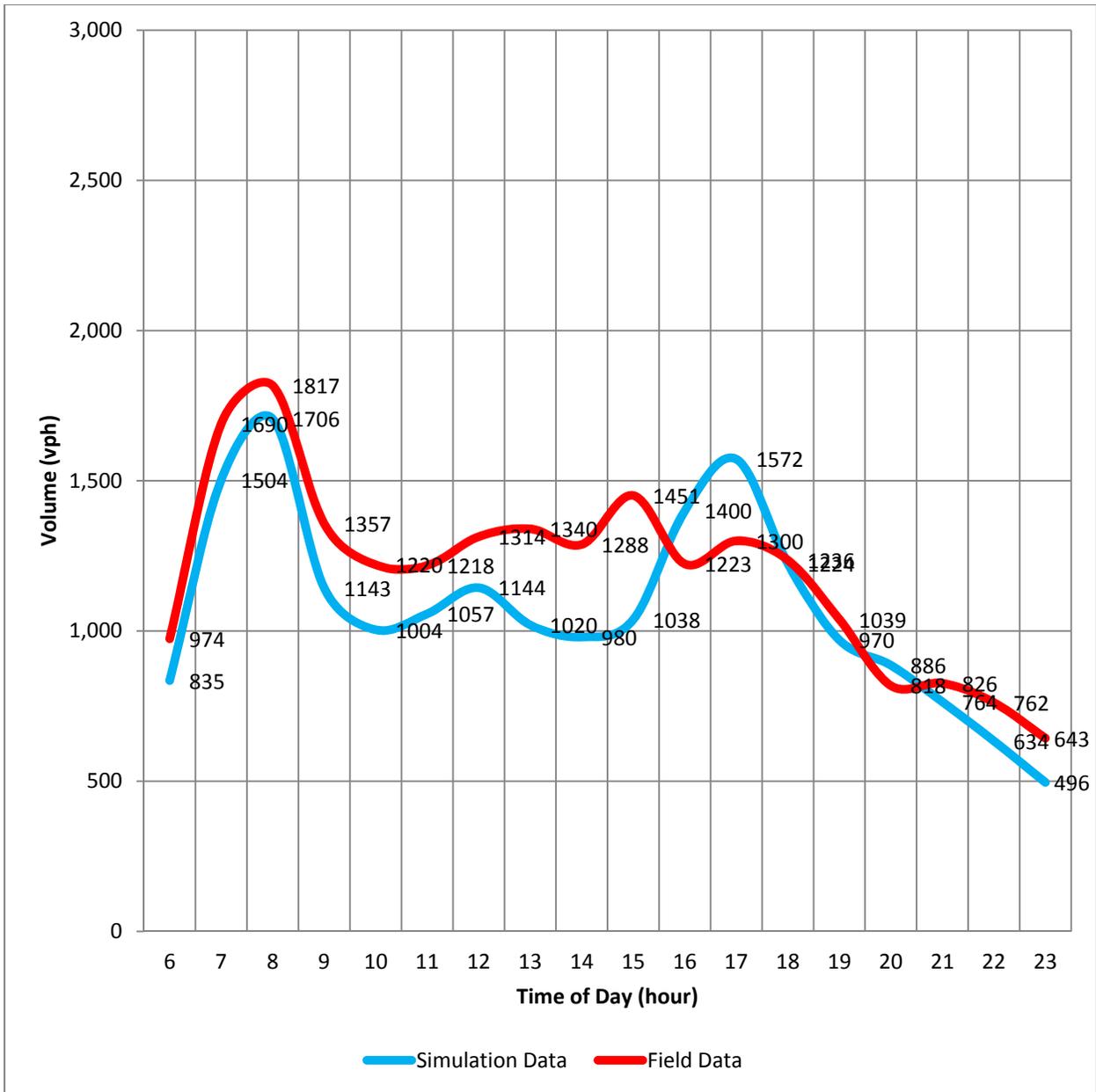
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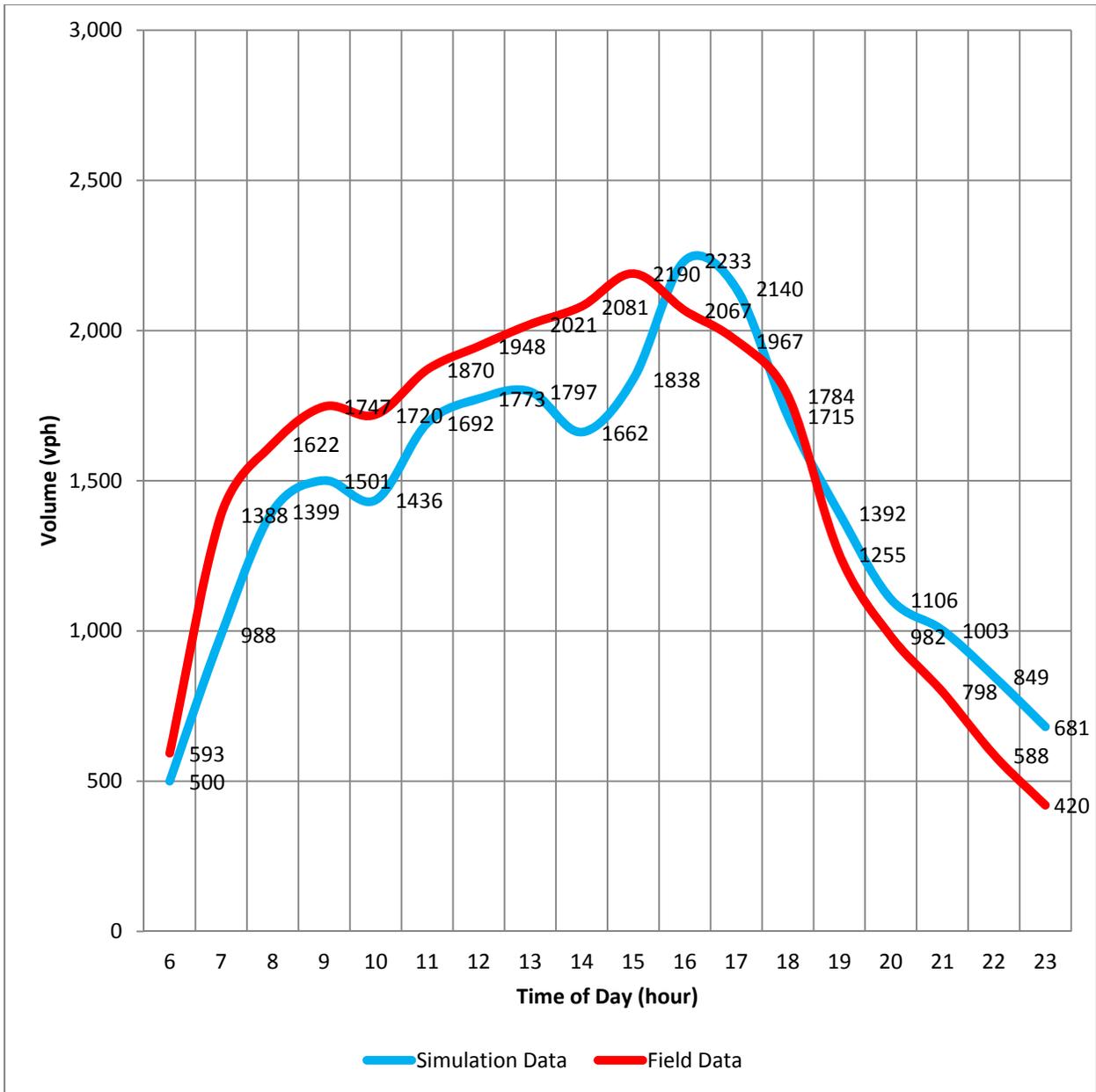
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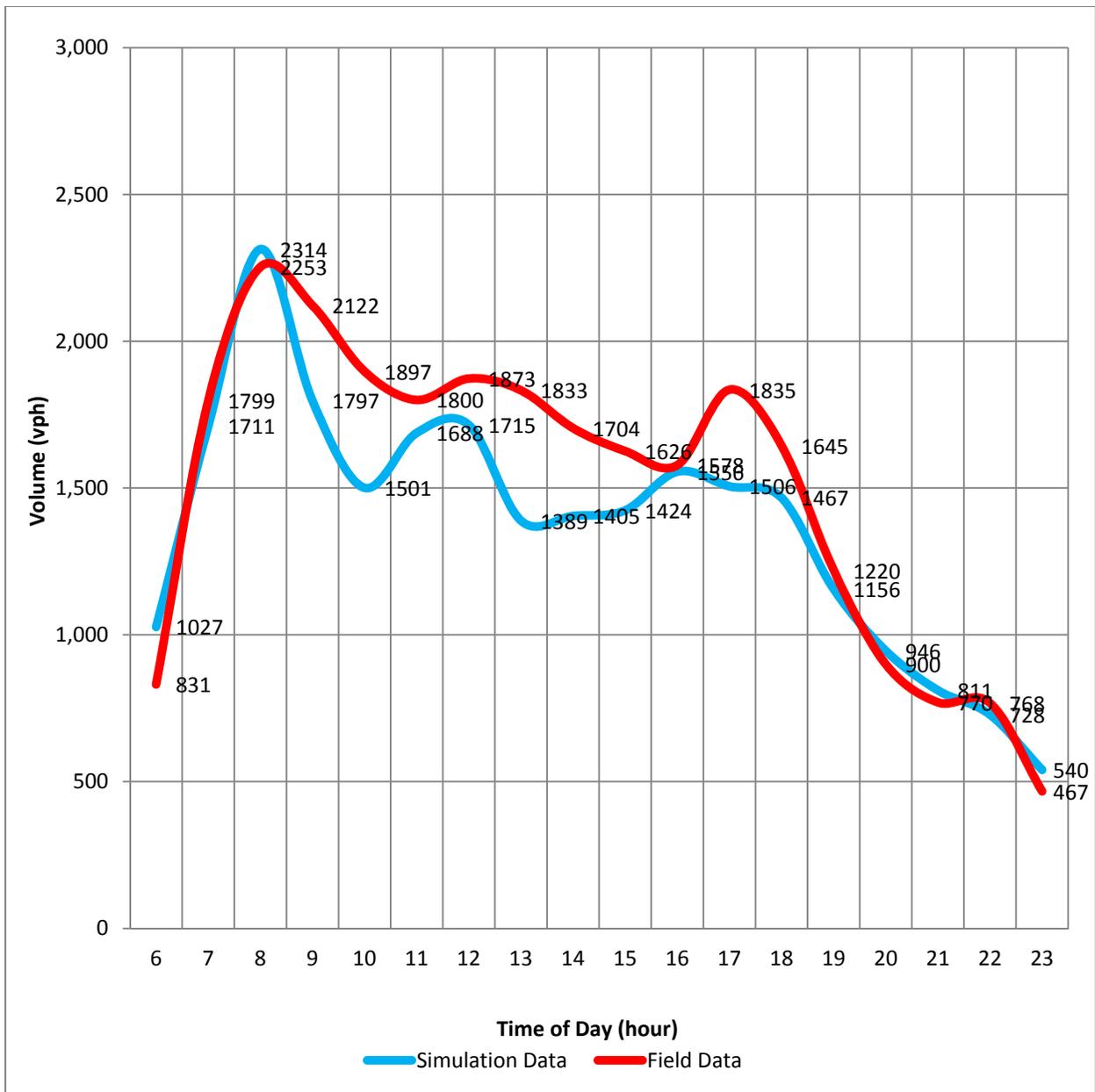
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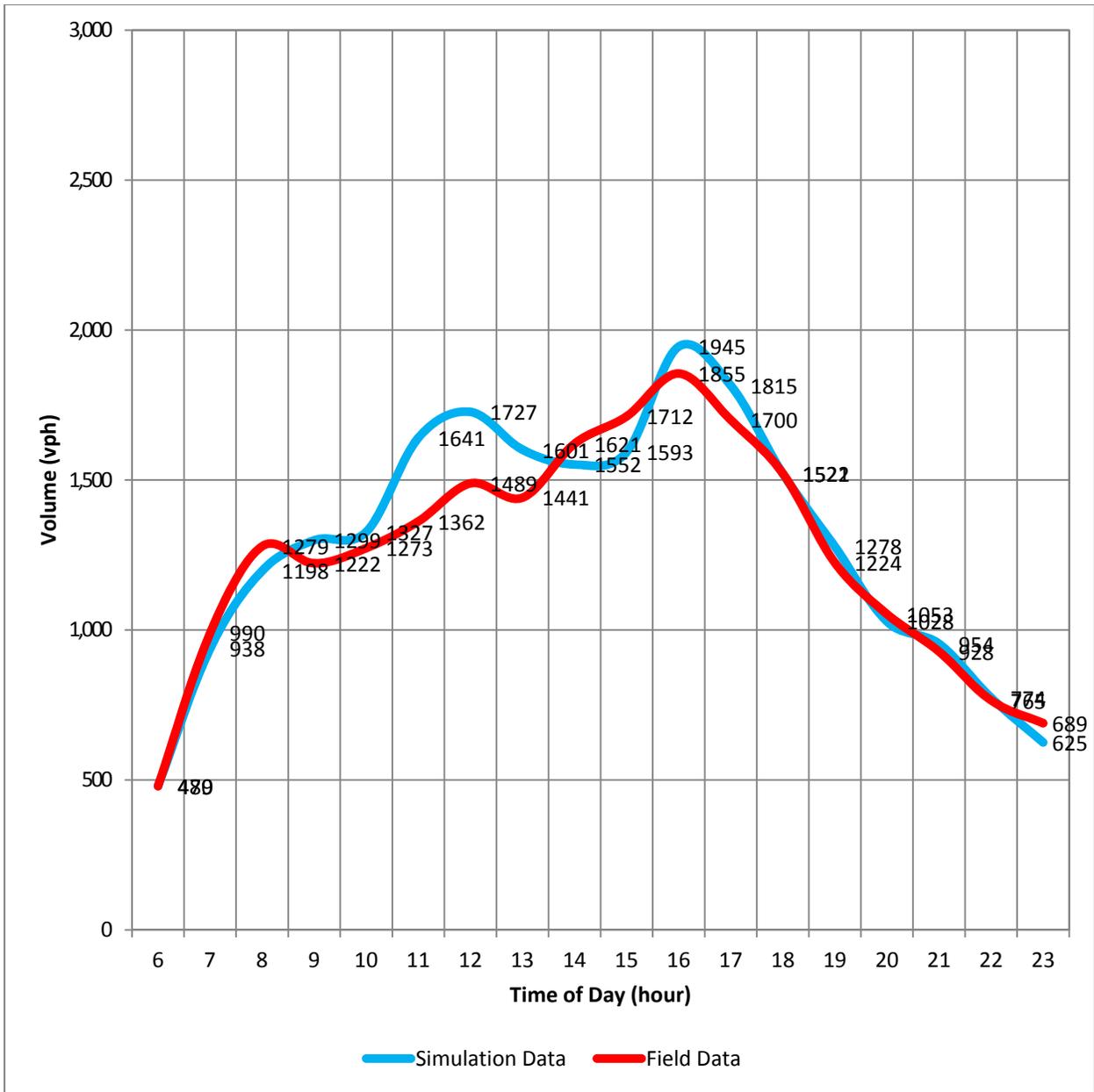
Figure 98- Broward Blvd. Model: Calibration Visualization for M-21 Detector near NW 7th Ave in Westbound Direction

Figure 99- Broward Blvd. Model: Calibration Visualization for M-21 Detector near NW 7th Ave in Eastbound Direction
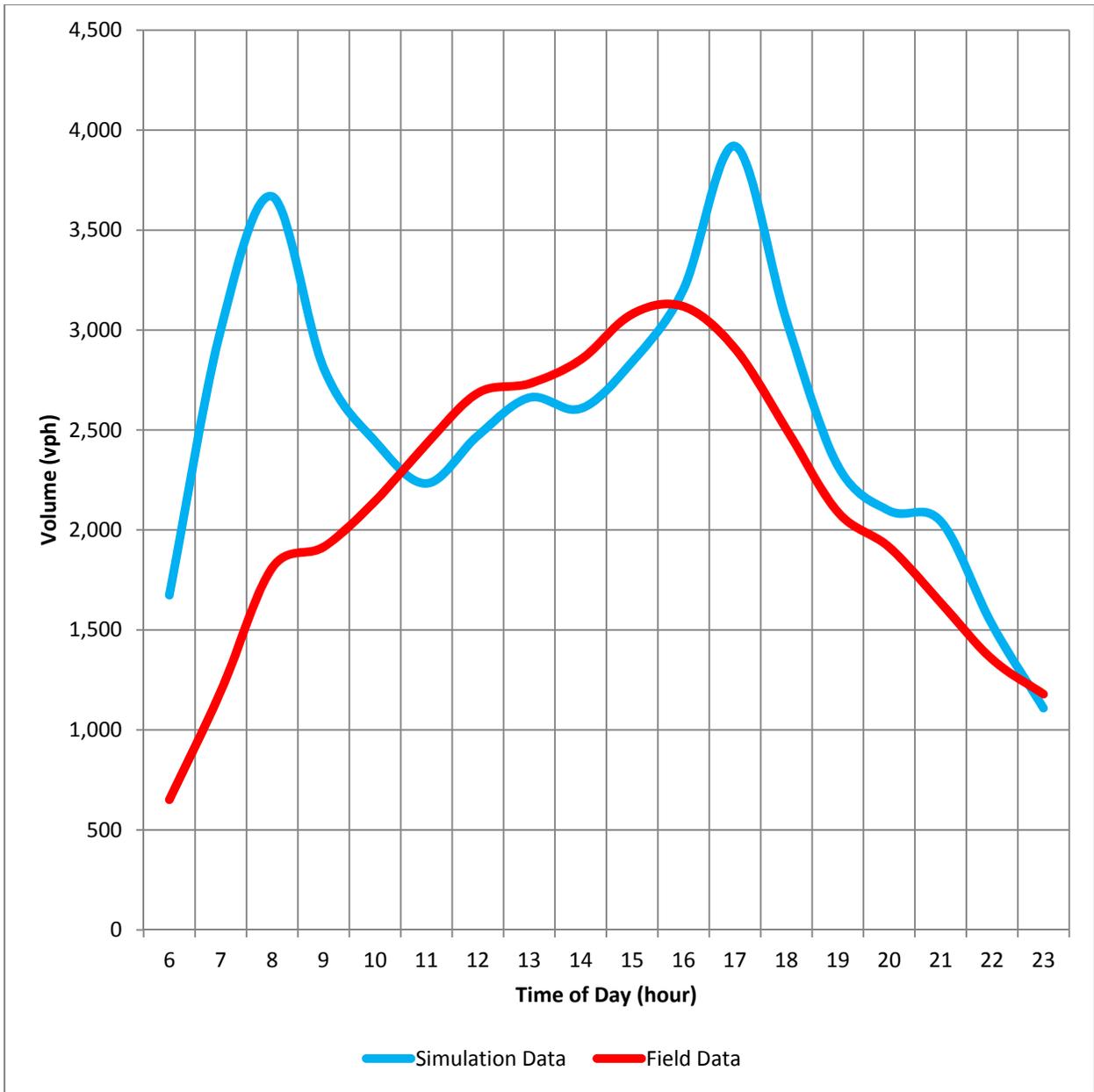
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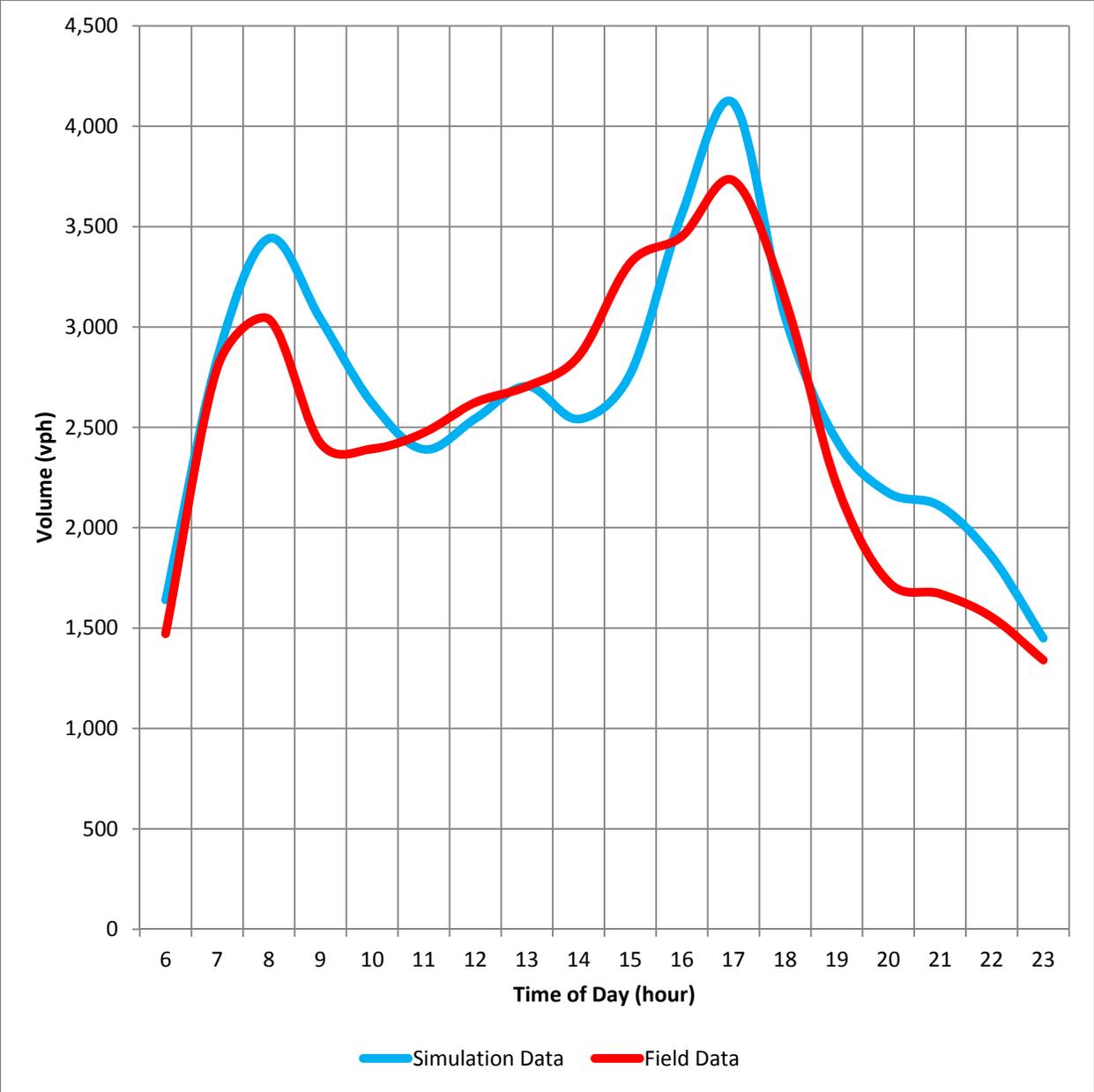
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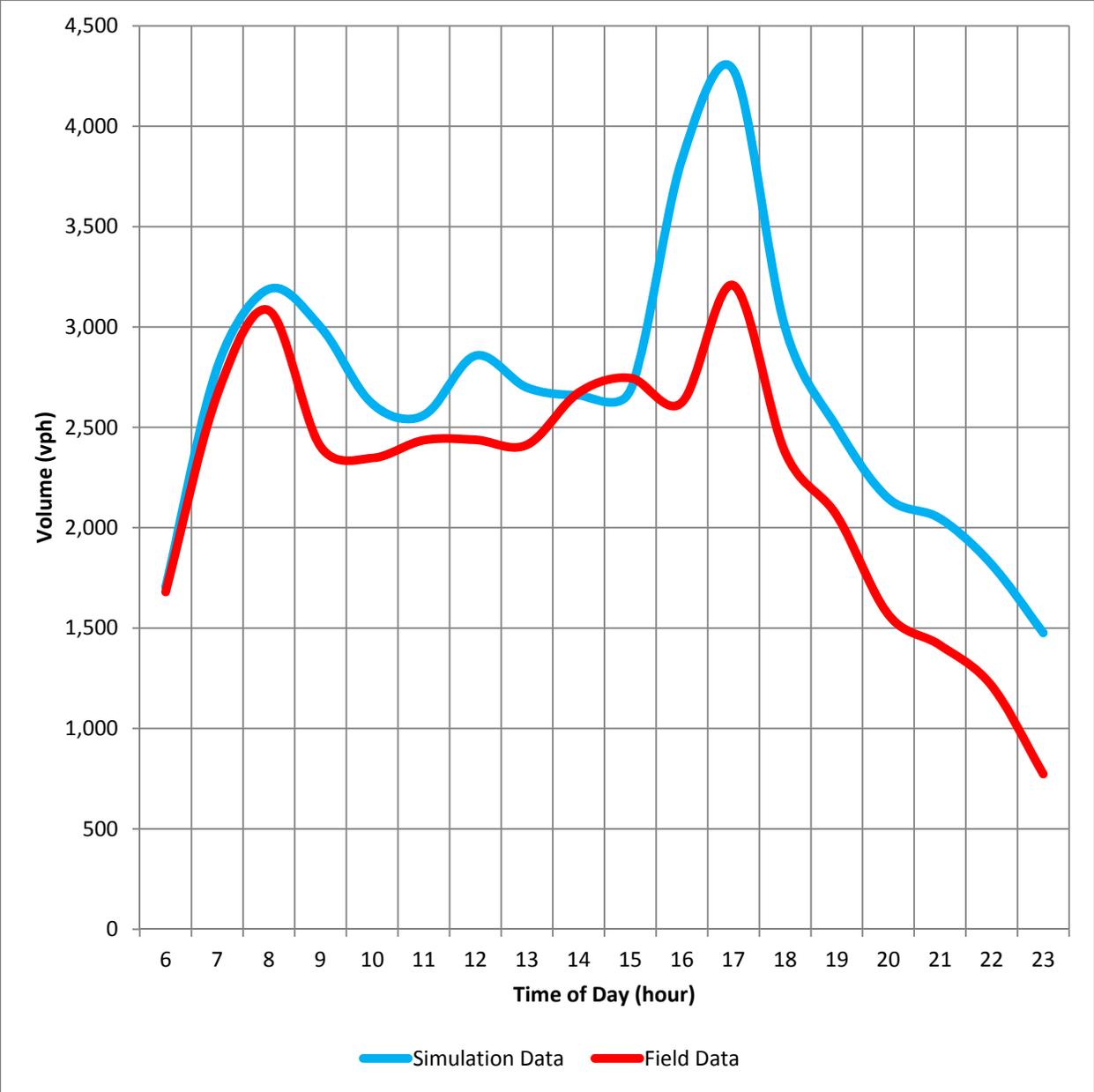
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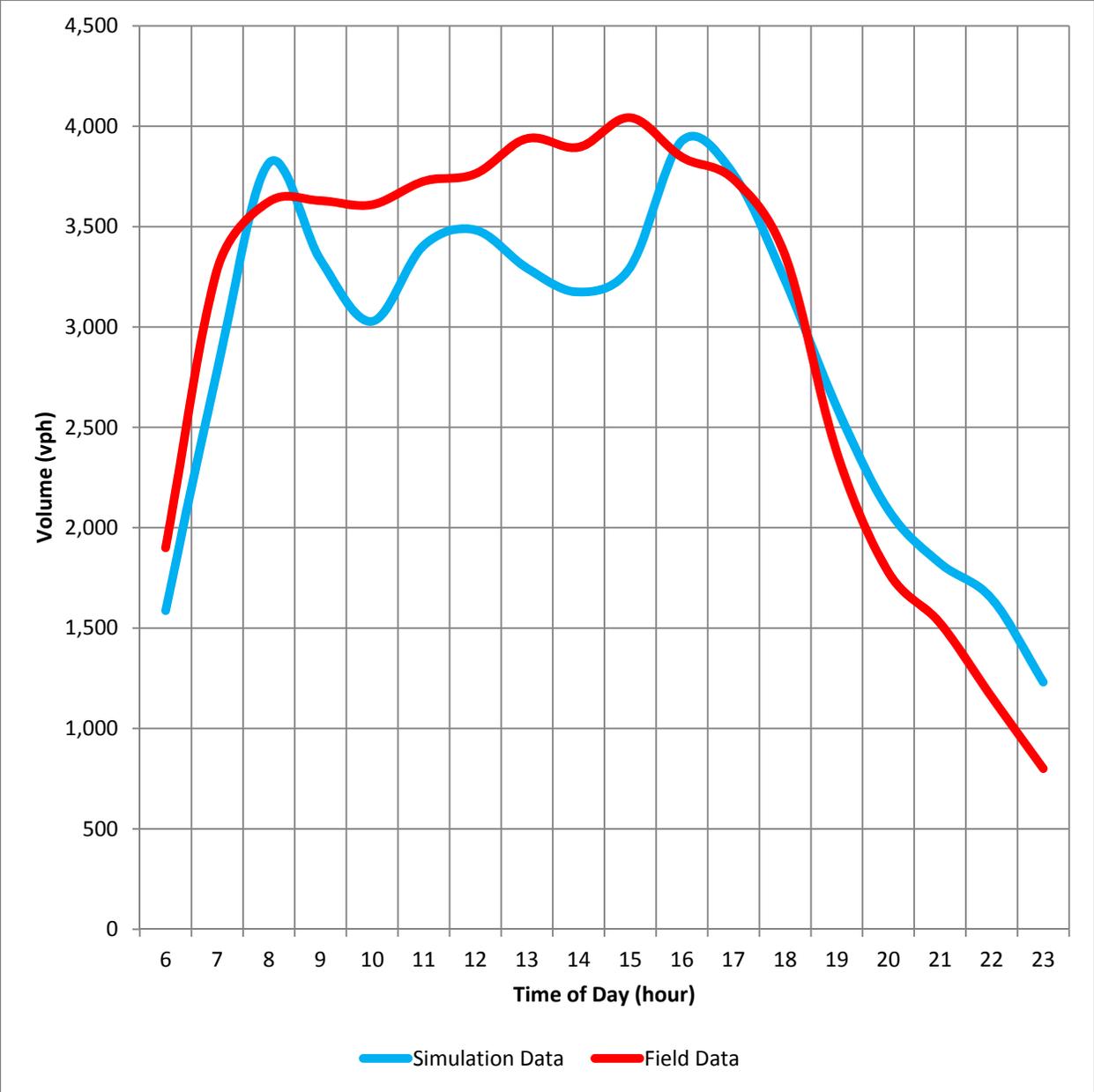
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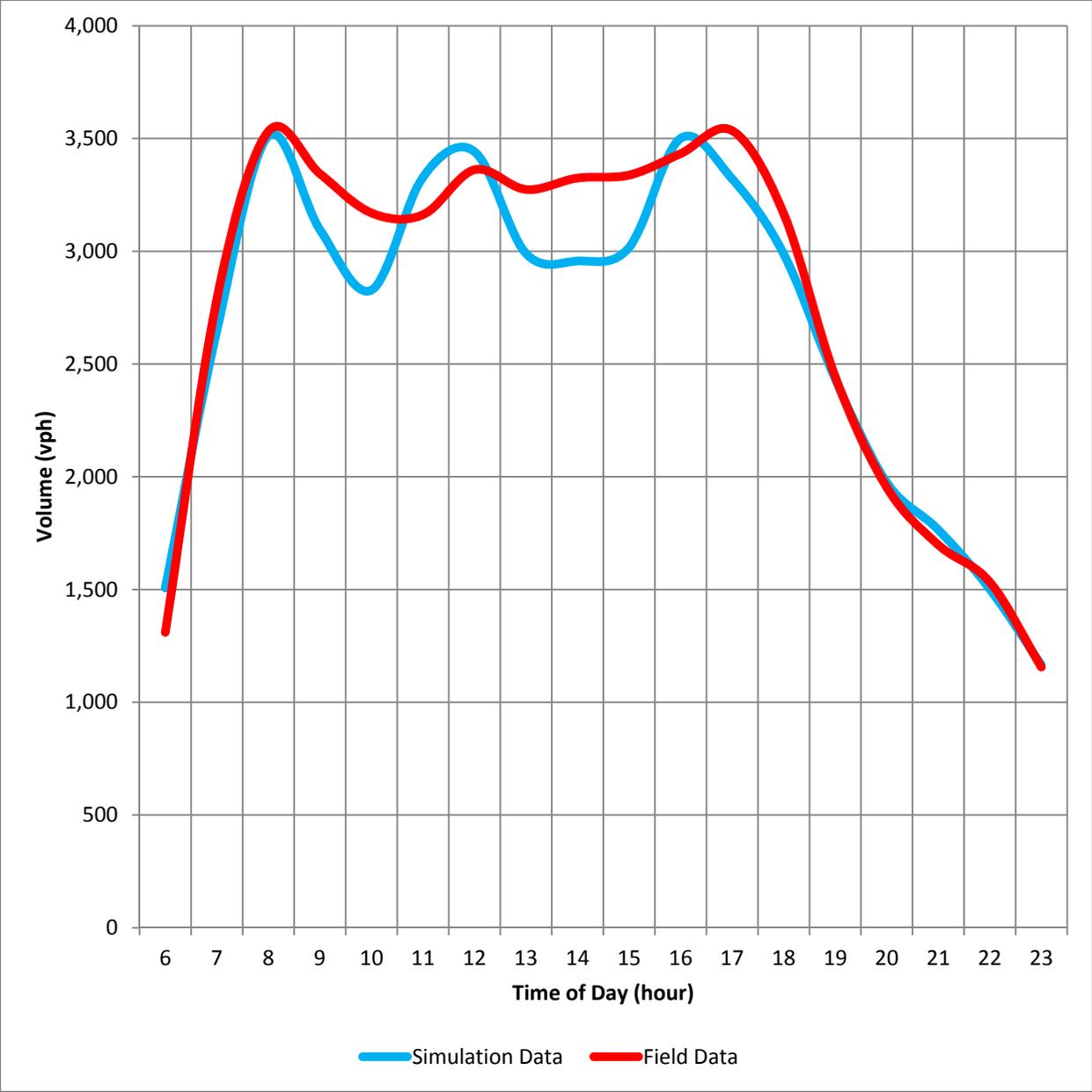
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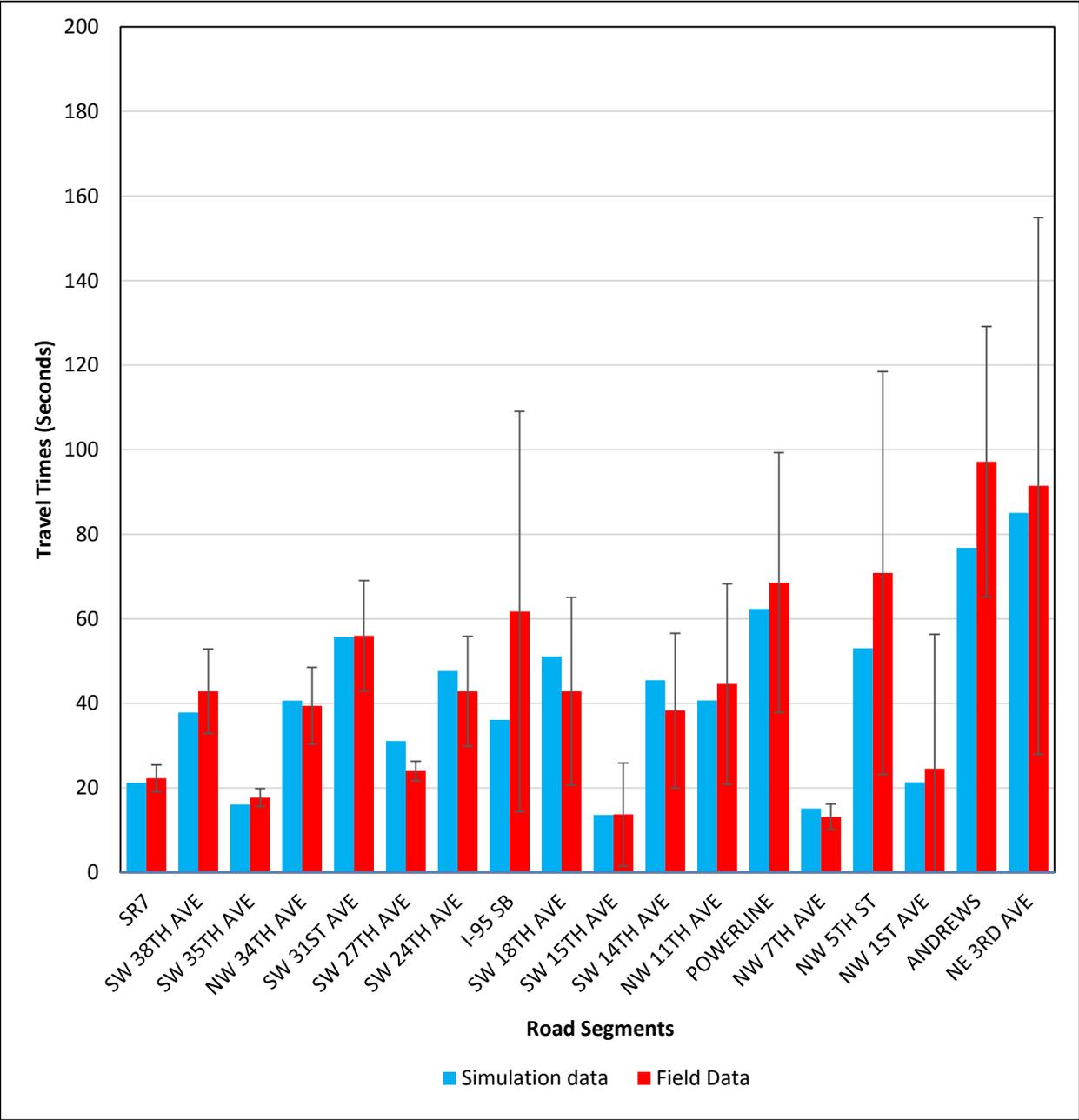
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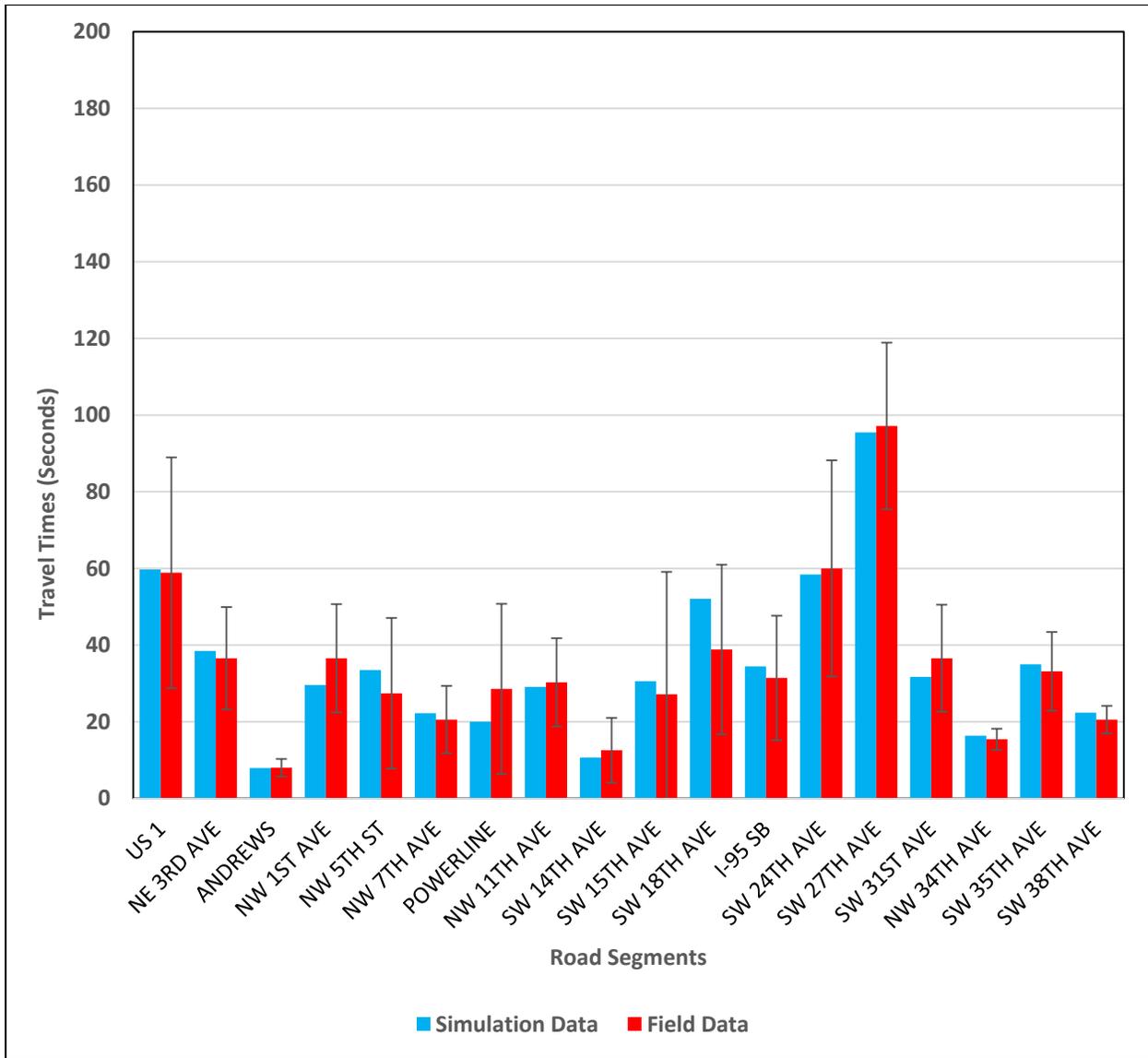
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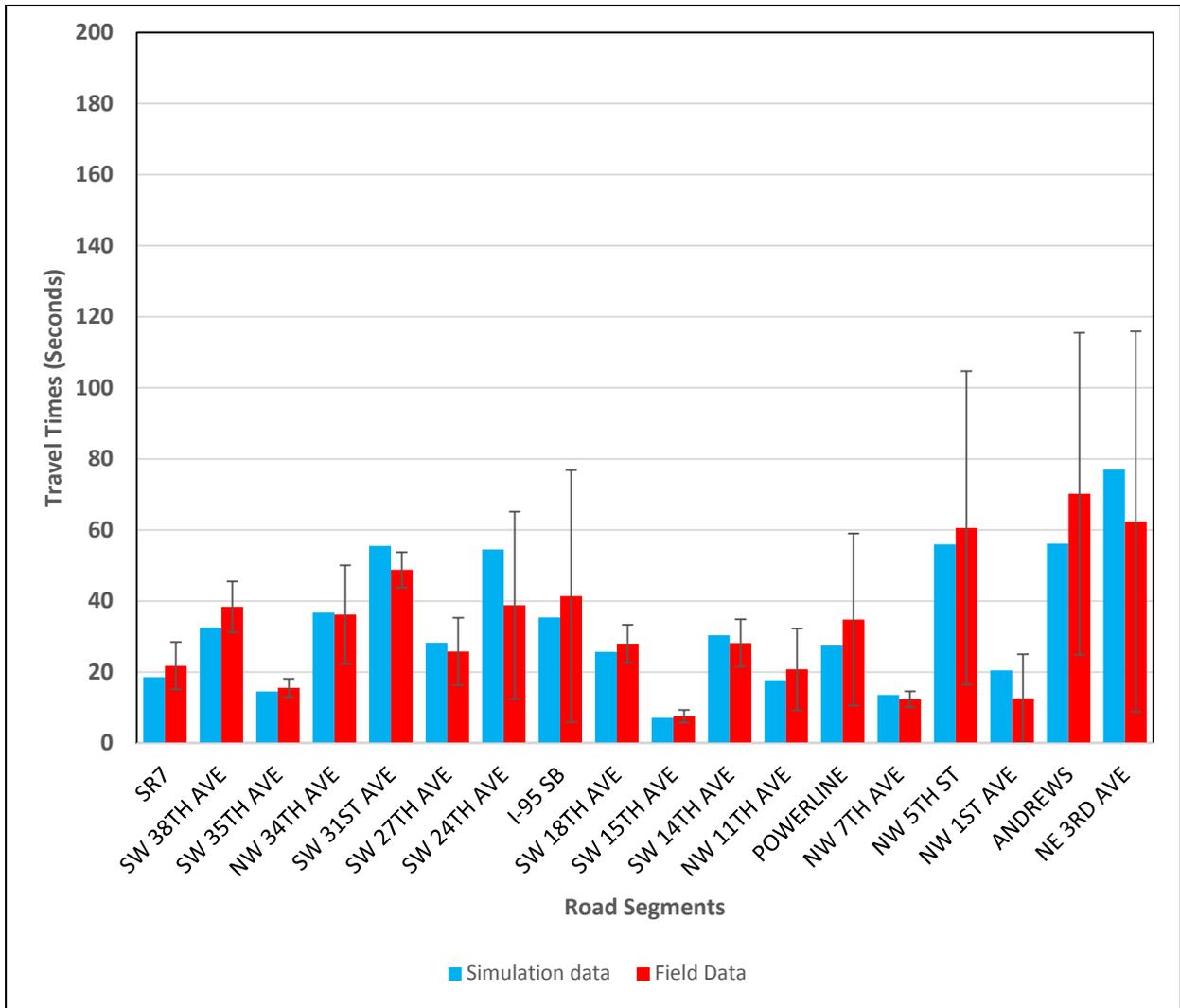
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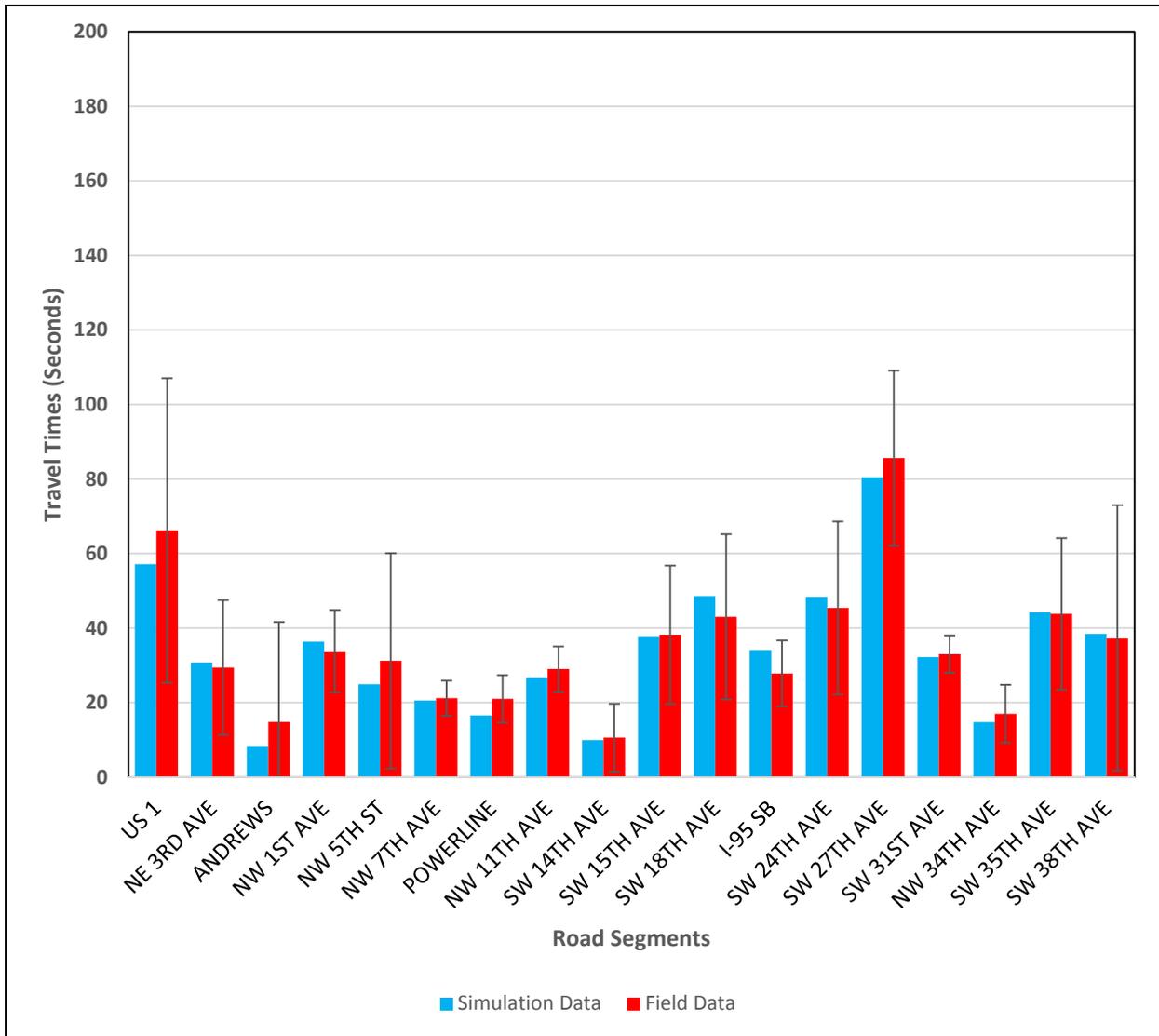
Figure 108- Broward Blvd. Validation Results Visualization: Westbound from 11:00 AM to 01:00 PM
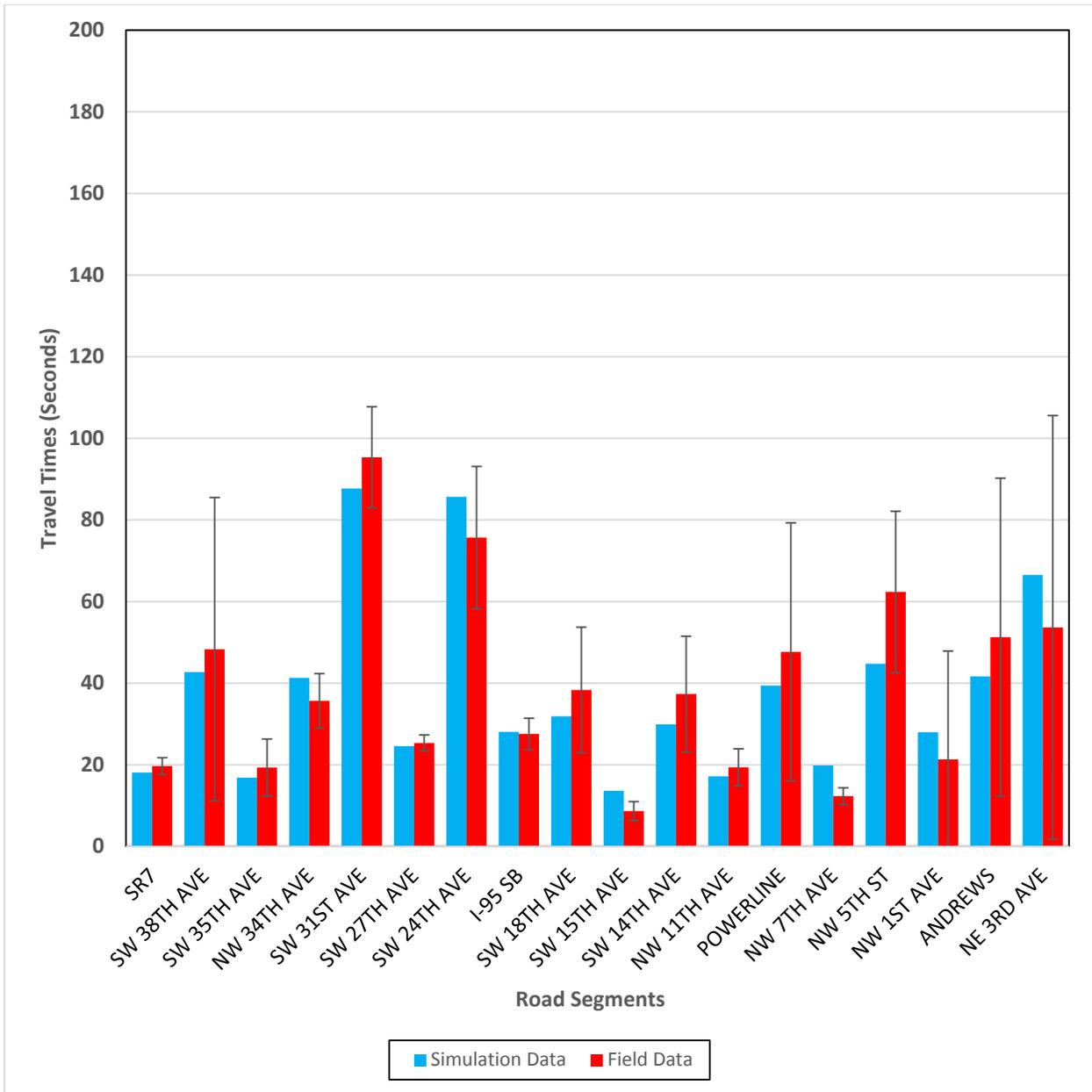
Figure 109- Broward Blvd. Validation Results Visualization: Eastbound from 04:00 PM to 06:00 PM
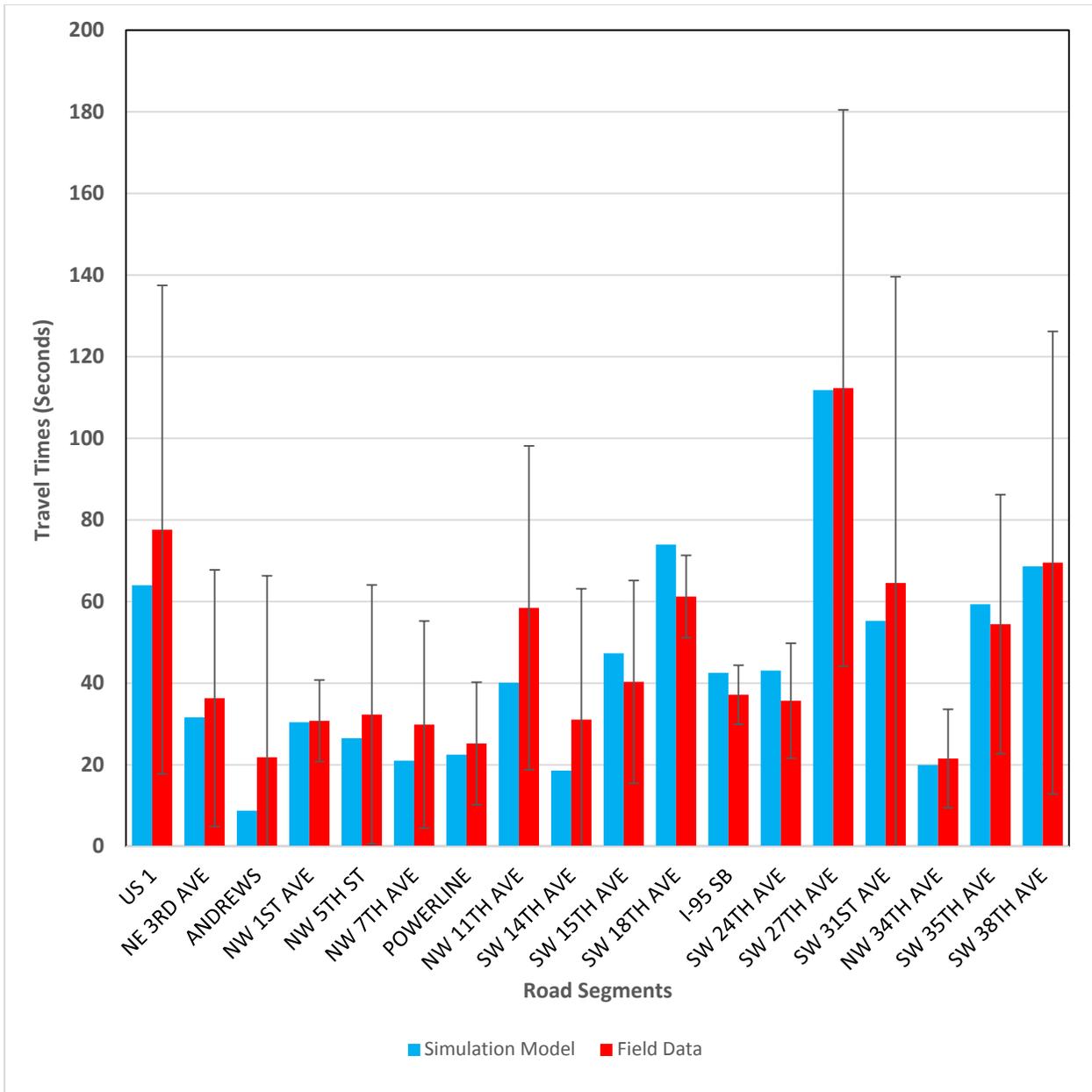
Figure 110- Broward Blvd. Validation Results Visualization: Westbound from 04:00 PM to 06:00 PM

Appendix C: Crash Data Analysis in the Study Area Charts
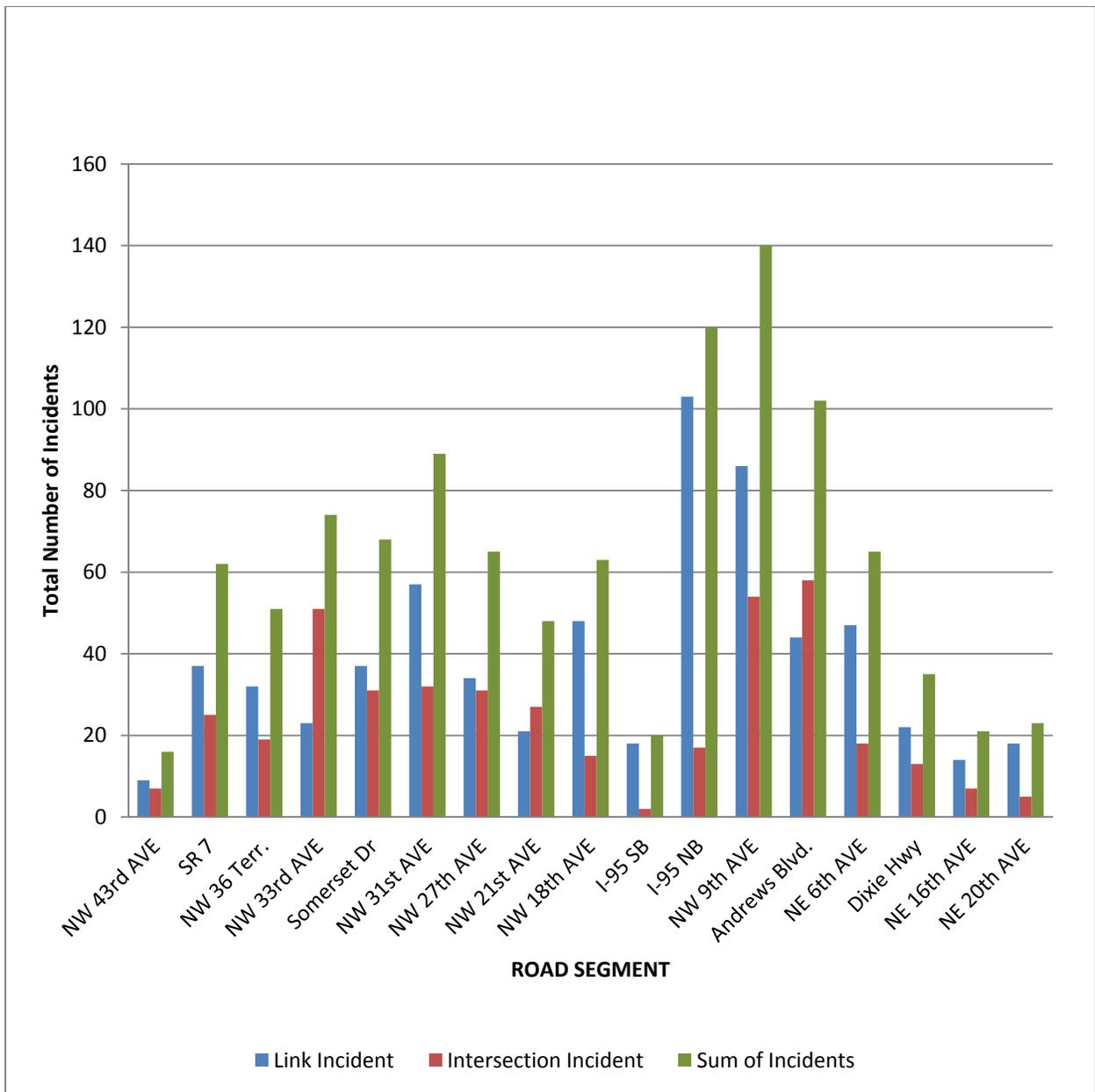
Figure 111- Oakland Blvd. EB Incident Data Analysis (2009-2011)
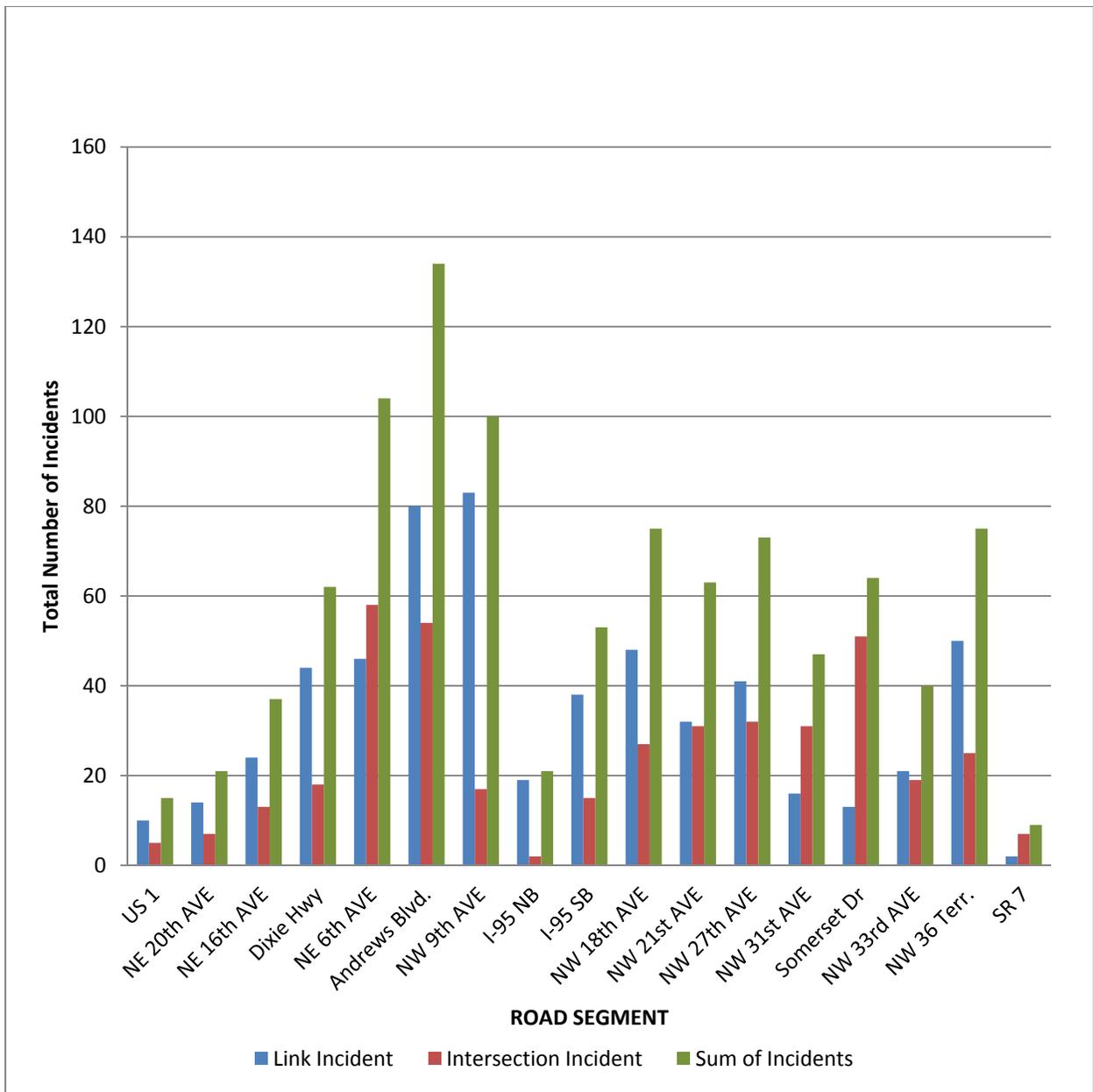
Figure 112- Oakland Blvd. WB Incident Data Analysis (2009-2011)
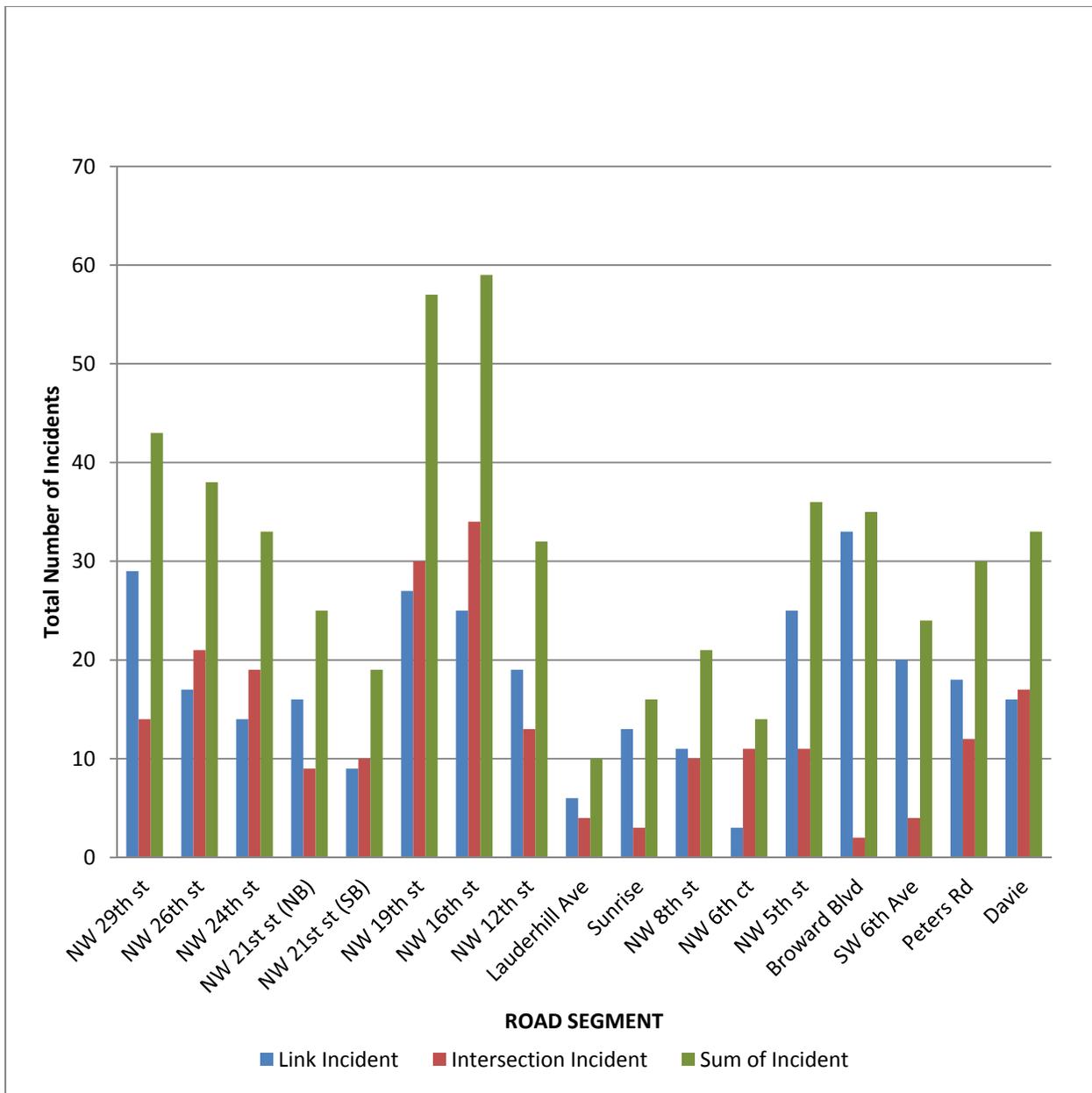
Figure 113- Oakland Blvd. SB Incident Data Analysis (2009-2011)
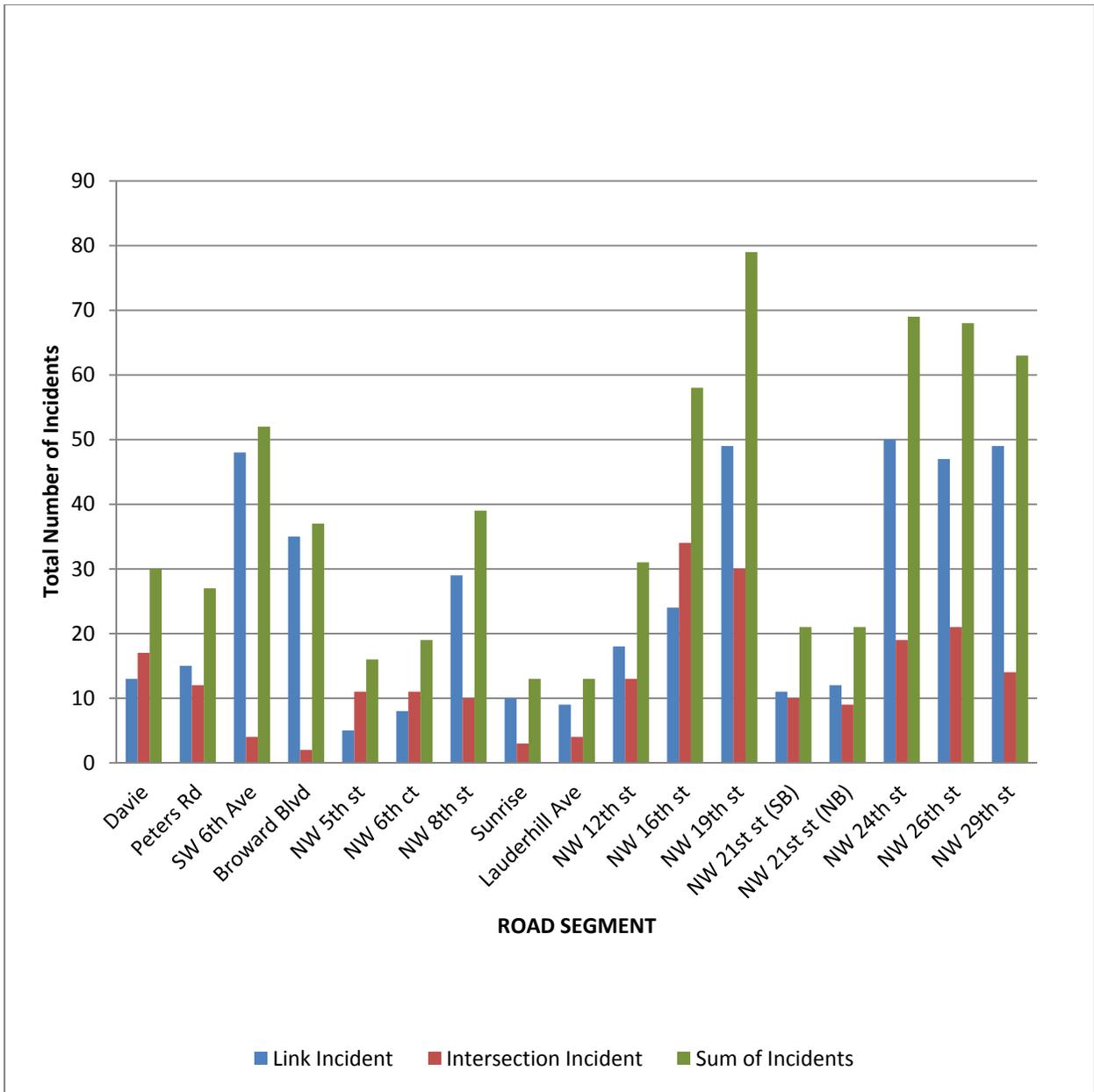
Figure 114- SR-7NB Incident Data Analysis (2009-2011)
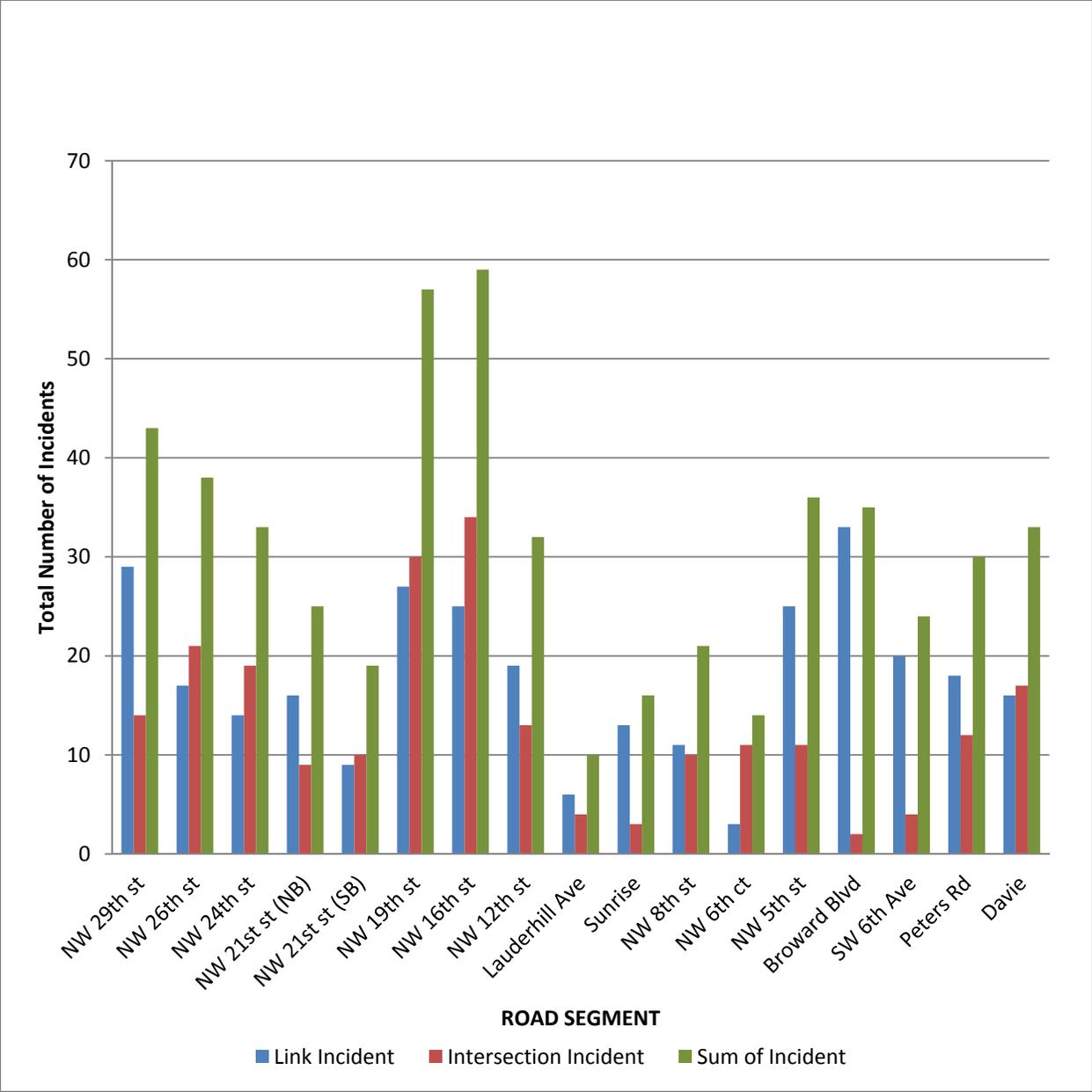
Figure 115- SR-7 SB Incident Data Analysis (2009-2011)
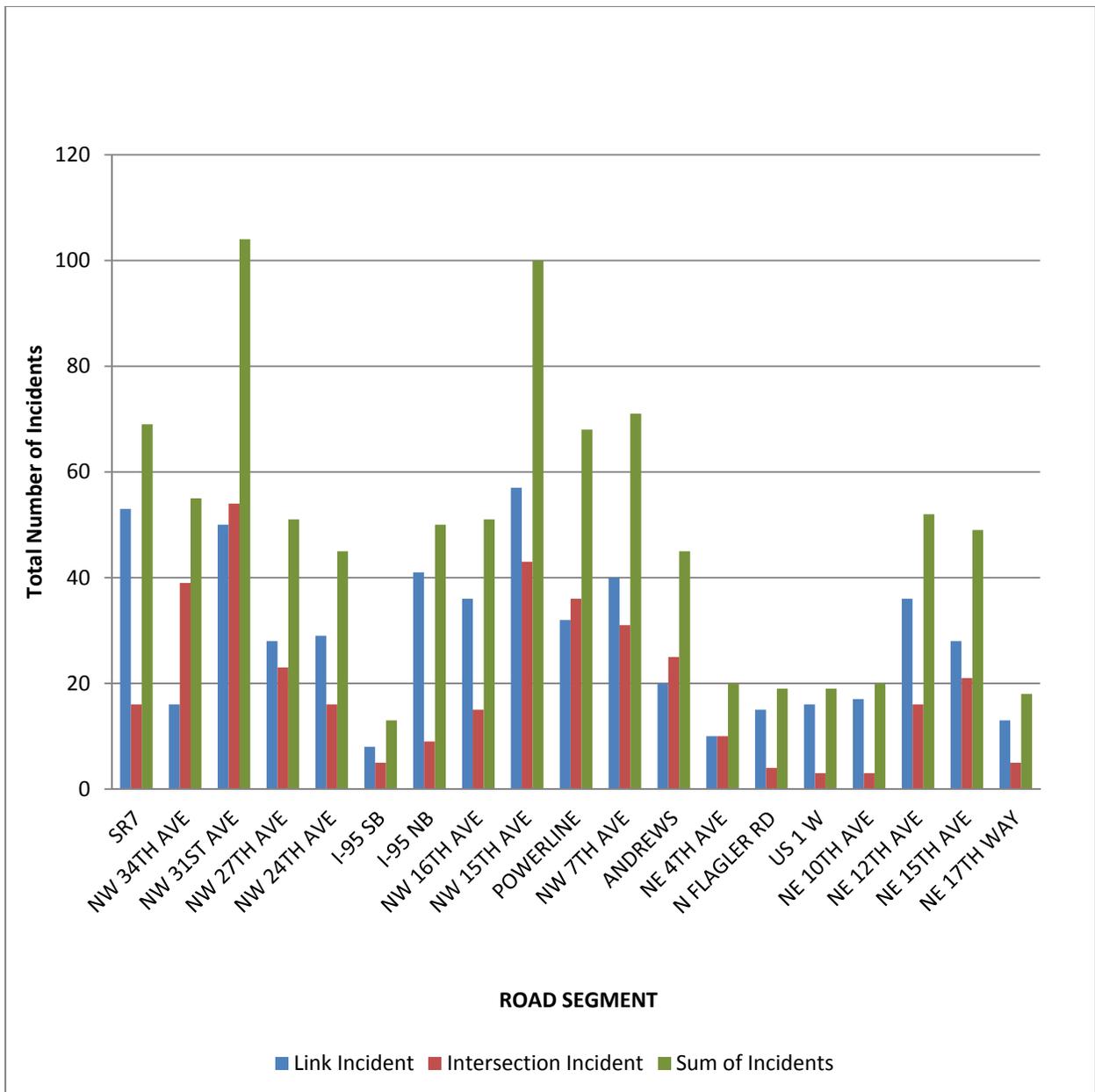
Figure 116- Sunrise Blvd. EB Incident Data Analysis (2009-2011)
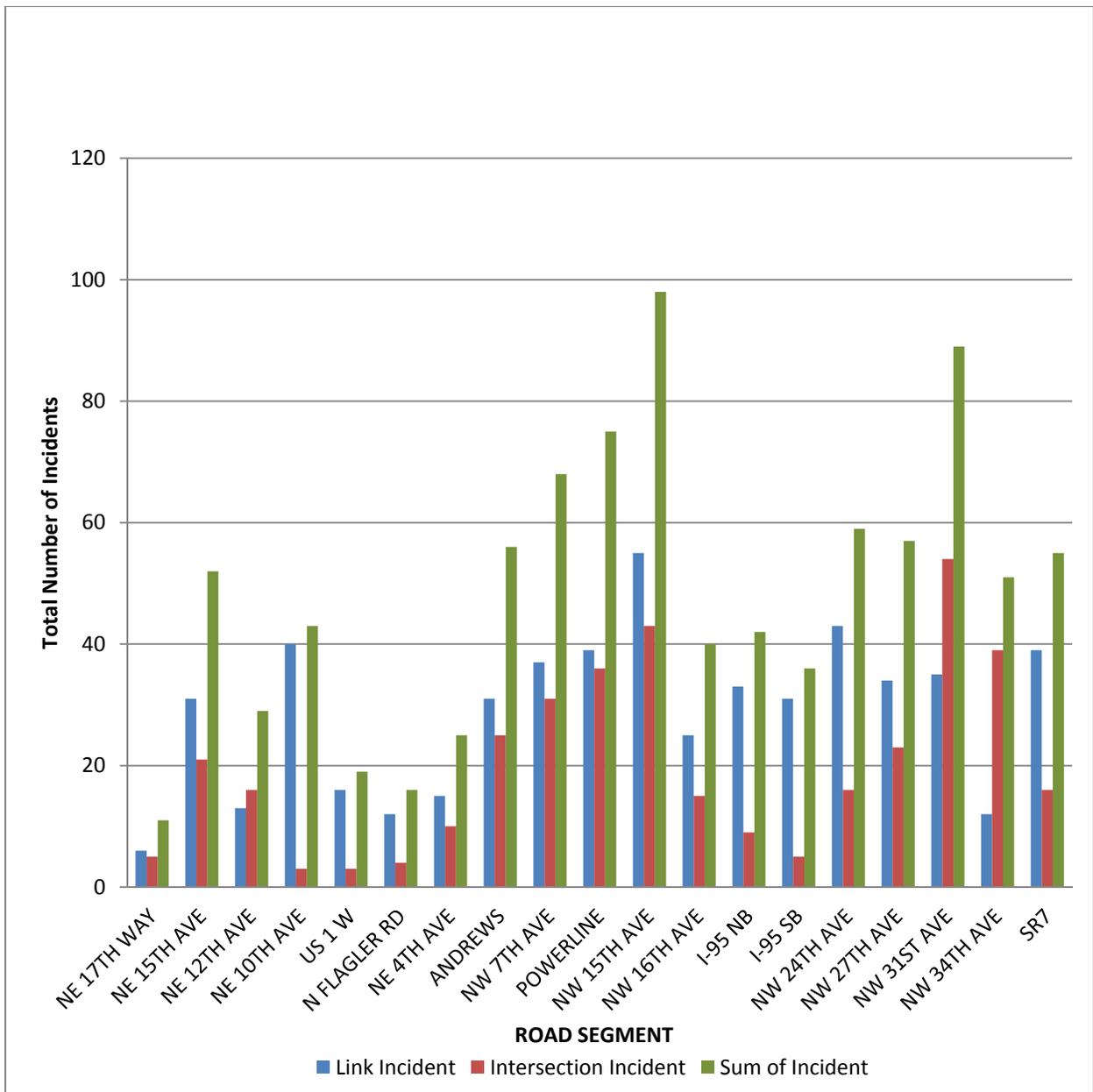
Figure 117- Sunrise Blvd. WB Incident Data Analysis (2009-2011)
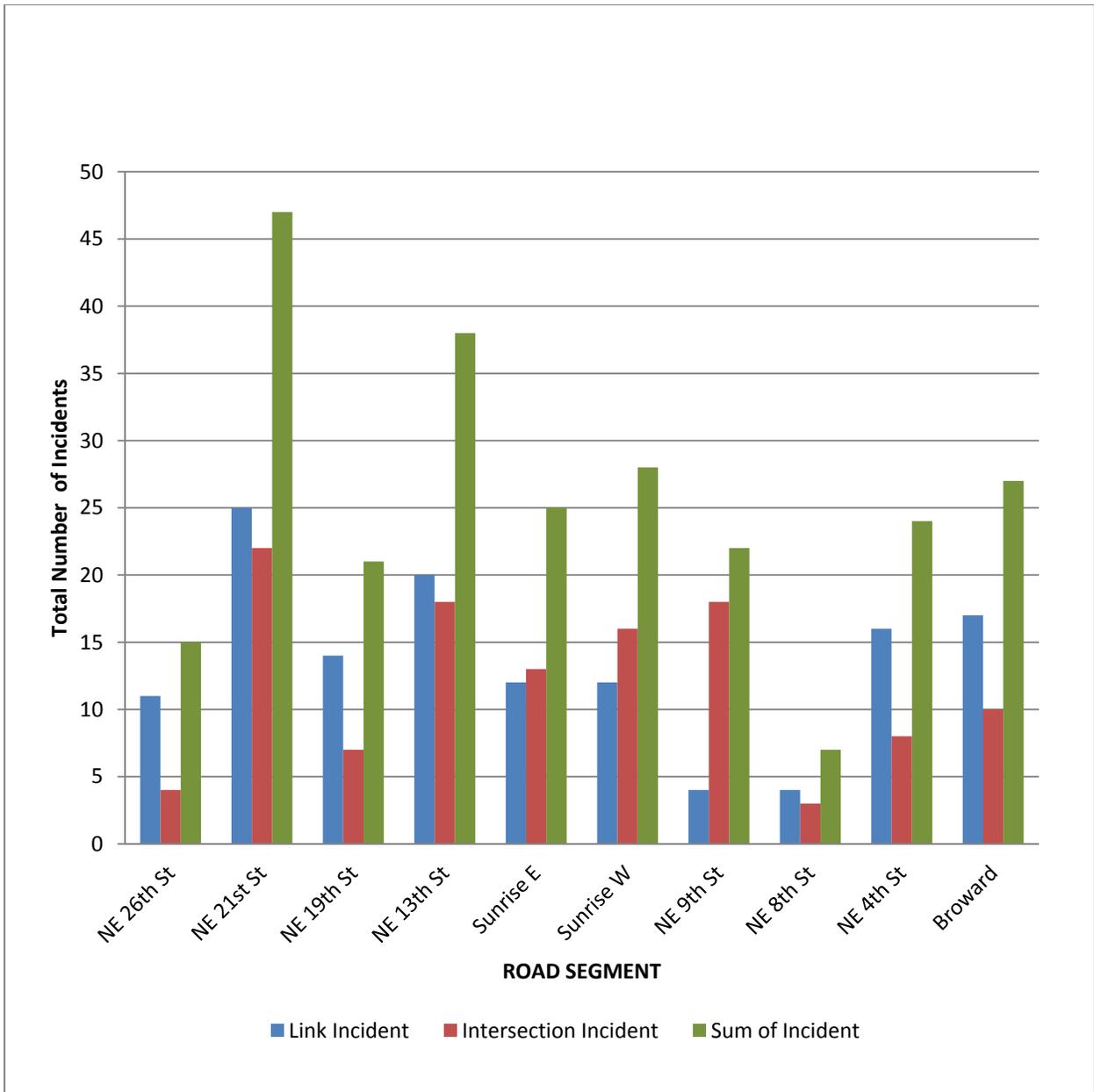
Figure 118- US-1 SB Incident Data Analysis (2009-2011)
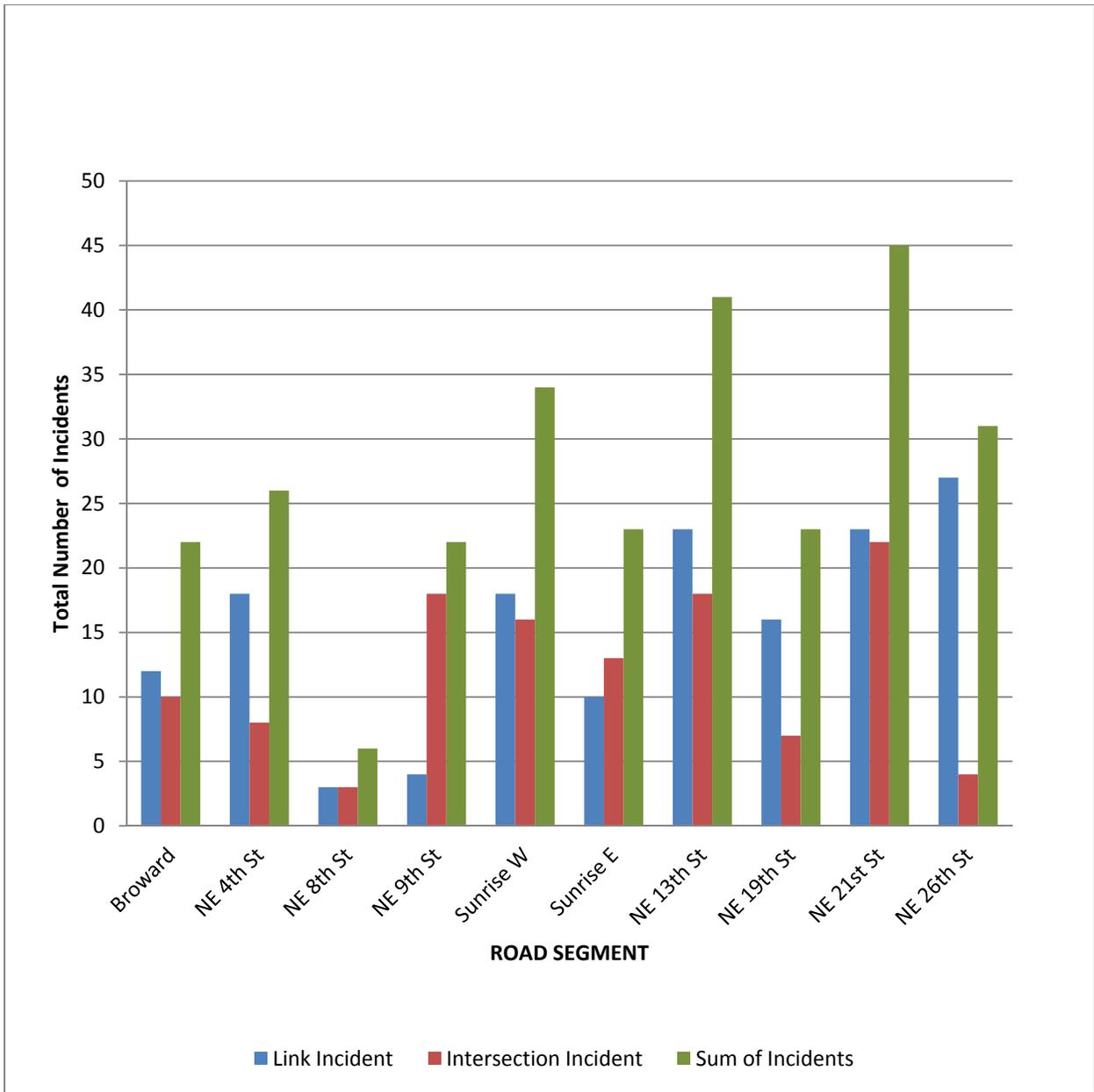
Figure 119- US-1 NB Incident Data Analysis (2009-2011)

Appendix D: Demand Modeling Parameters

Table 48- Demand Modeling Parameters of Field Detectors Using Mid-Block Detectors Data

a) Eastbound

Sensor Number	EB1	EB2	EB3	EB4	EB5
R-Squared	0.57	0.65	0.71	0.85	0.83
Link Distance (ft.)*	0.2059	0.3413	0.3592	-0.0627	-0.2752
Throughput*	3.6008	3.6268	2.4793	-2.1506	3.7281
Occupancy Rate (%)*	56.1545	9.3524	34.0646	48.785	27.6676
Spot Speed (mph)*	-13.0987	-39.4379	-16.3851	-31.3826	-22.1999

b) Westbound

Sensor Number	WB1	WB2	WB3	WB4	WB5
R-Squared	0.63	0.77	0.86	0.83	0.77
Link Distance (ft.)*	0.1869	-0.0549	1.5671	-0.0878	-0.1279
Throughput*	3.2349	3.2091	5.9029	9.9823	2.4104
Occupancy Rate (%)*	23.4375	37.6627	27.0114	43.2298	32.1709
Spot Speed (mph)*	-11.44	-8.1149	-117.6565	-2.6517	-24.495

* The numbers in the cells should be multiplied by 10^{-4} to obtain the actual model parameters.

Table 49- Demand Modeling Parameters of Field Detectors Using Bluetooth Detectors Data

a) Eastbound

Sensor Number	EB1	EB2	EB3	EB4	EB5
R-Squared	0.64	0.75	0.78	0.88	0.75
Travel Time (Sec)*	7.7556	4.6715	4.3081	2.7806	4.2536
Link Distance (ft.)*	0.101	0.0451	0.2039	0.0326	0.3965

b) Westbound

Sensor Number	WB1	WB2	WB3	WB4	WB5
R-Squared	0.69	0.81	0.85	0.84	0.78
Travel Time (Sec)*	3.594	2.7884	14.5357	10.7991	5.6865
Link Distance (ft.)*	0.2773	0.046	0.1393	-0.0223	0.0465

* The numbers in the cells should be multiplied by 10^{-4} to obtain the actual model parameters.

Table 50- Demand Modeling Parameters of Simulation Detectors Using All Detection System

a) Eastbound

EB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R-Squared	0.73	0.69	0.60	0.81	0.79	0.69	0.67	0.62	0.77	0.82	0.78	0.69	0.71	0.68	0.76	0.81	0.80	0.78
Link Distance (ft.)	0.06	0.01	-0.12	0.03	0.03	0.03	0.02	0.062	0.05	-0.33	-0.19	-0.32	0.07	0.12	0.06	-0.74	0.07	-0.25
Throughput	2.09	14.98	1.08	5.83	2.26	1.09	4.65	1.83	10.11	2.00	0.34	2.62	5.54	-1.31	5.59	13.04	8.00	4.79
Occupancy Rate (%)	4.48	133.31	43.91	17.36	3.79	15.92	13.46	8.36	48.79	18.01	10.89	0.27	1.46	21.37	1.60	19.16	10.62	1.43
Spot Speed (mph)	-2.88	-8.30	-5.95	-4.52	0.91	-8.50	-1.80	-18.12	-15.70	-25.52	-18.95	-19.1	-0.64	-9.60	0.35	-6.26	-0.62	-20.98
Travel Time (Sec)	5.38	10.62	-4.83	5.04	3.13	-1.92	1.32	3.90	16.95	25.44	0.73	5.16	1.12	-0.99	0	12.66	0	3.15

b) Westbound

WB	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
R-Squared	0.78	0.73	0.77	0.70	0.66	0.61	0.62	0.73	0.71	0.78	0.87	0.74	0.75	0.86	0.70	0.69	0.76	0.66
Link Distance (ft.)	0.05	0.07	-0.68	0.05	0.12	0.06	0.08	0.054	0.17	0.04	0.08	0.04	0.06	0.02	0.05	0.08	0.04	0.07
Throughput	17.30	7.40	3.13	2.82	8.91	2.55	1.11	2.07	11.44	3.10	7.29	6.57	3.38	5.07	5.50	3.05	4.23	3.63
Occupancy Rate (%)	16.54	5.19	30.52	1.20	20.49	4.14	3.93	1.83	10.68	2.32	16.83	61.09	3.93	28.50	65.40	7.81	20.62	16.73
Spot Speed (mph)	-23.86	-0.89	-35.28	-5.40	-7.62	-4.45	-5.99	-5.92	-38.0113	-0.38	-33.66	-9.72	-7.72	-4.68	-9.25	-1.78	-0.64	-6.47
Travel Time (Sec)	3.60	-0.38	17.86	0.42	18.71	4.40	0.28	0.62	12.5376	2.35	5.41	22.74	1.51	4.53	29.14	21.52	9.36	20.40

Table 51- Demand Modeling Parameters of Simulation Detectors Using Bluetooth Detection Only

a) Eastbound

Link Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R-Squared	0.70	0.65	0.50	0.78	0.75	0.61	0.49	0.37	0.65	0.77	0.60	0.51	0.54	0.61	0.63	0.67	0.62	0.69
Travel Time (Sec)	5.69	42.07	13.71	15.98	13.10	6.11	13.58	3.37	6.55	11.19	36.52	5.80	5.07	7.09	11.63	20.23	39.45	37.36
Link Distance (ft.)	0.05	0.05	0.02	0.23	0.03	0.04	0.07	0.11	0.13	0.08	0.31	0.28	0.32	0.14	0.18	0.09	0.38	0.10

b) Westbound

Link Number	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
R-Squared	0.52	0.43	0.64	0.38	0.58	0.45	0.47	0.48	0.61	0.62	0.60	0.73	0.70	0.83	0.66	0.66	0.73	0.65
Travel Time (sec.)	3.87	3.45	37.30	1.80	16.35	4.49	2.74	3.25	40.87	6.90	13.27	17.51	13.15	6.07	13.85	36.68	13.85	19.72
Link Distance (ft.)	0.13	0.16	0.46	0.13	0.19	0.11	0.17	0.10	0.24	0.11	0.16	0.043	0.054	0.02	0.06	0.11	0.04	0.06

Table 52- Demand Modeling Parameters of Simulation Detectors Using Mid-Block Detectors Only

a) Eastbound

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R-Squared	0.73	0.69	0.60	0.81	0.78	0.69	0.66	0.62	0.75	0.79	0.78	0.69	0.72	0.68	0.76	0.80	0.80	0.77
Link Distance (ft)	0.05	0.02	-0.12	0.03	0.03	0.03	0.02	0.0628	0.05	-0.32	-0.19	-0.30	0.06	0.12	0.06	-0.75	0.07	-0.22
Throughput	2.15	11.26	2.19	5.10	2.39	1.52	4.20	0.9184	4.09	-8.19	0.21	0.67	4.91	-0.69	5.59	8.18	8.00	4.78
Occupancy Rate (%)	5.45	86.85	31.30	3.14	2.54	10.35	6.08	3.9483	3.06	58.31	12.90	12.38	4.97	19.2	1.60	35.08	10.62	7.20
Spot Speed (mph)	5.34	-1.31	-4.22	-0.73	3.36	-7.25	-3.27	20.3912	-4.65	60.76	-19.40	-23.91	2.67	-7.89	-0.35	20.26	-0.62	-27.57

b) Westbound

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
R-Squared	0.75	0.73	0.75	0.70	0.64	0.61	0.62	0.73	0.71	0.77	0.86	0.72	0.75	0.83	0.68	0.68	0.76	0.63
Link Distance (ft)	0.05	0.07	-0.61	0.05	0.12	0.07	0.08	0.05	0.18	0.05	0.08	0.04	0.05	0.02	0.05	0.07	0.03	0.06
Throughput	13.39	7.59	-1.97	2.56	2.07	1.05	1.02	1.82	7.77	2.42	6.07	1.58	2.80	2.27	-0.60	0.87	2.52	-0.82
Occupancy Rate (%)	6.46	3.69	52.80	3.10	21.66	7.81	4.64	3.98	26.17	9.34	1.68	7.37	0.21	1.87	14.90	20.24	0.67	35.17
Spot Speed (mph)	-16.93	-1.27	-43.46	-6.02	-13.20	-7.73	-6.22	-6.56	-26.93	-2.27	-40.64	-8.71	10.05	-5.54	-11.29	-9.94	-7.64	-12.60

Appendix E: Traffic Parameters Visualization Based on Simulation Detectors
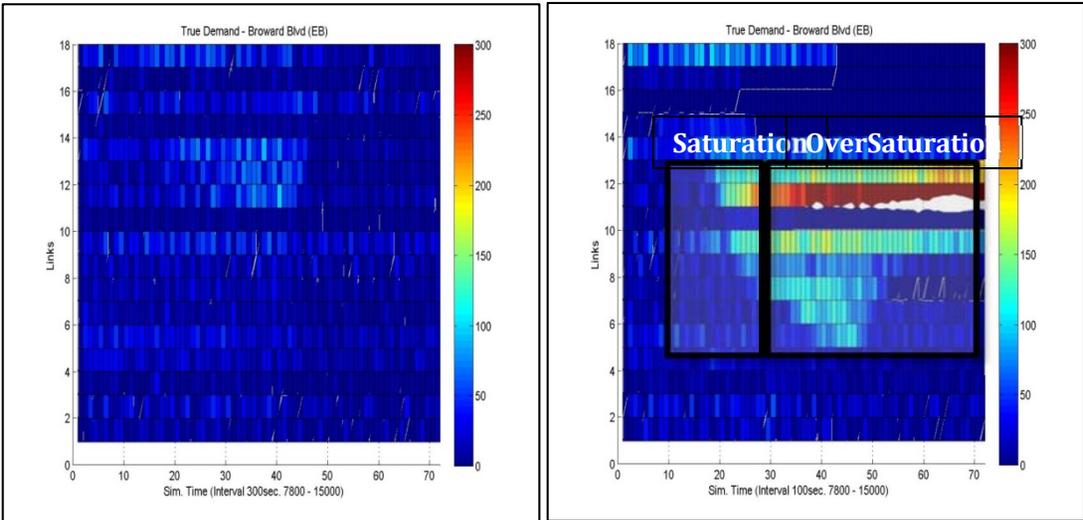
a) Base   b) Scenario

Figure 120- True Demand in Saturation Scenario
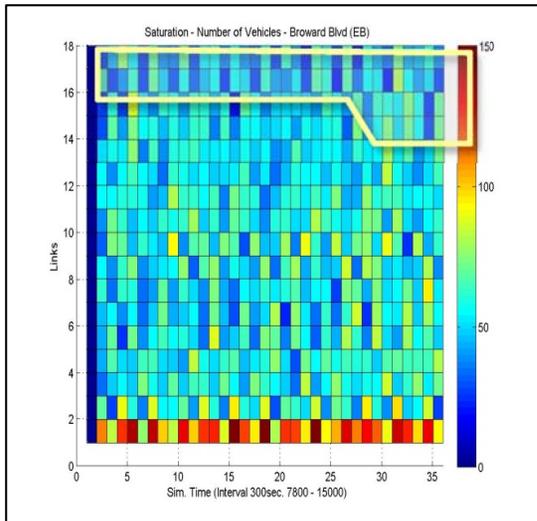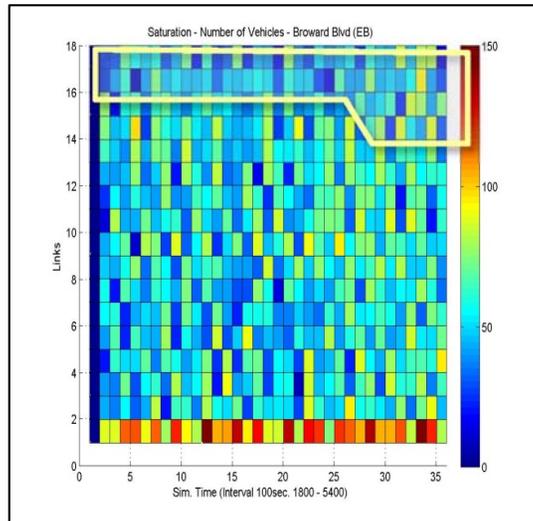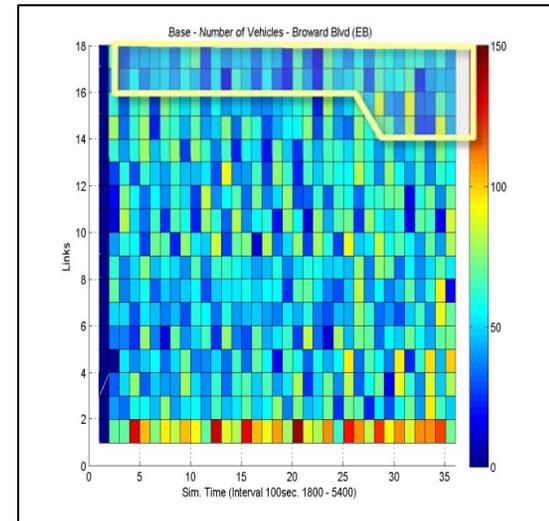
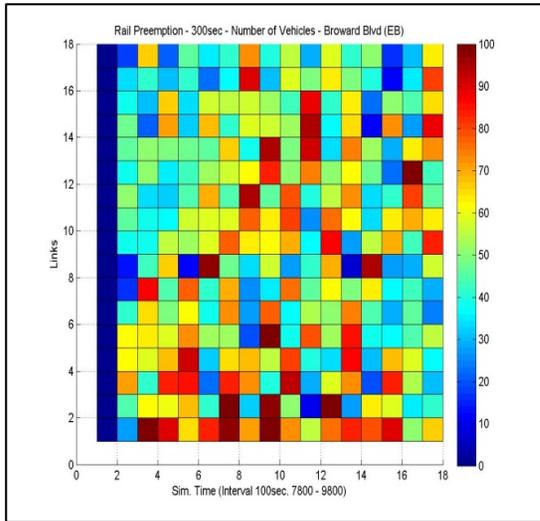a) Base   b) Scenario   c) Strategy-Applied
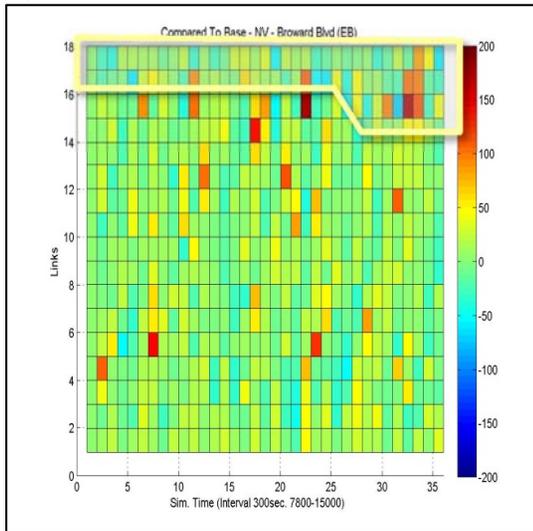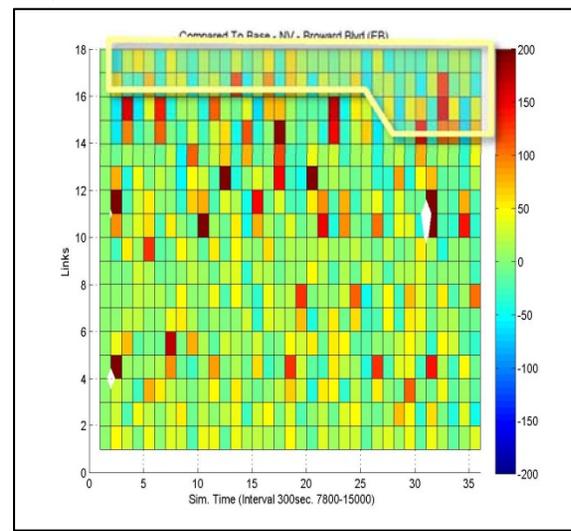
d) Scenario Compared to Base   e) Strategy Compared to Base
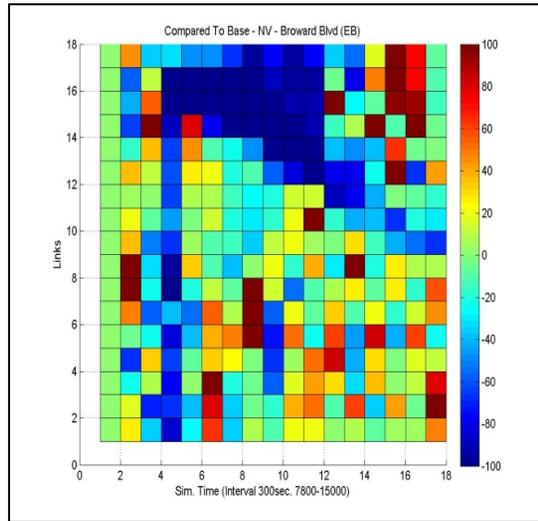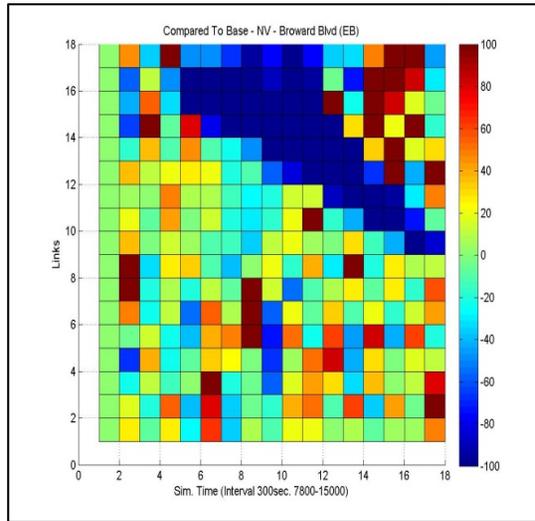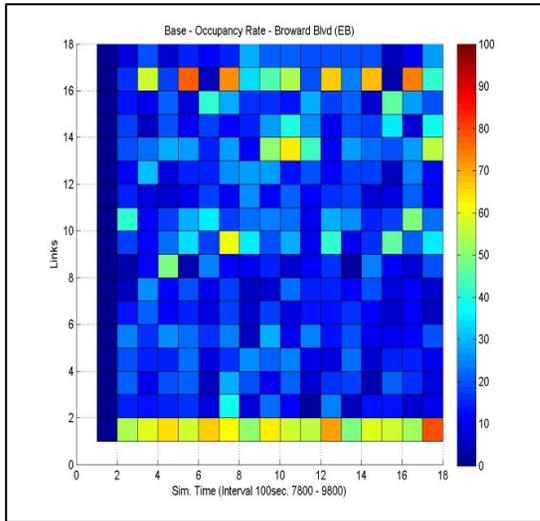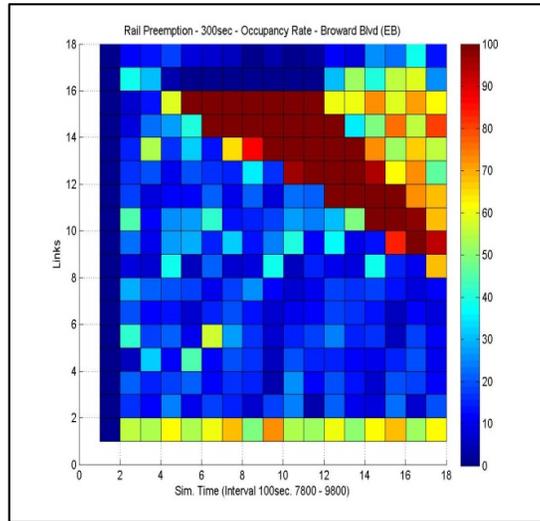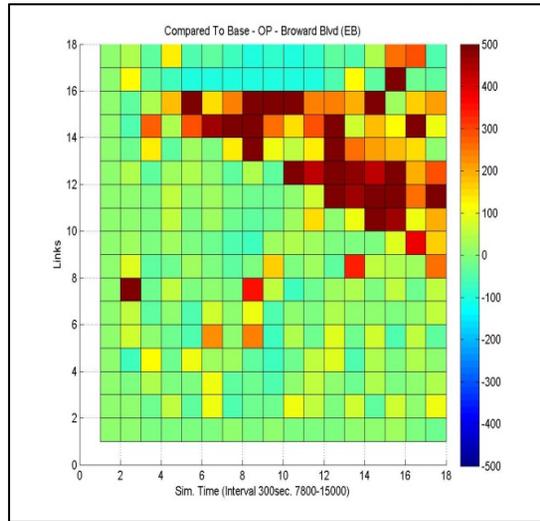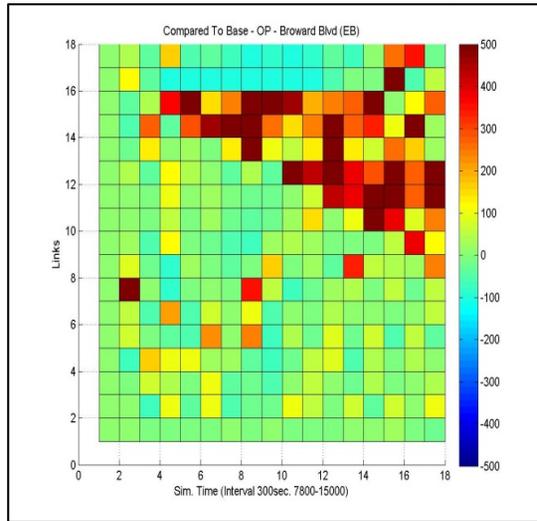
Figure 121- Visualization of the Throughput Performance Measure in Saturation Scenario
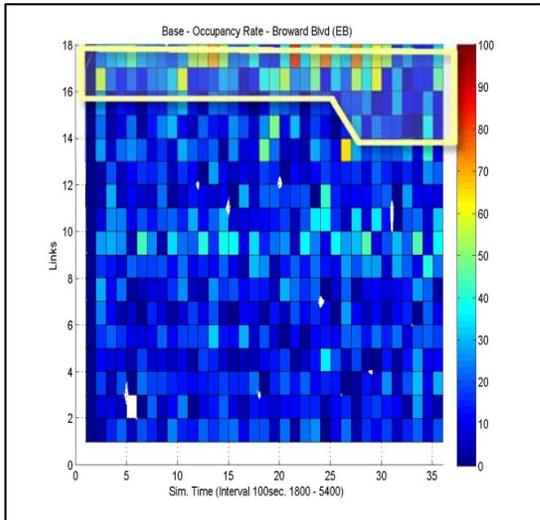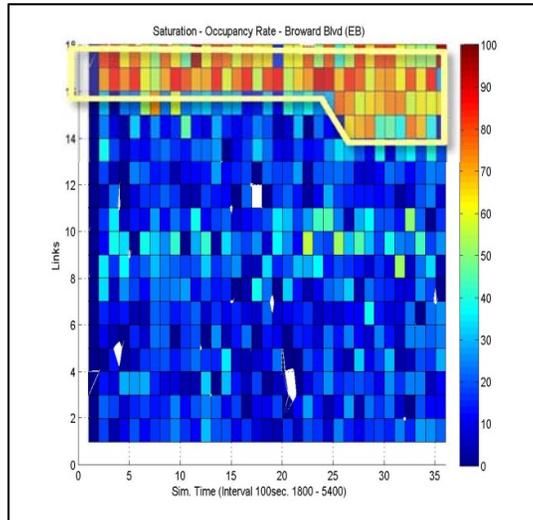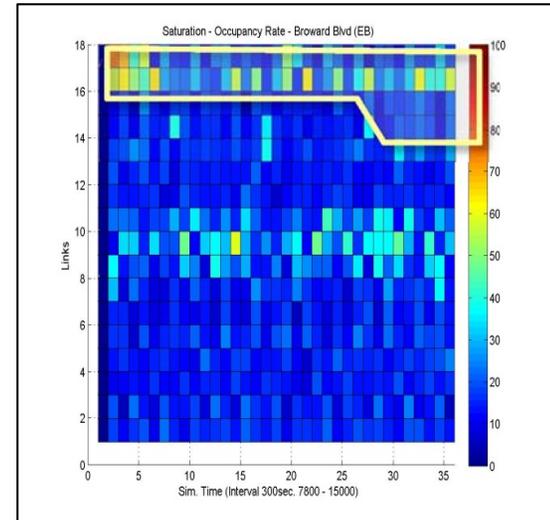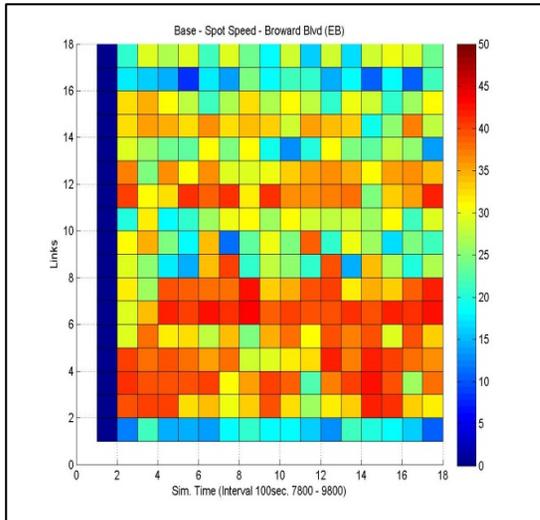
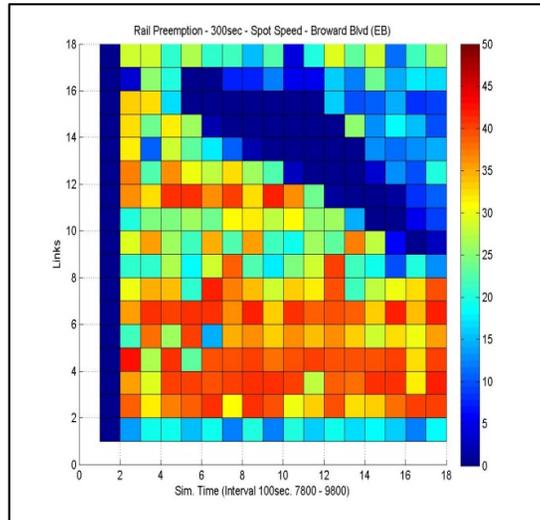a) Base　　　　　　　　　b) Scenario　　　　　　　　　c) Strategy-Applied
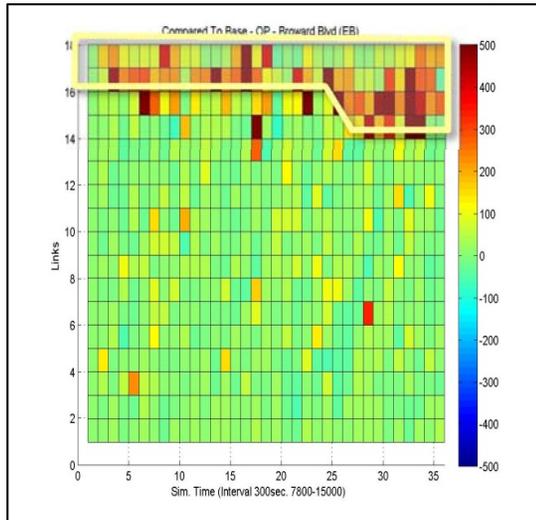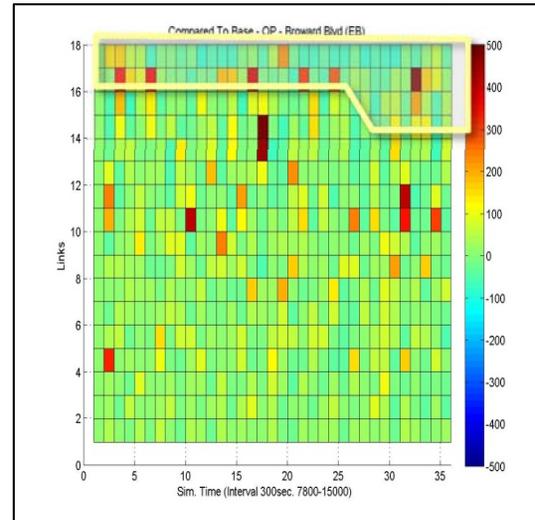
d) Scenario Compared to Base　　　　　e) Strategy Compared to Base
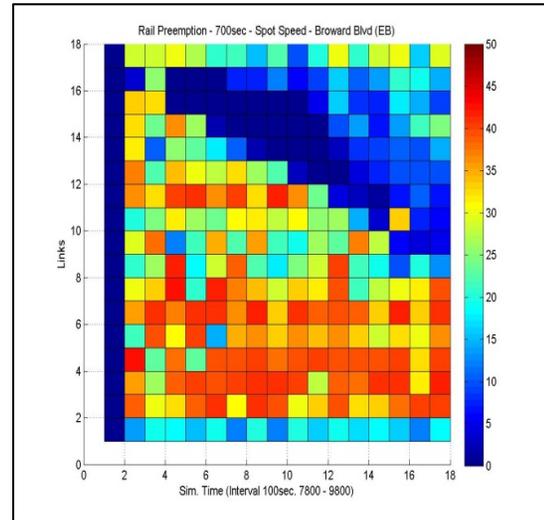
Figure 122- Visualization of the Occupancy Performance Measure in Saturation Scenario
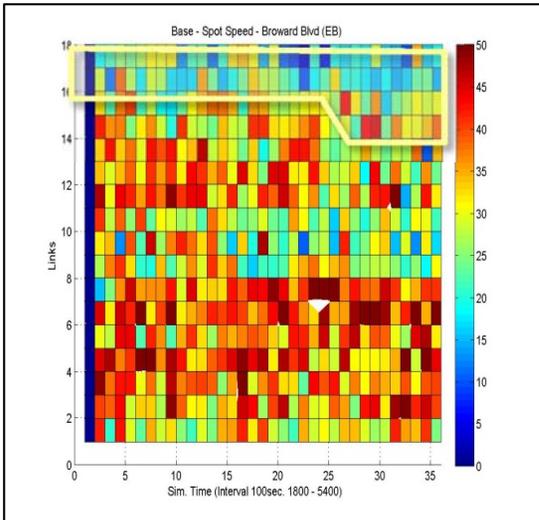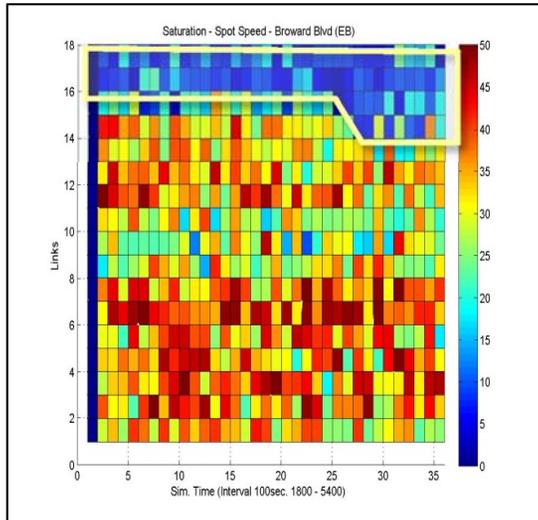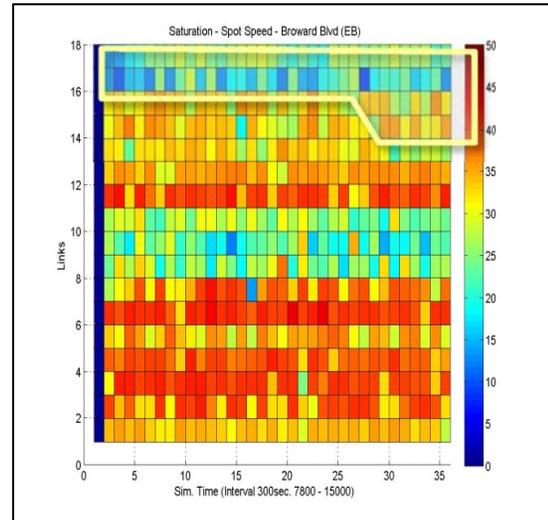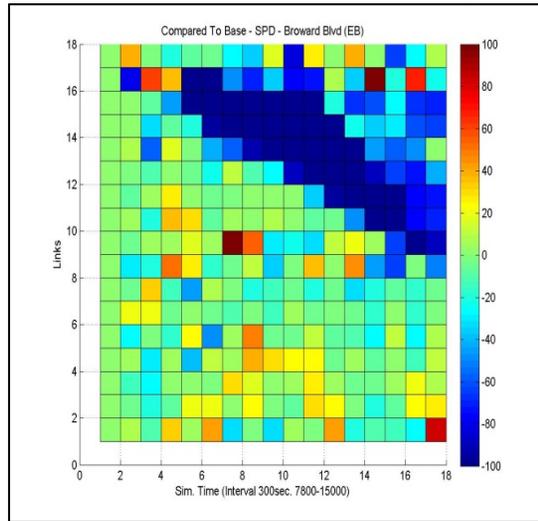
a) Base   b) Scenario   c) Strategy-Applied
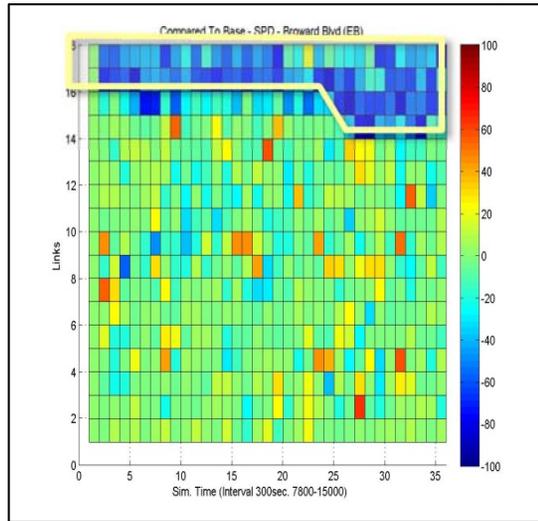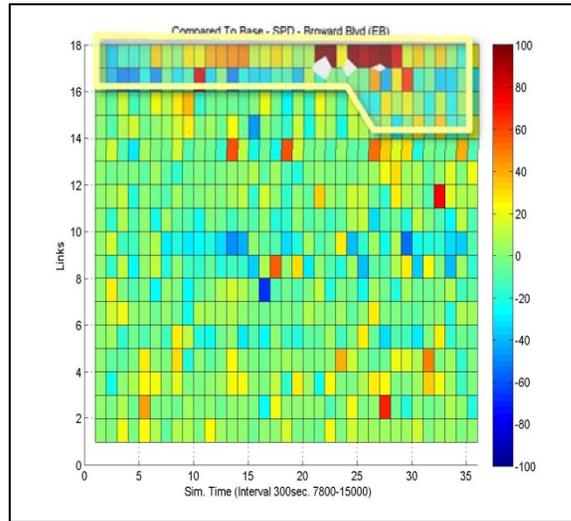
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 123- Visualization of the Spot Speed Performance Measure in Saturation Scenario
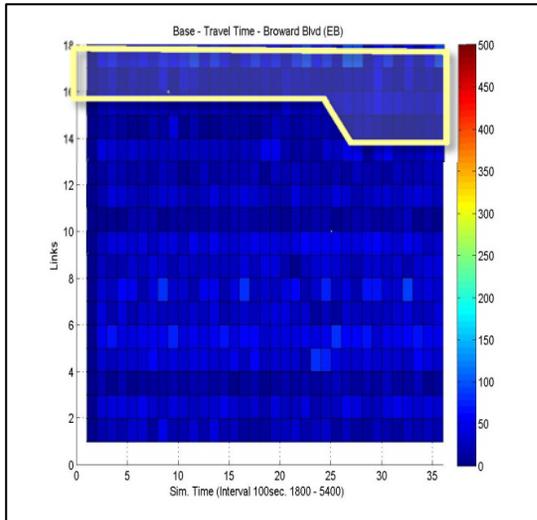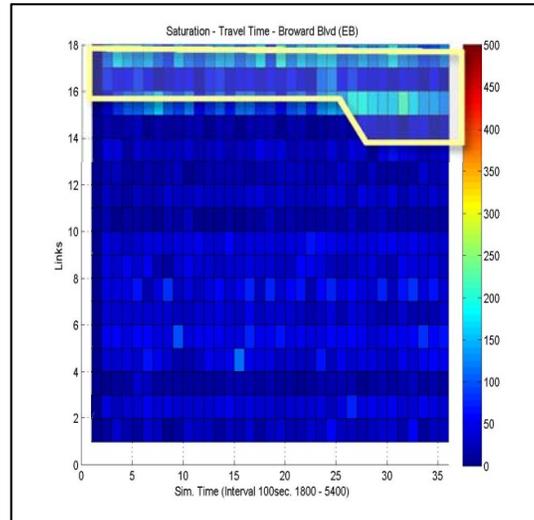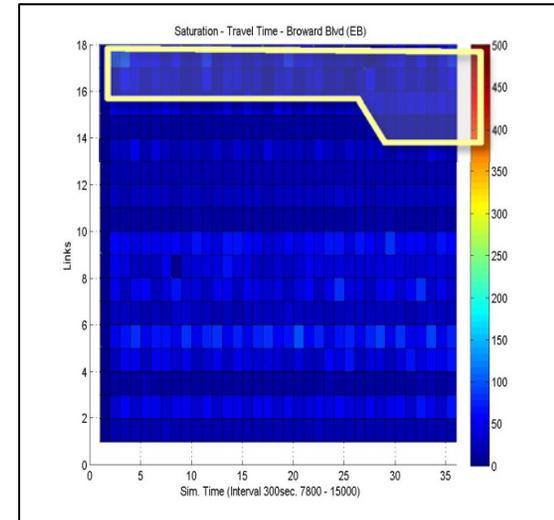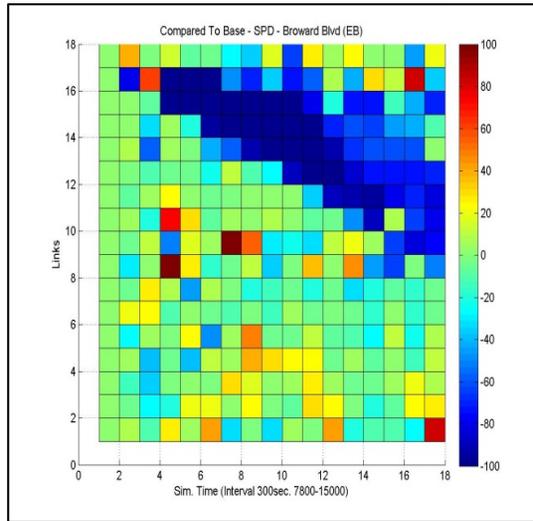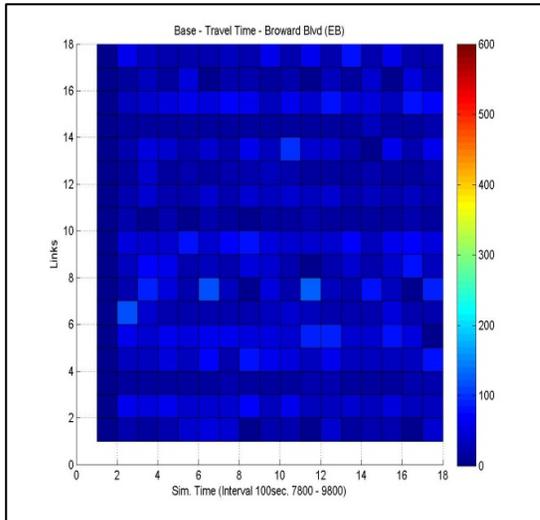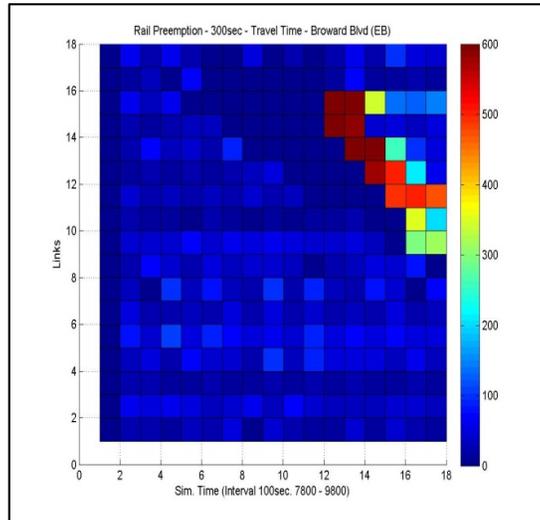
a) Base   b) Scenario   c) Strategy-Applied
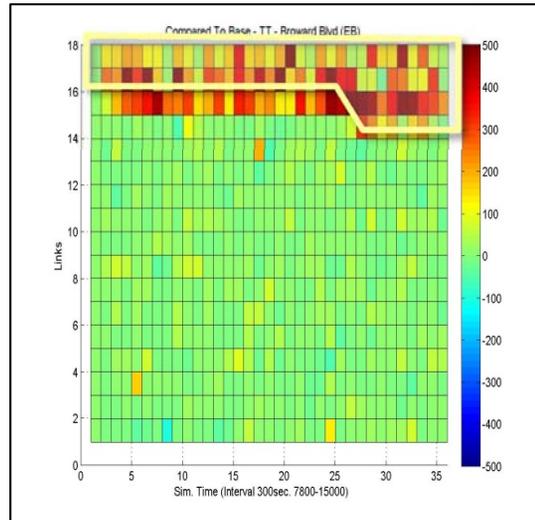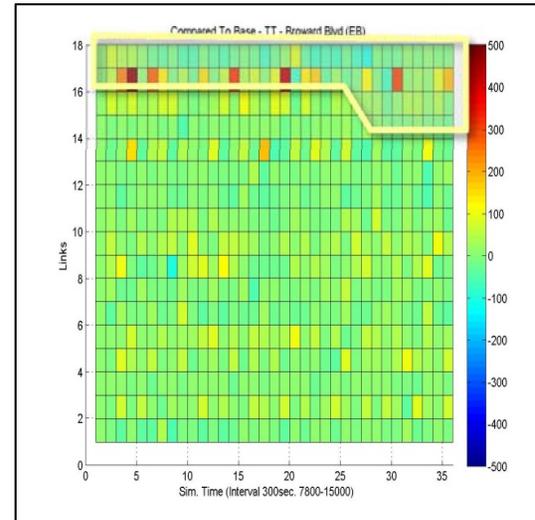
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 124- Visualization of the Travel Time Performance Measure in Saturation Scenario
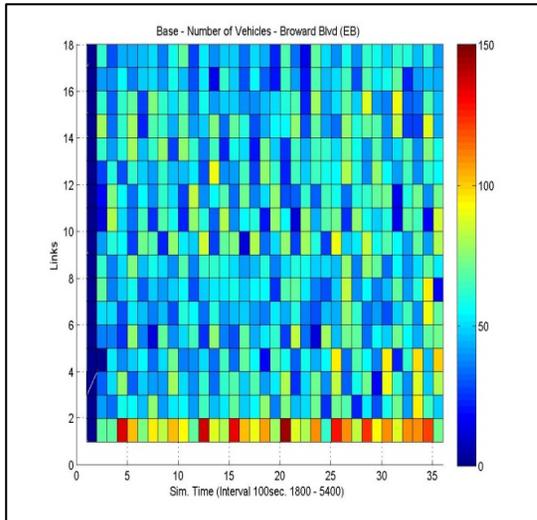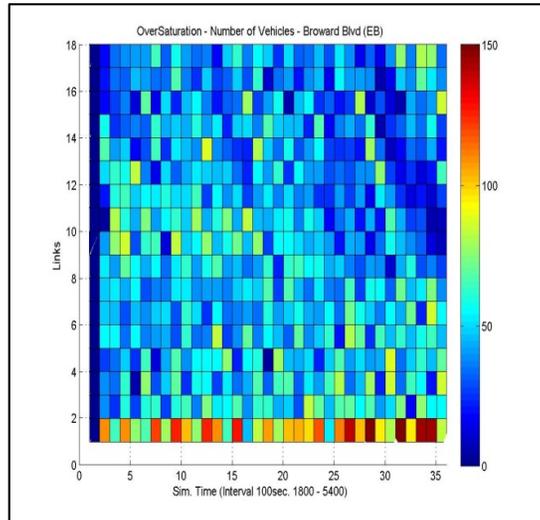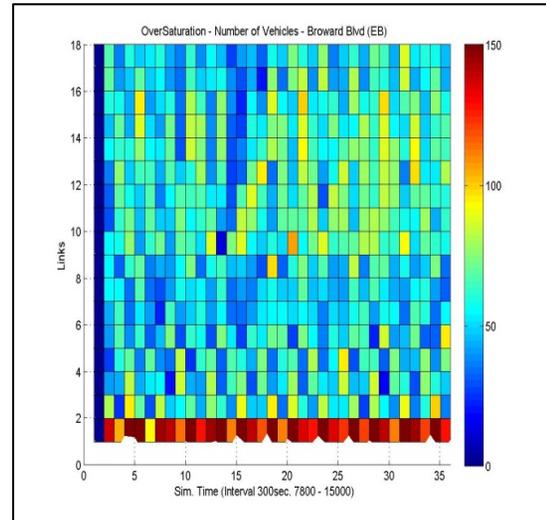
a) Base   b) Scenario   c) Strategy-Applied
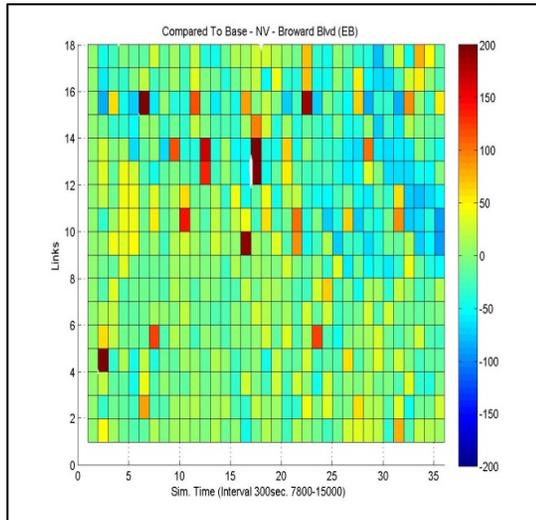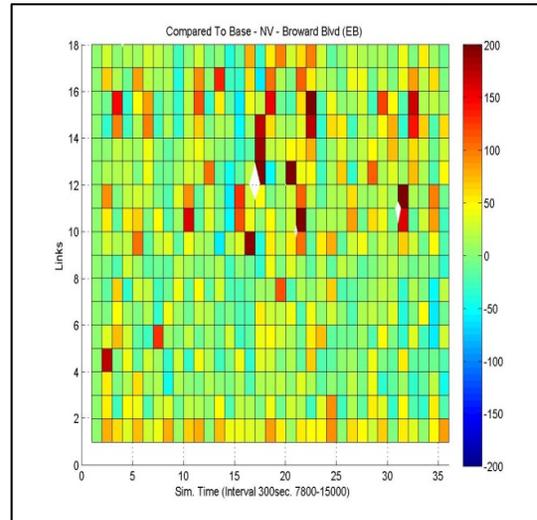
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 125- Visualization of the Throughput Performance Measure in Oversaturation Scenario
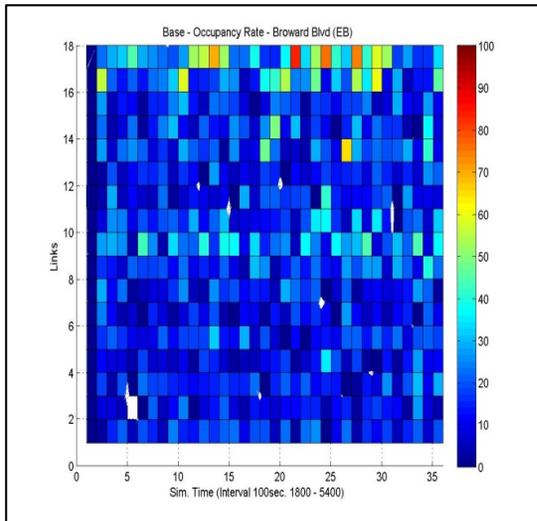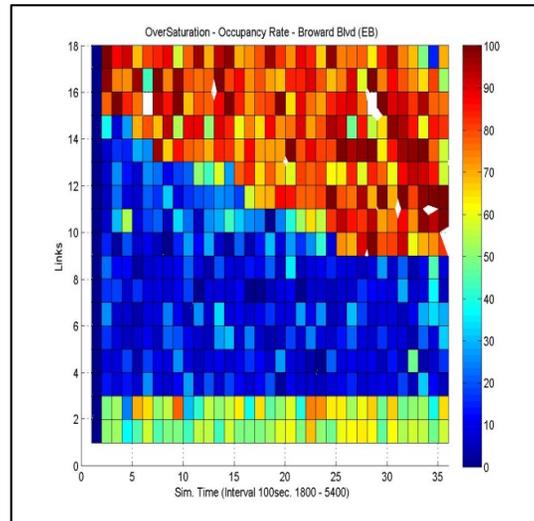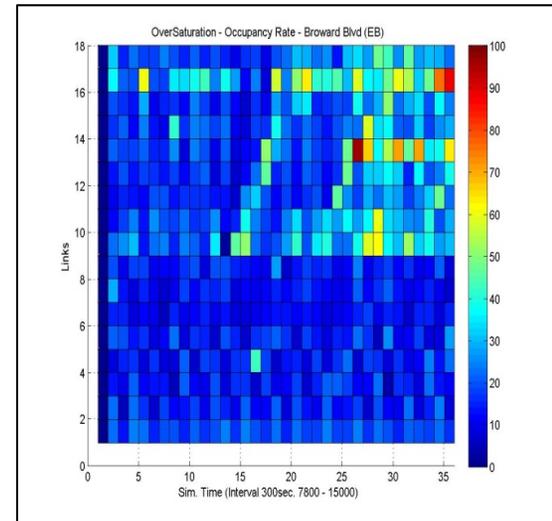
a)Base b) Scenario c) Strategy-Applied
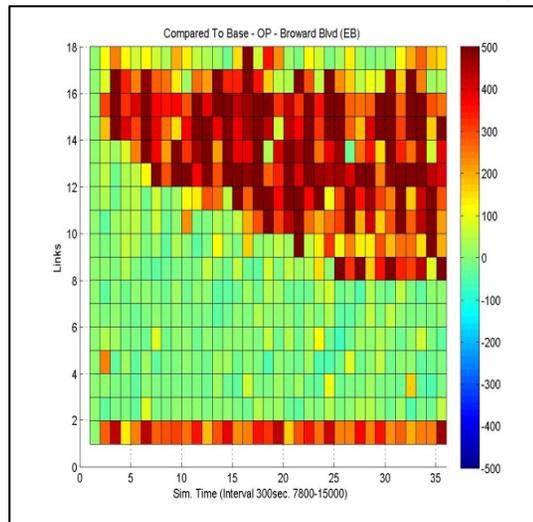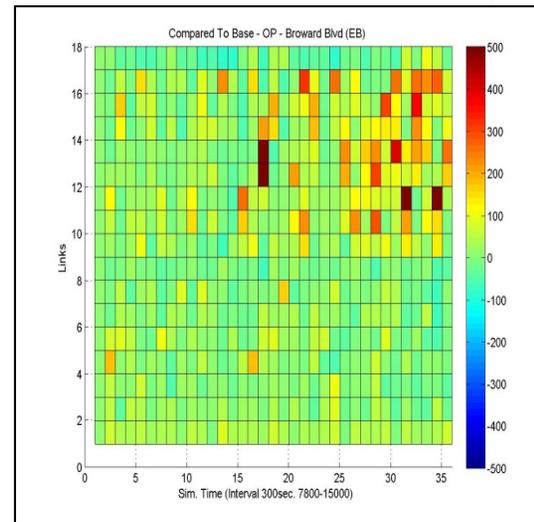
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 126- Visualization of the Occupancy Performance Measure in Oversaturation Scenario
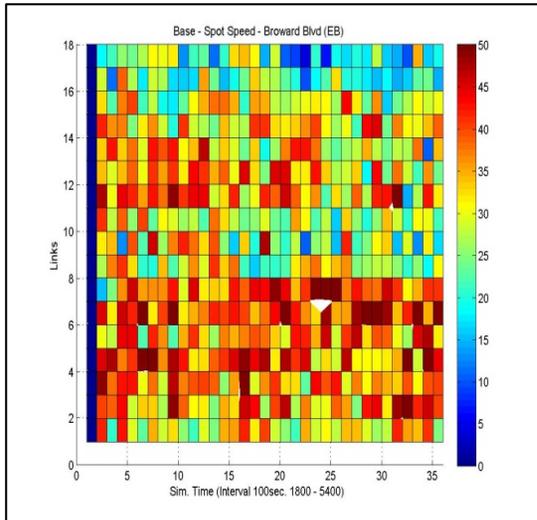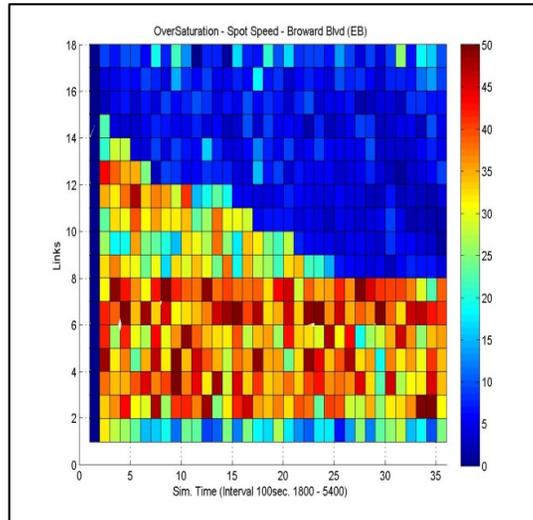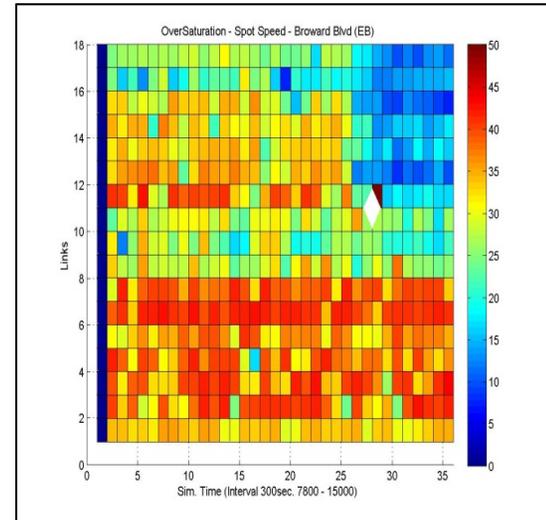
a)Base b) Scenario c) Strategy-Applied
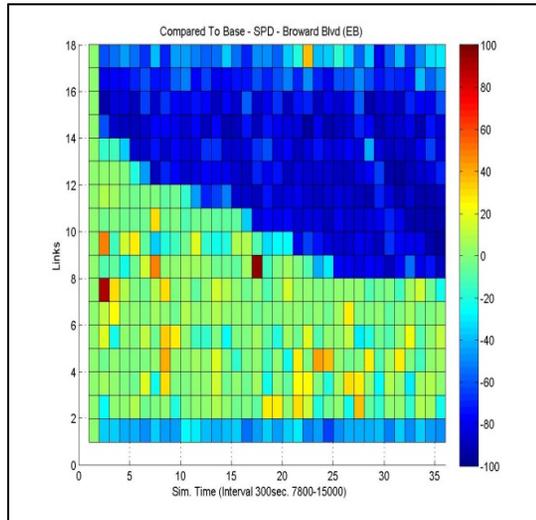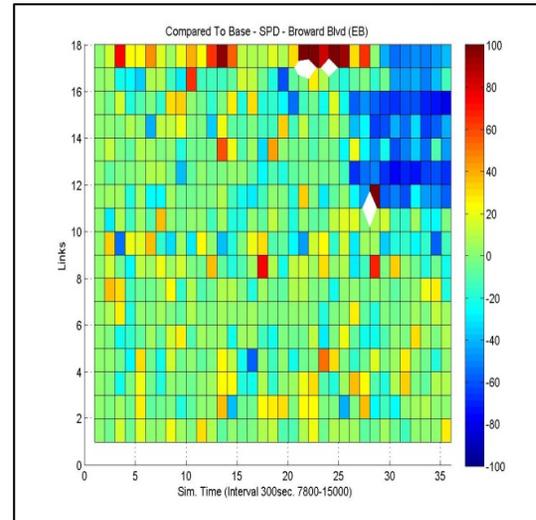
d) Scenario Compared to Base e) Strategy Compared to Base
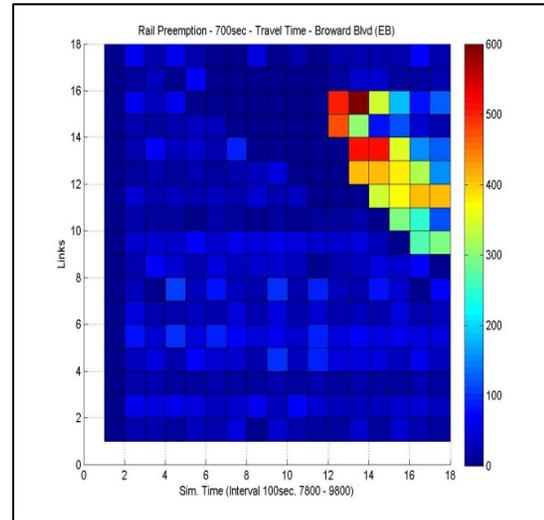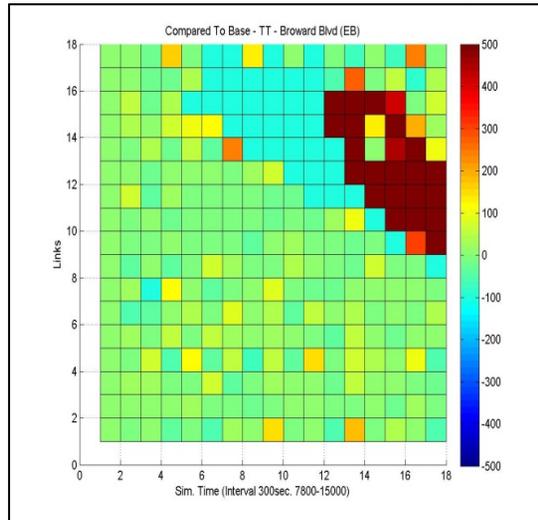Figure 127- Visualization of the Spot Speed Performance Measure in Oversaturation Scenario
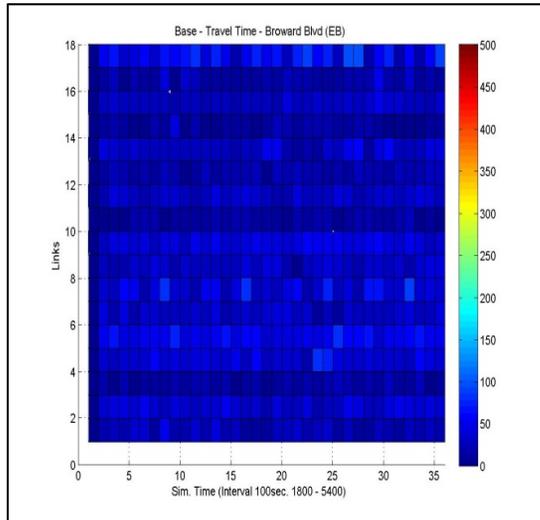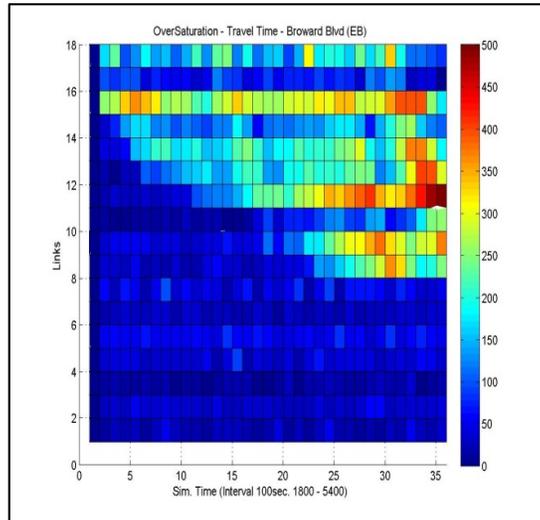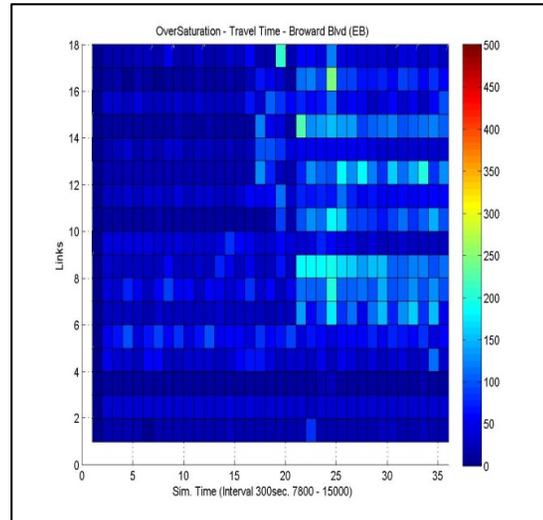
a)Base   b) Scenario   c) Strategy-Applied
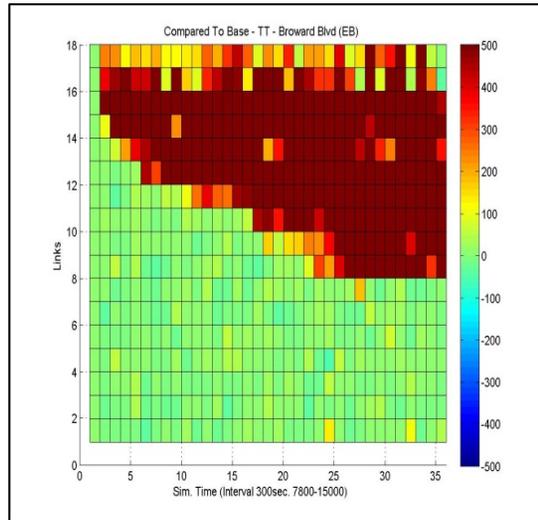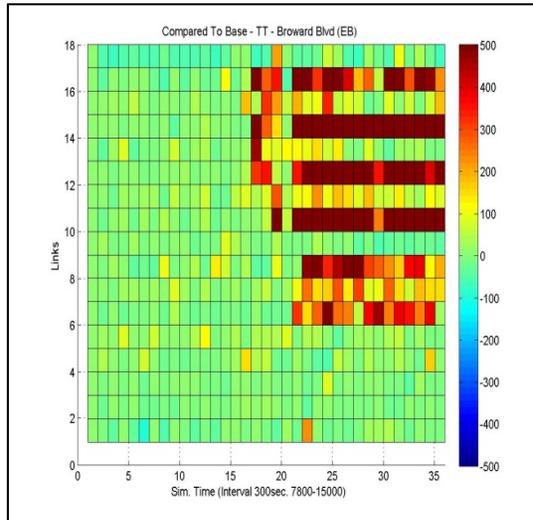
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 128- Visualization of the Travel Time Performance Measure in Oversaturation Scenario
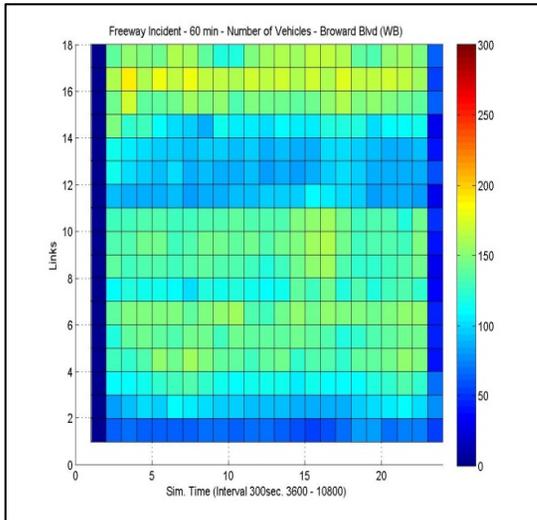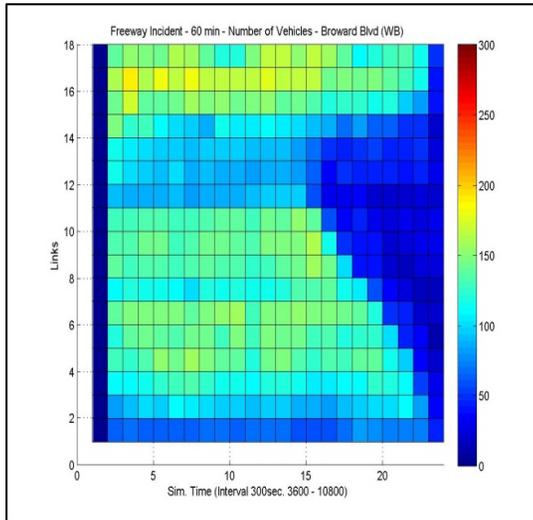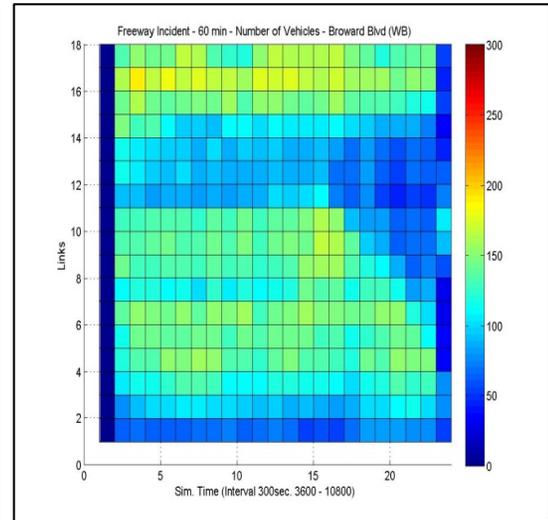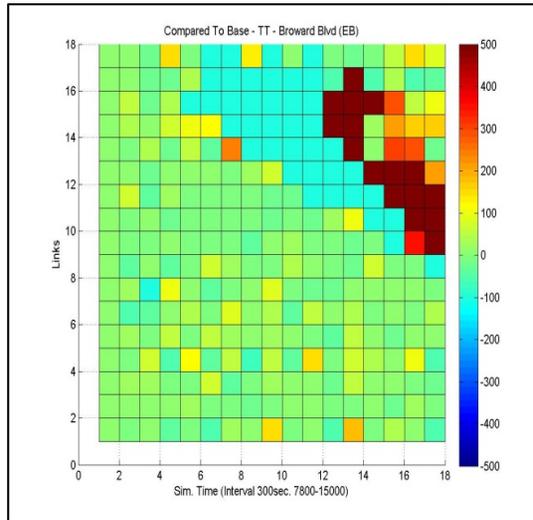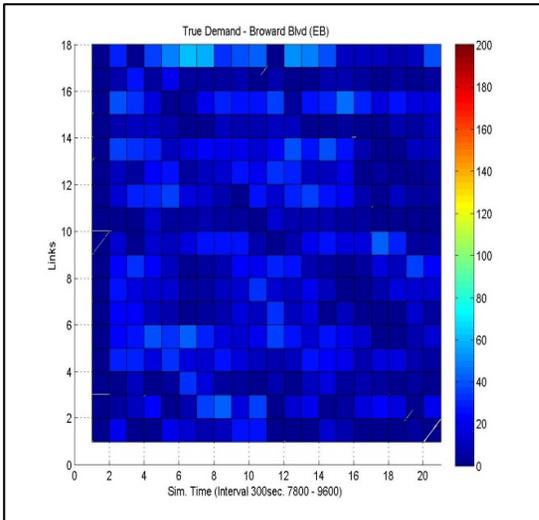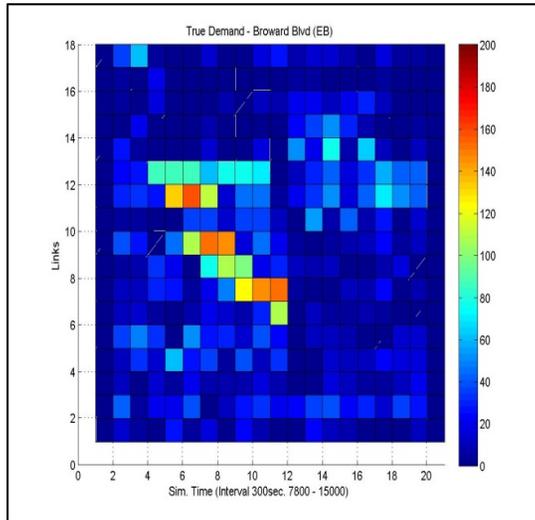
a)Base   b) Scenario   c) Strategy-Applied
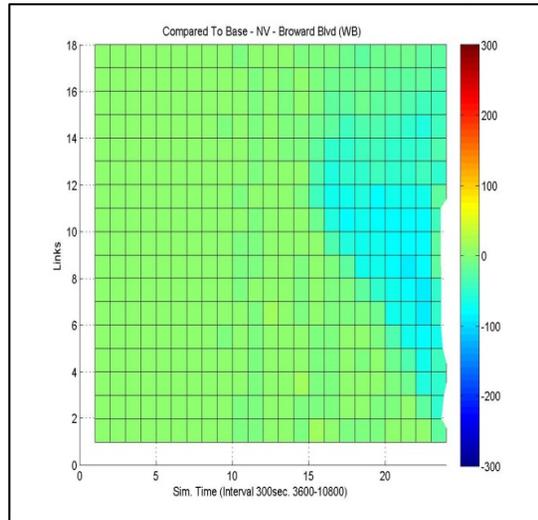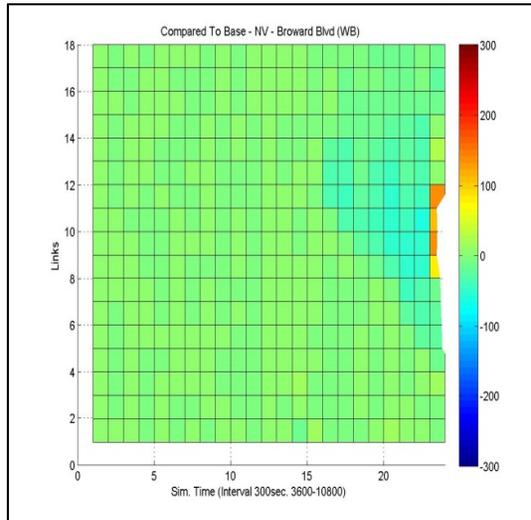
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 129- Visualization of the Throughput Performance Measure in Freeway Incident Scenario
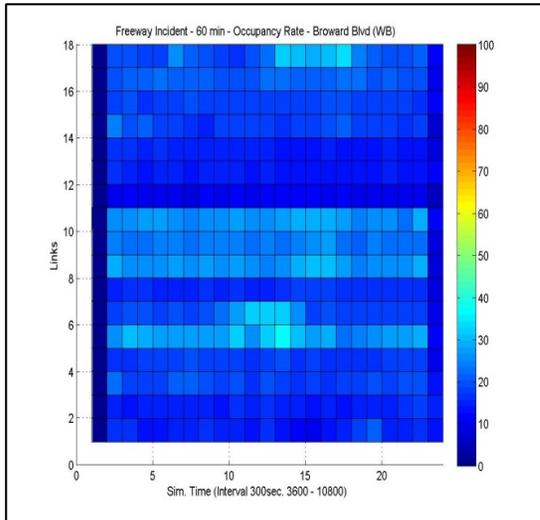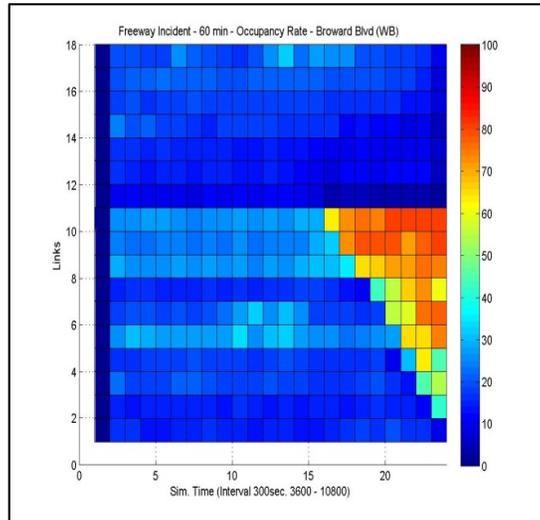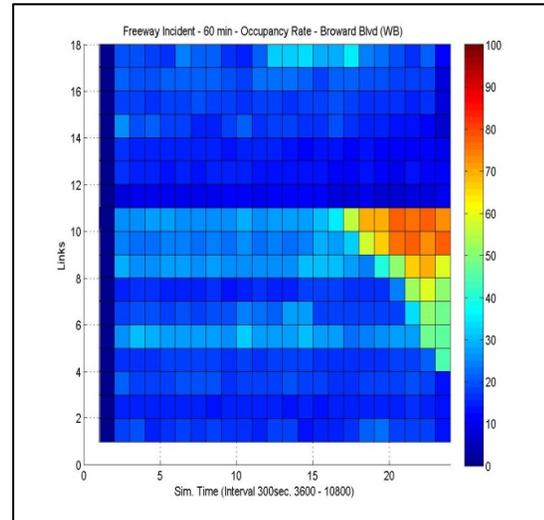
a)Base b) Scenario c) Strategy-Applied
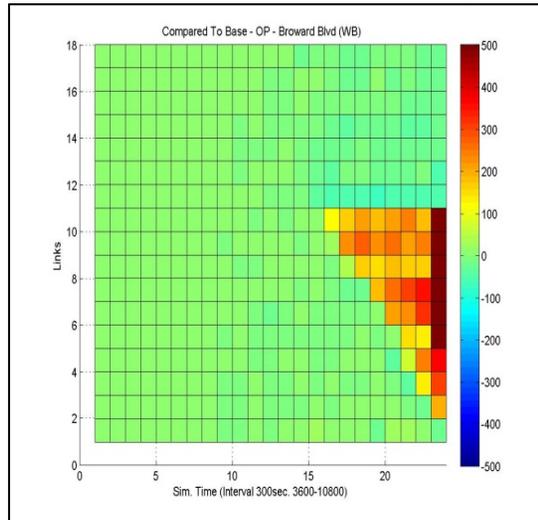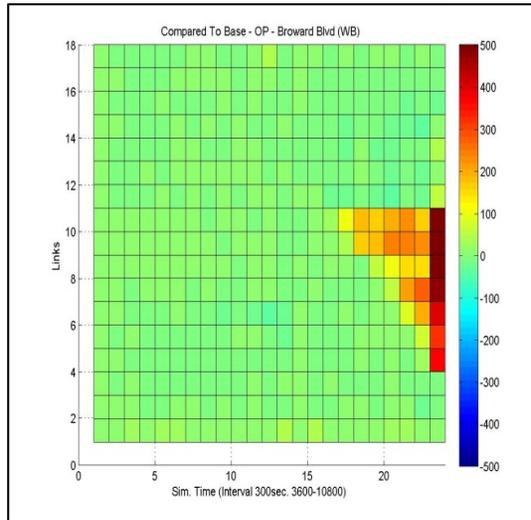
d) Scenario Compared to Base e) Strategy Compared to Base

Figure 130- Visualization of the Occupancy Performance Measure in Freeway Incident Scenario
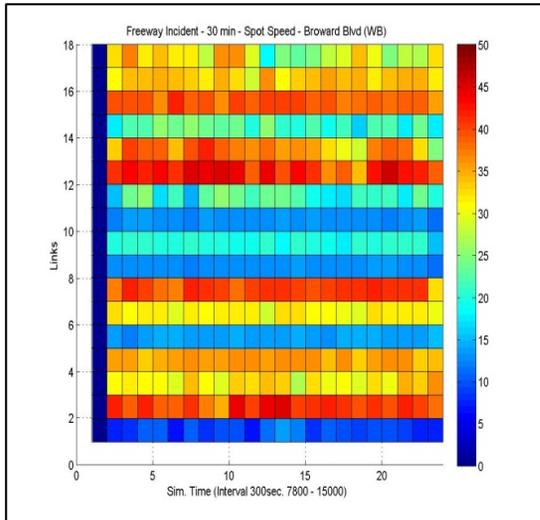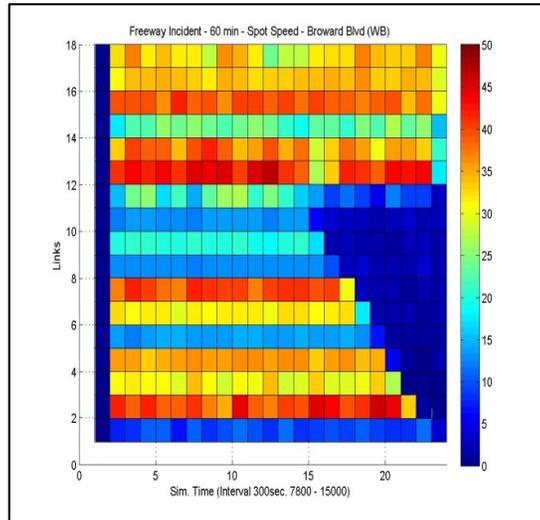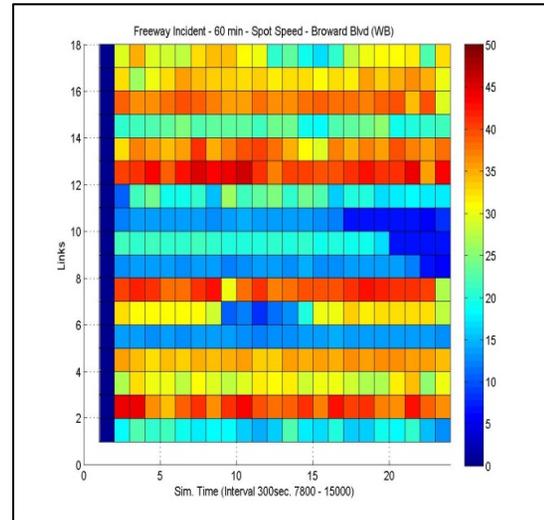
a)Base   b) Scenario   c) Strategy-Applied
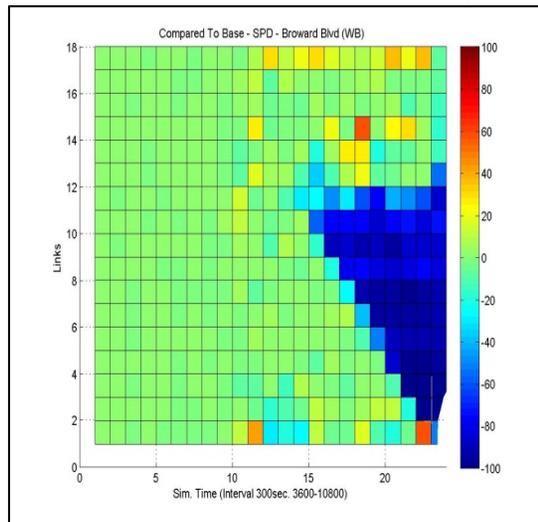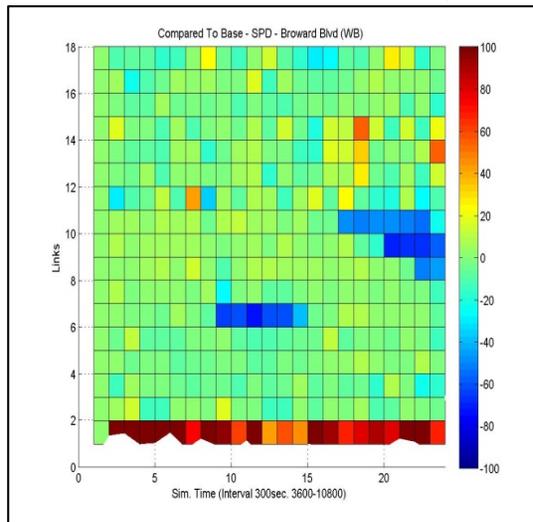
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 131- Visualization of the Spot Speed Performance Measure in Freeway Incident Scenario
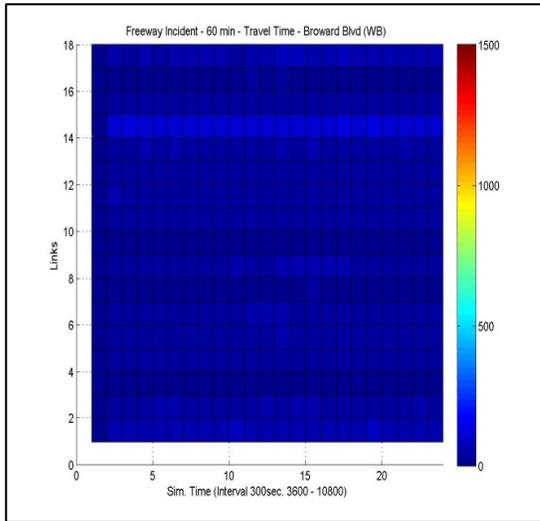
207
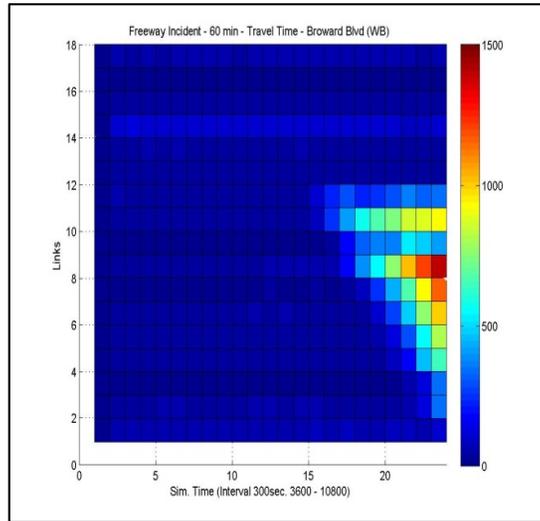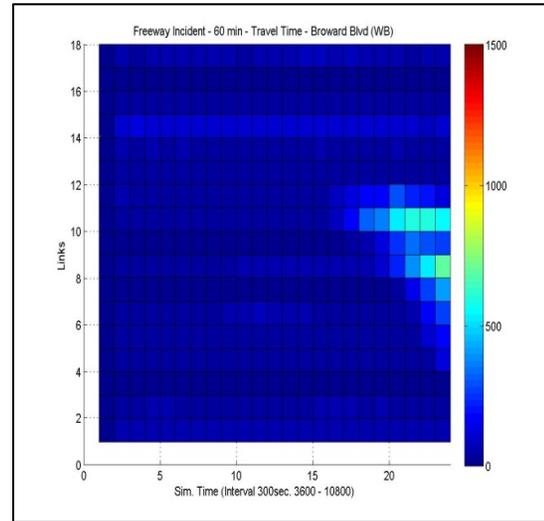
a)Base   b) Scenario   c) Strategy-Applied
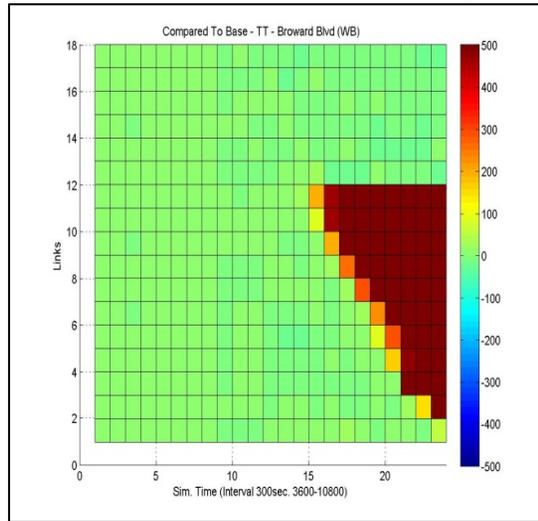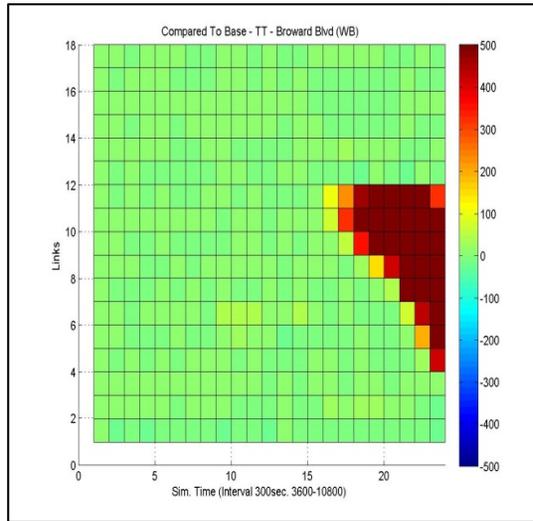
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 132- Visualization of the Travel Time Performance Measure in Freeway Incident Scenario
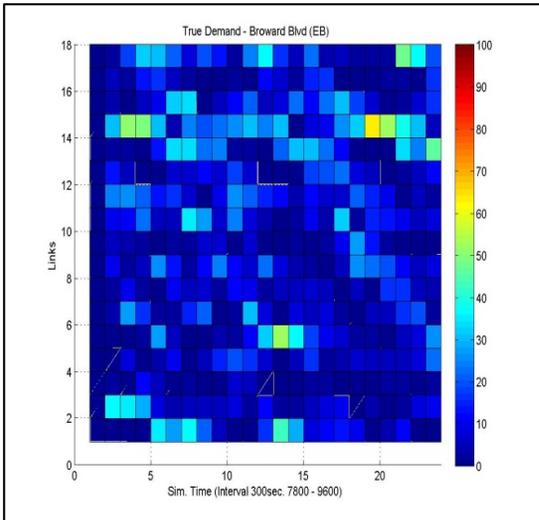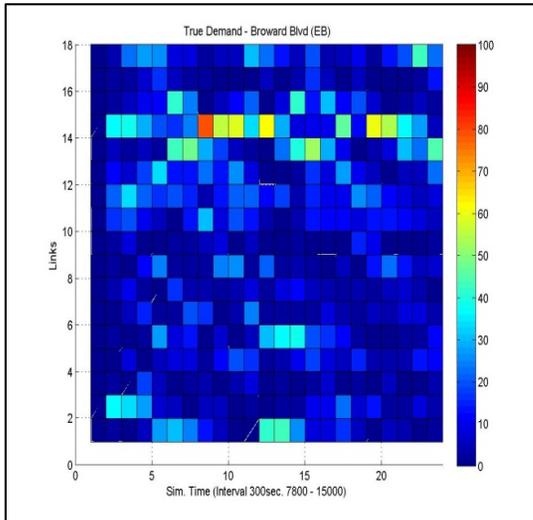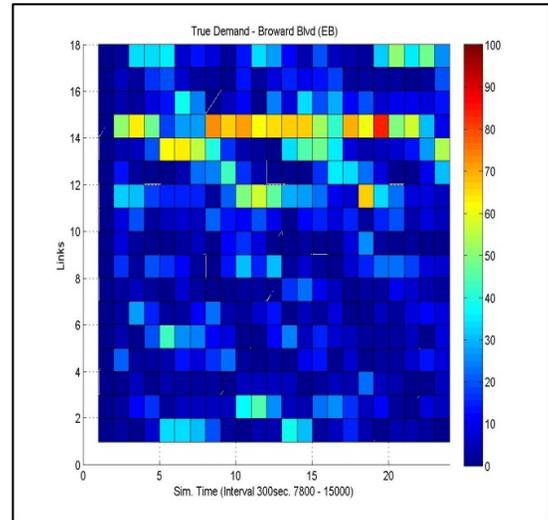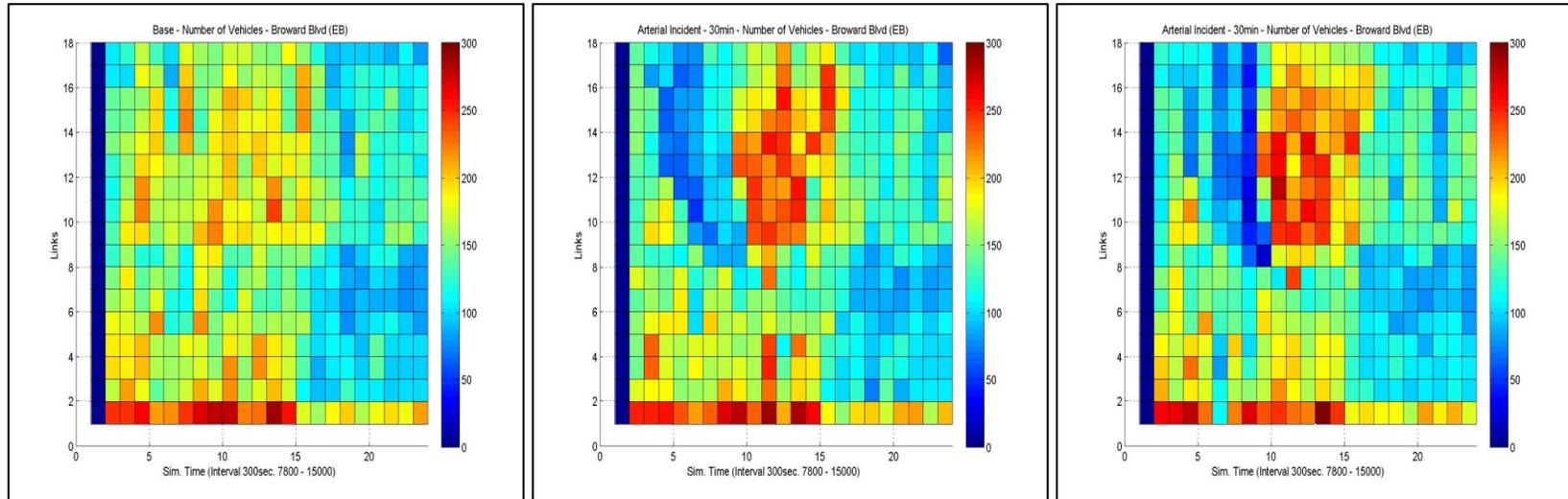
a)Base   b) LTSO (30 min)   c) LTSO (60 min)

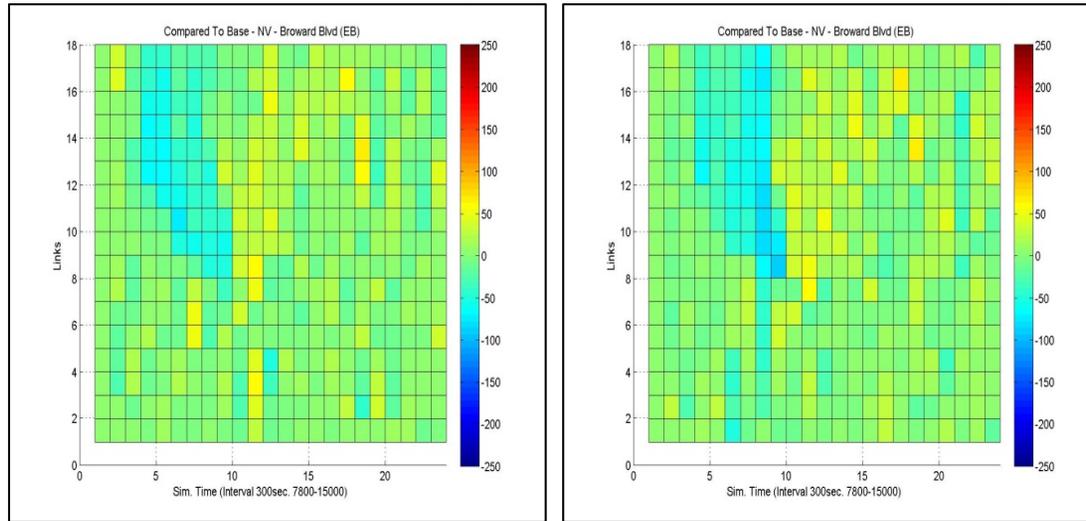Figure 133- True Demand Under LTSO
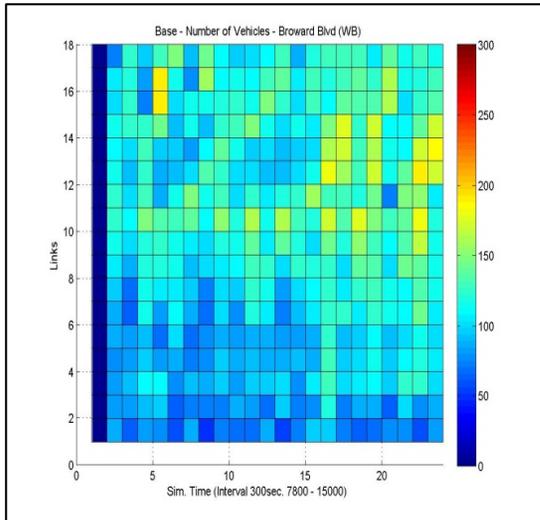
a)Base   b) Scenario   c) Strategy-Applied
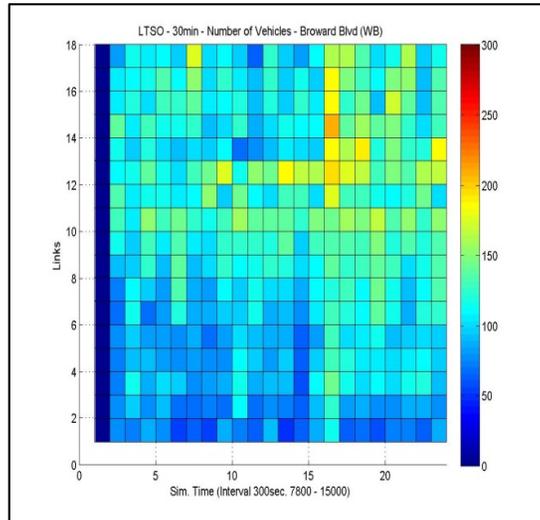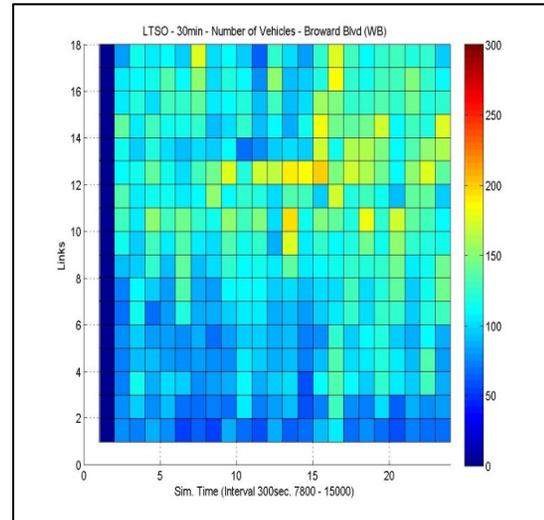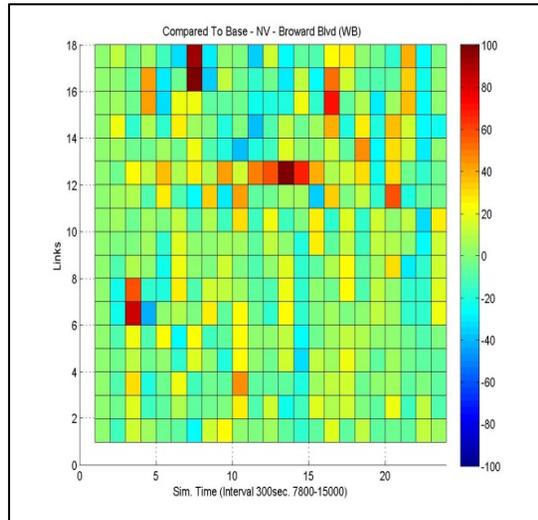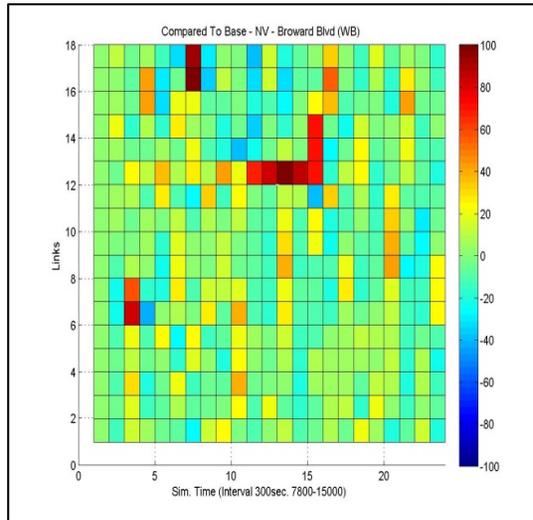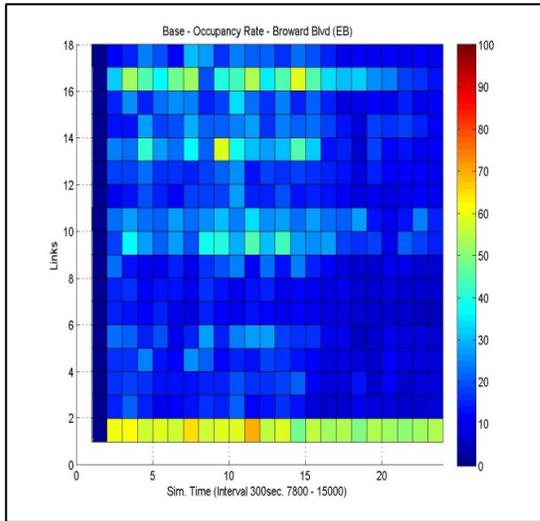

d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 134- Visualization of the Throughput Performance Measure in Left Turn Spillover (30 min) Scenario
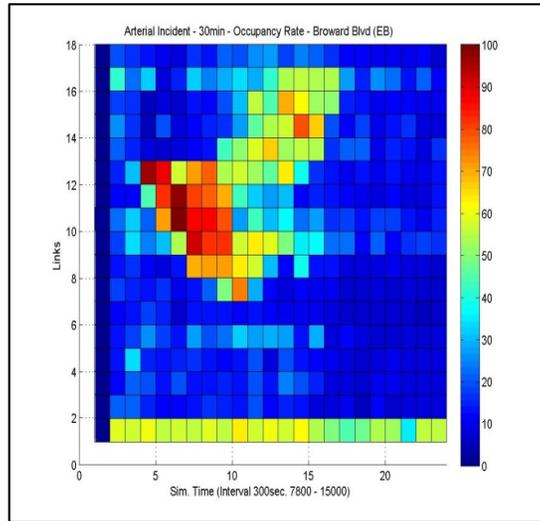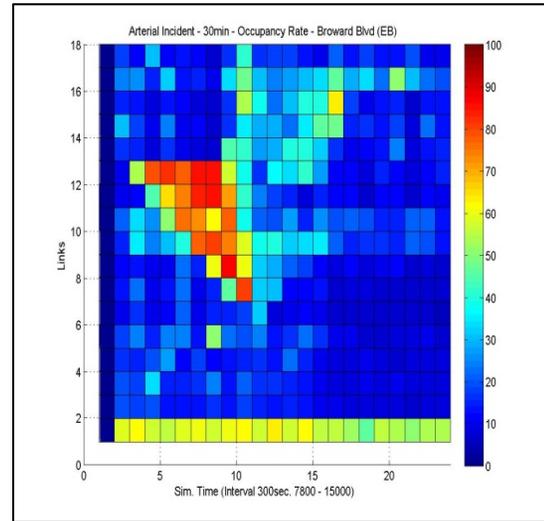
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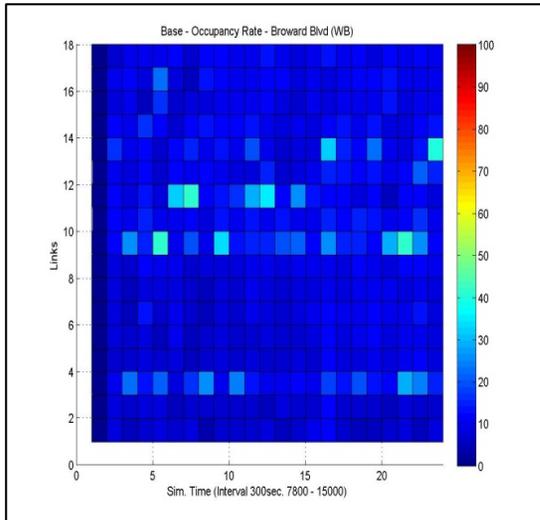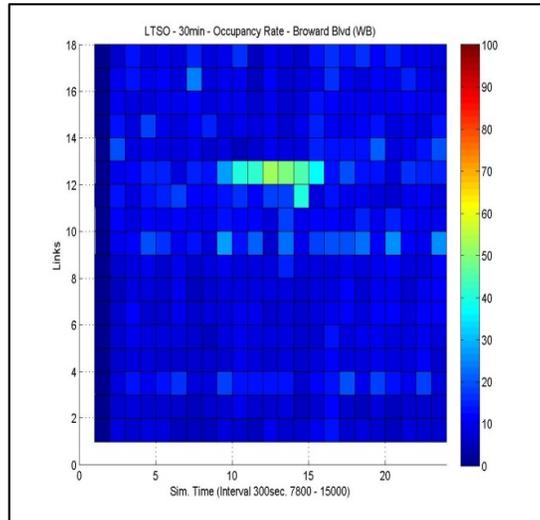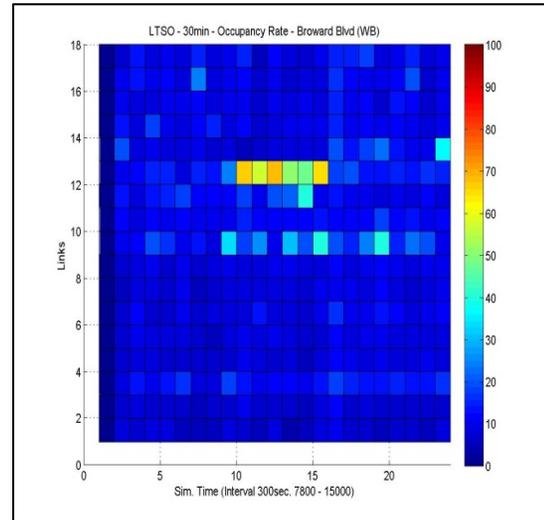
a)Base   b) Scenario   c) Strategy-Applied
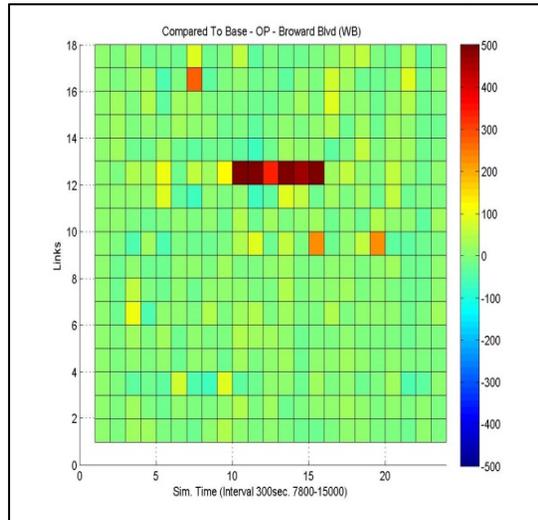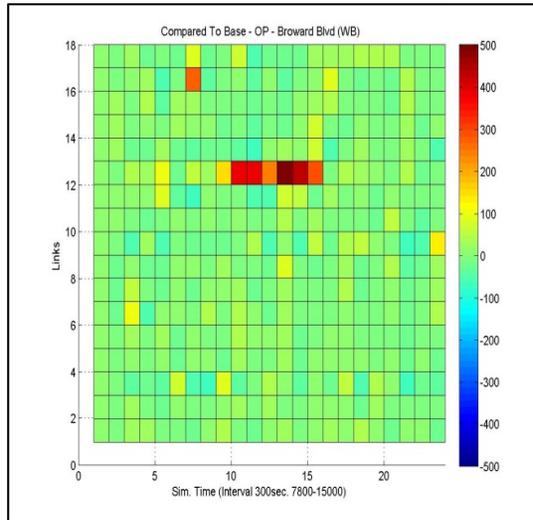
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 135- Visualization of the Occupancy Performance Measure in Left Turn Spillover (30 min) Scenario
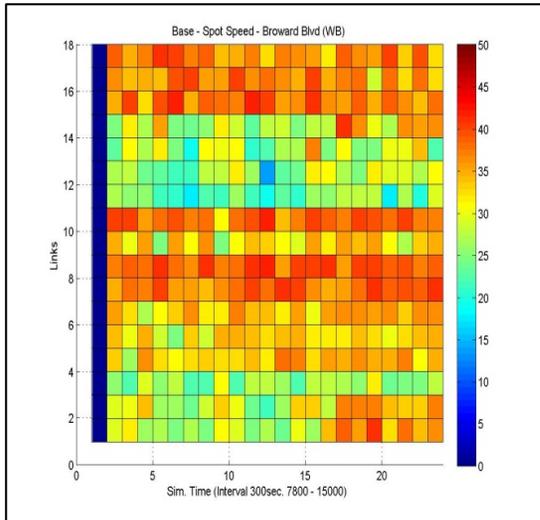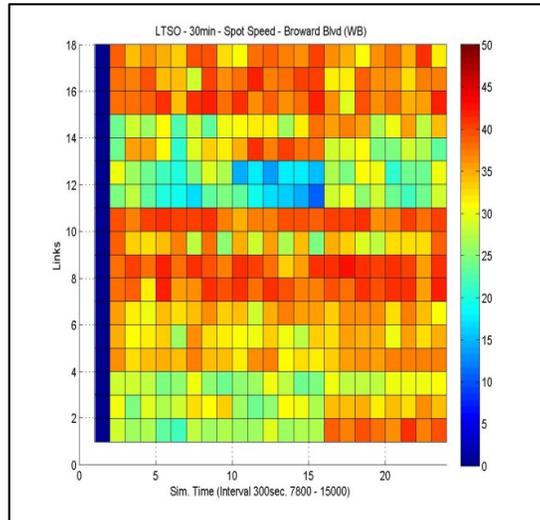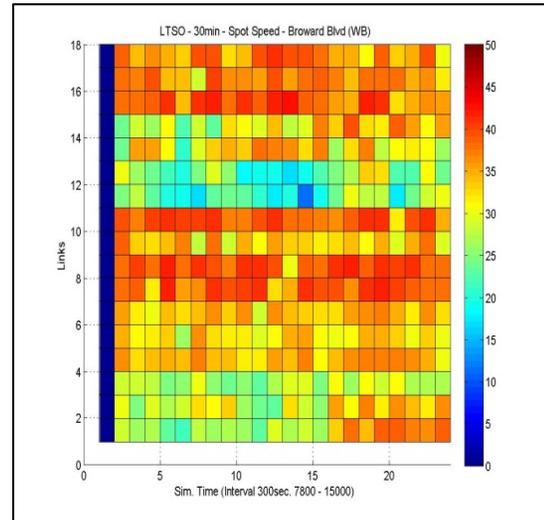
a)Base   b) Scenario   c) Strategy-Applied
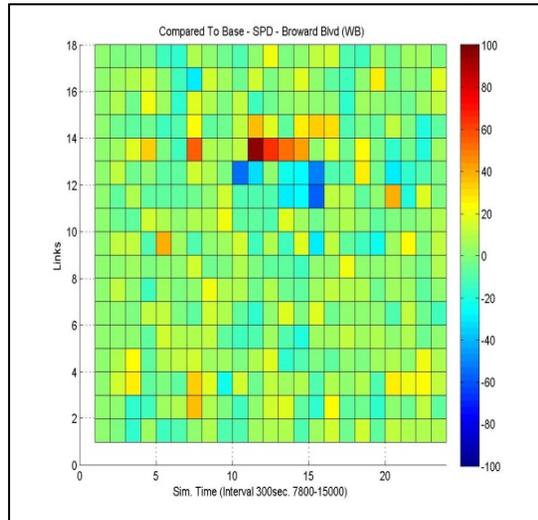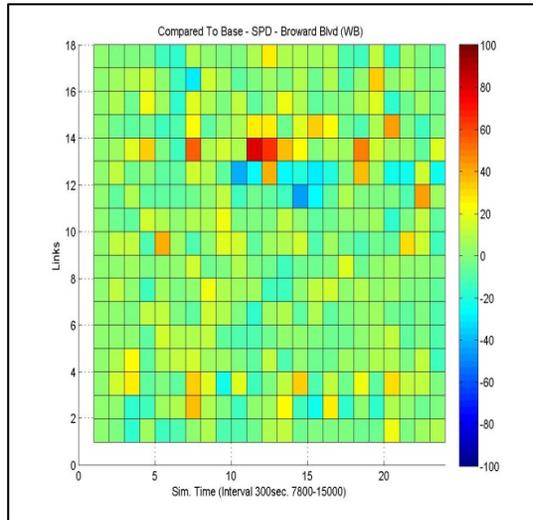
d) Scenario Compared to Base   e) Strategy Compared to Base

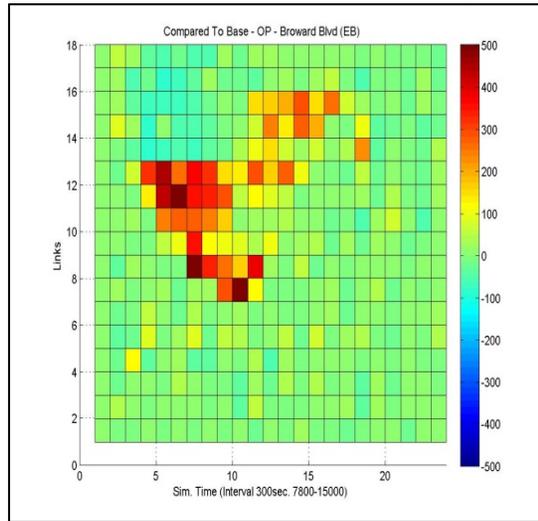Figure 136- Visualization of the Spot Speed Performance Measure in Left Turn Spillover (30 min) Scenario
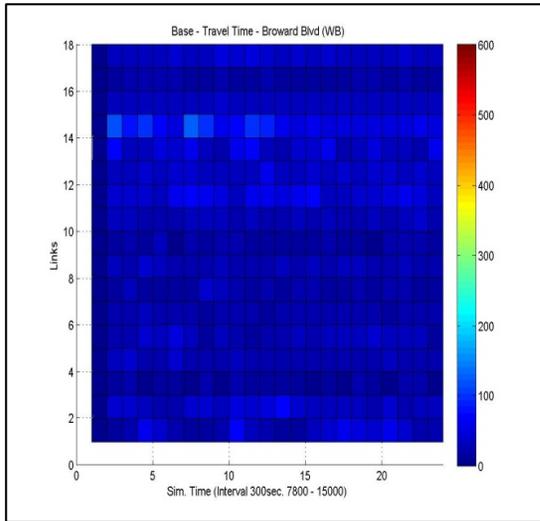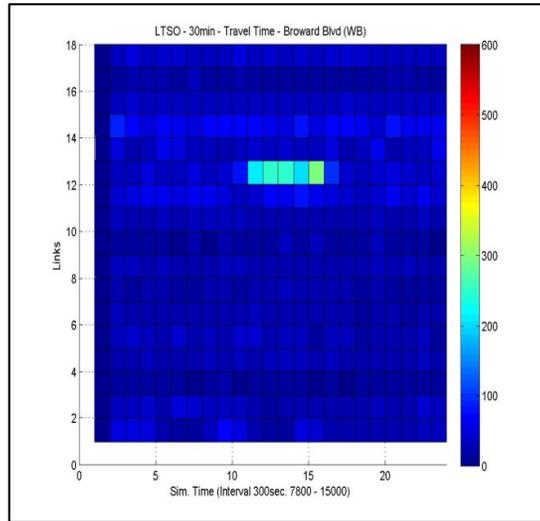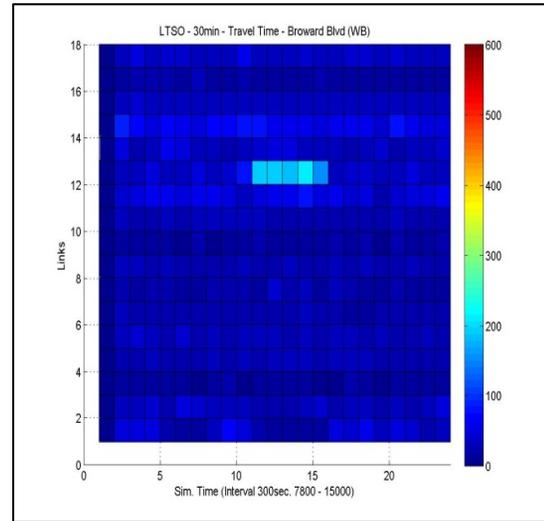
a)Base   b) Scenario   c) Strategy-Applied
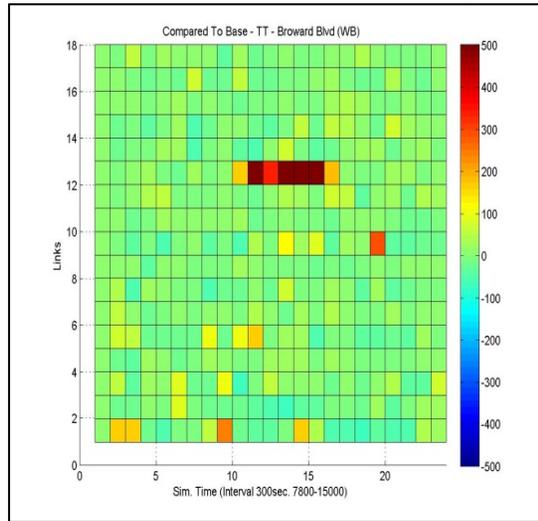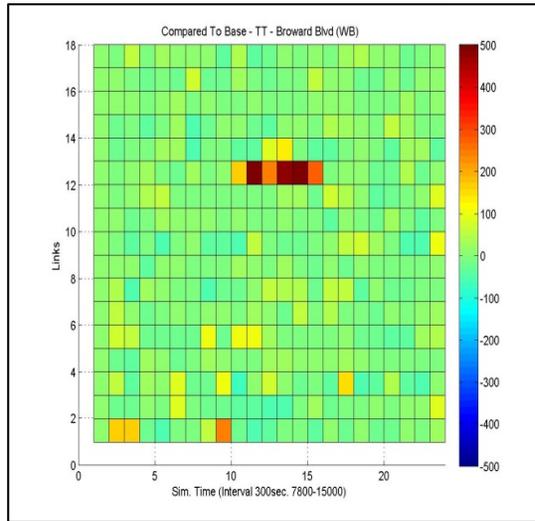
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 137- Visualization of the Travel Time Performance Measure in Left Turn Spillover (30 min) Scenario
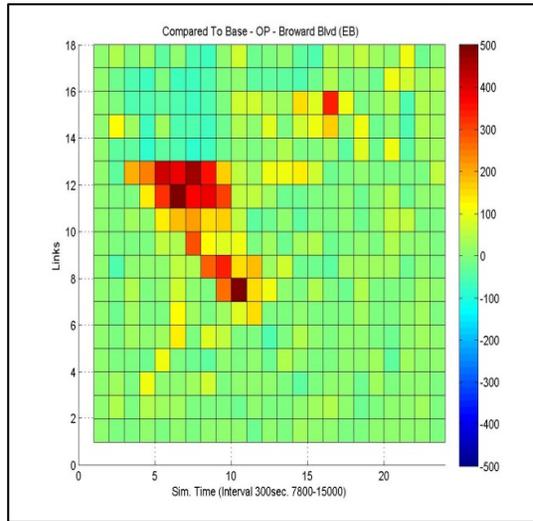
213
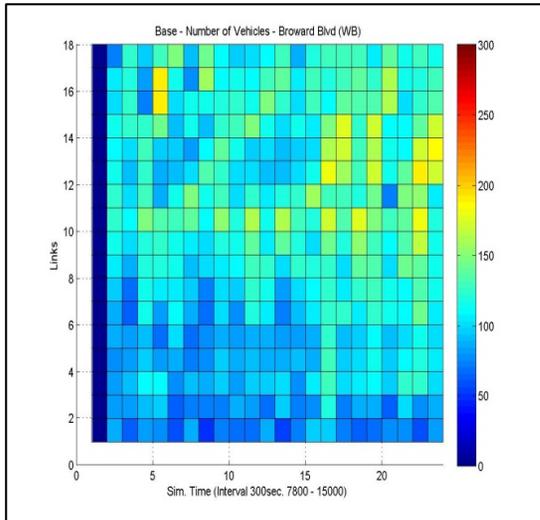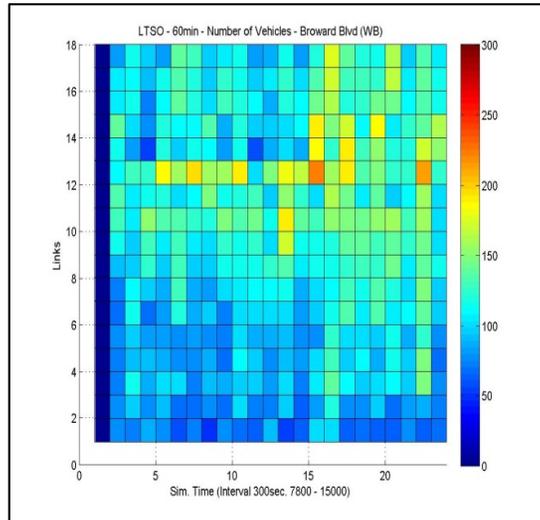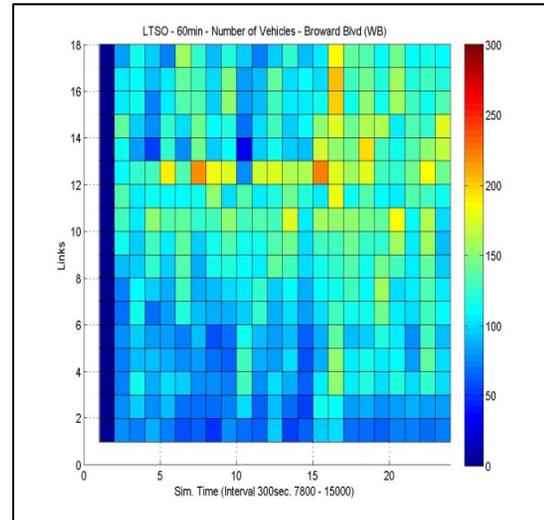
a)Base　　　　　　　　　　　b) Scenario　　　　　　　　　c) Strategy-Applied
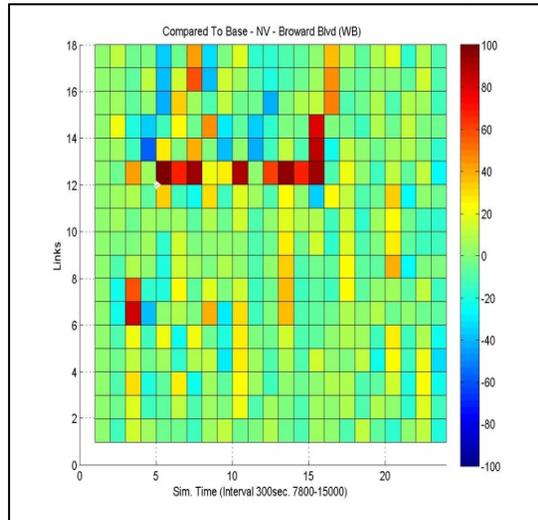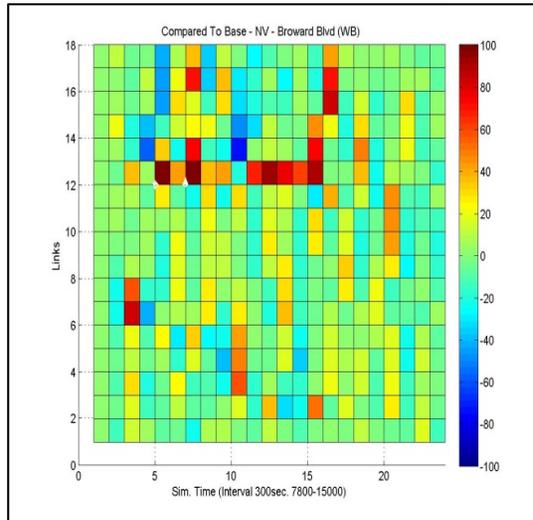
d) Scenario Compared to Base　　　　　e) Strategy Compared to Base

Figure 138- Visualization of the Throughput Performance Measure in Left Turn Spillover (60 min) Scenario
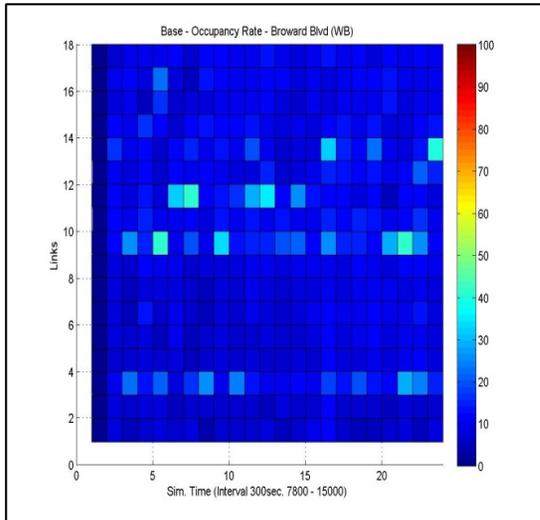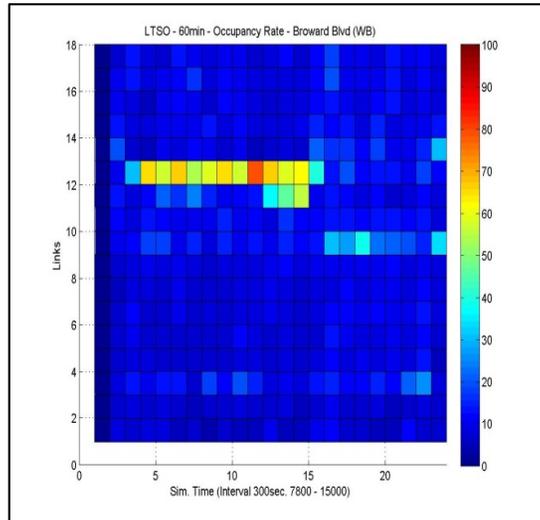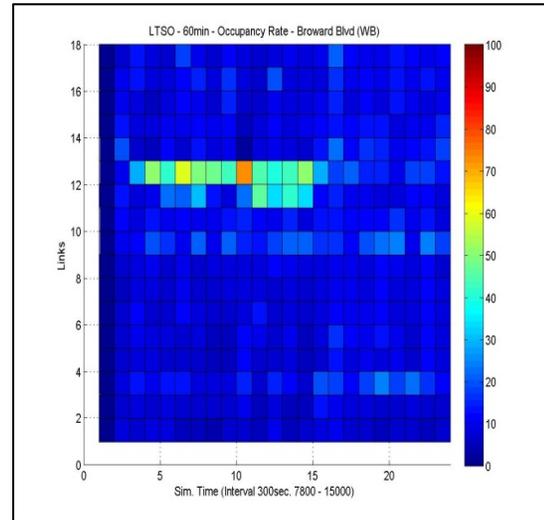
a)Base   b) Scenario   c) Strategy-Applied
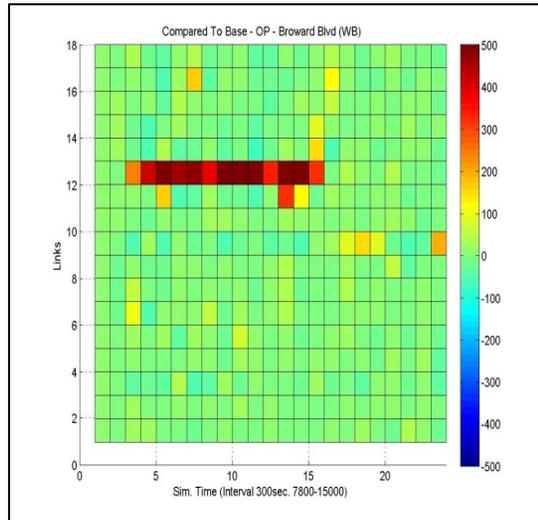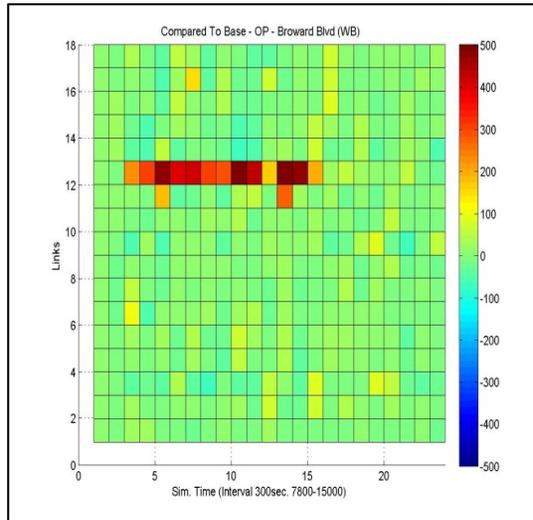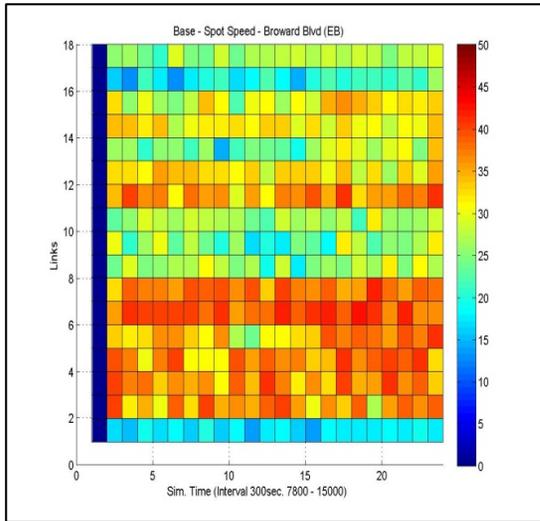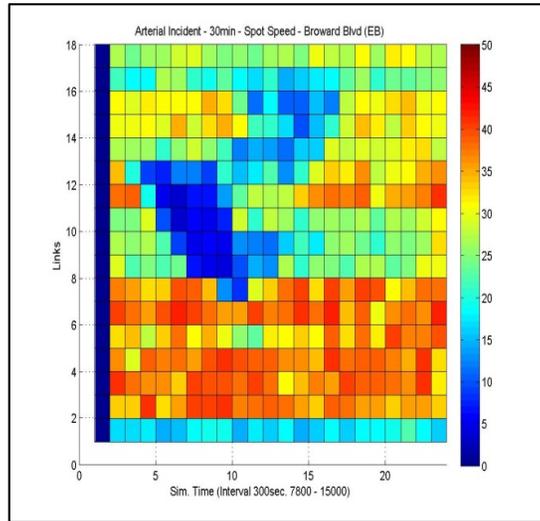
d) Scenario Compared to Base   e) Strategy Compared to Base
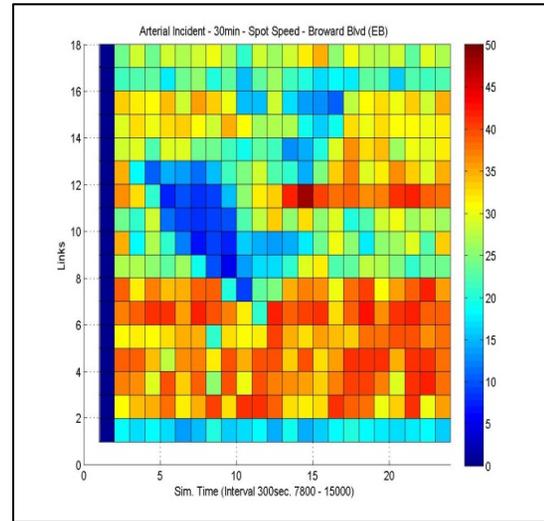
Figure 139- Visualization of the Occupancy Performance Measure in Left Turn Spillover (60 min) Scenario
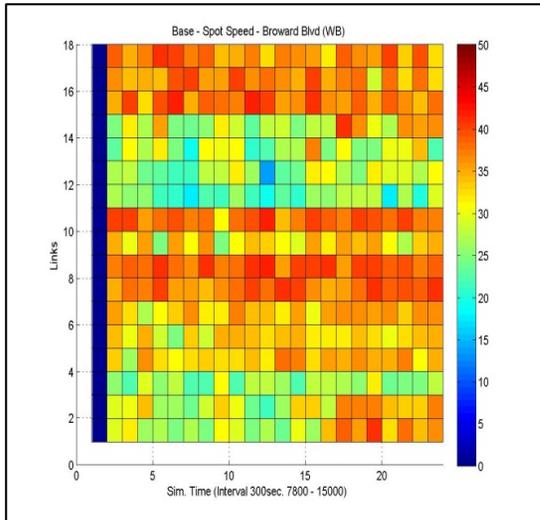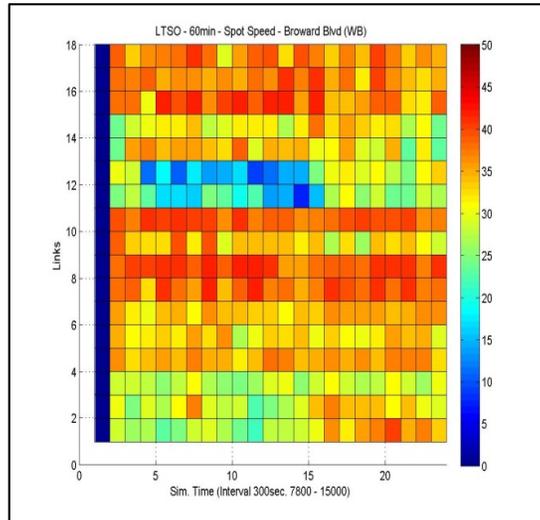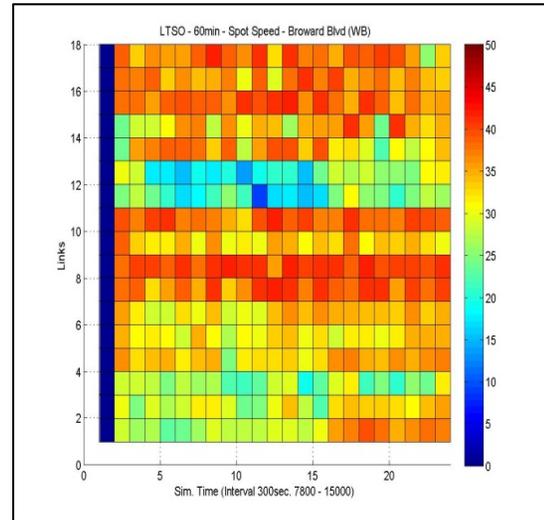
a)Base   b) Scenario   c) Strategy-Applied
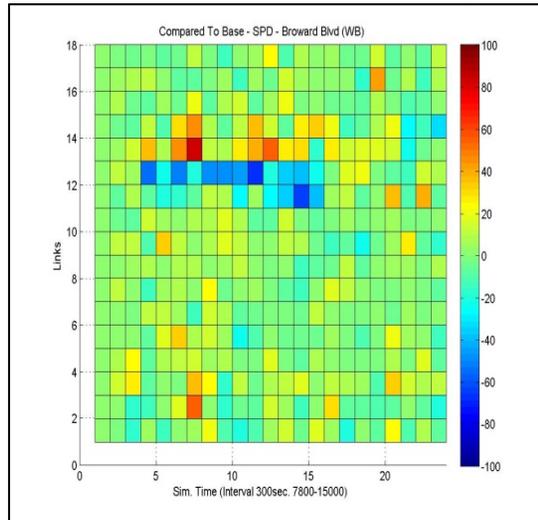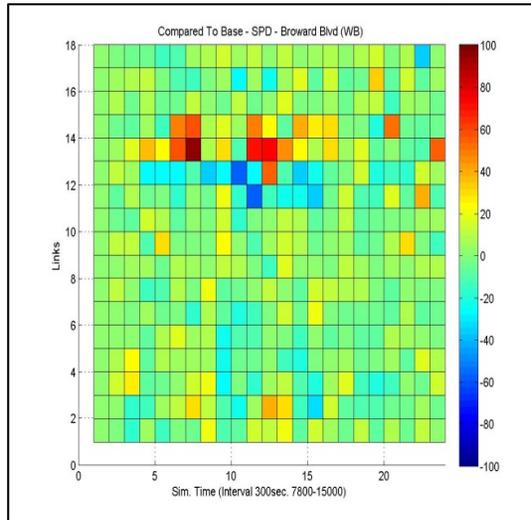
d) Scenario Compared to Base   e) Strategy Compared to Base

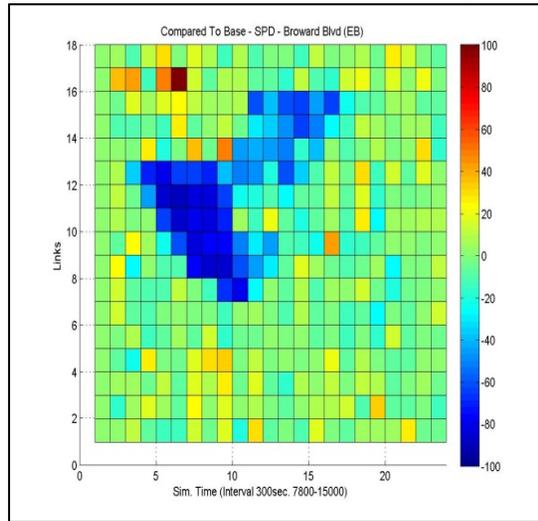Figure 140- Visualization of the Spot Speed Performance Measure in Left Turn Spillover (60 min) Scenario
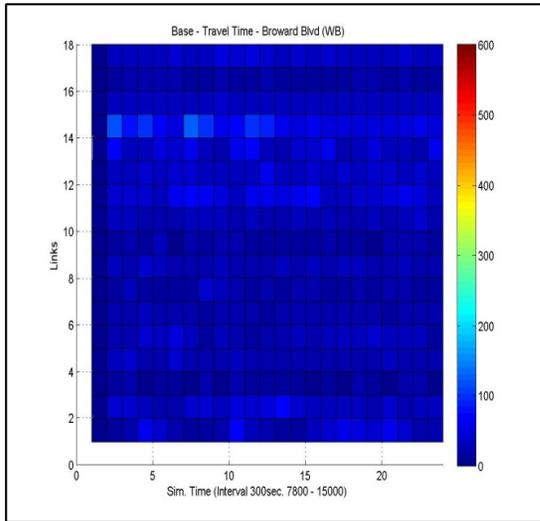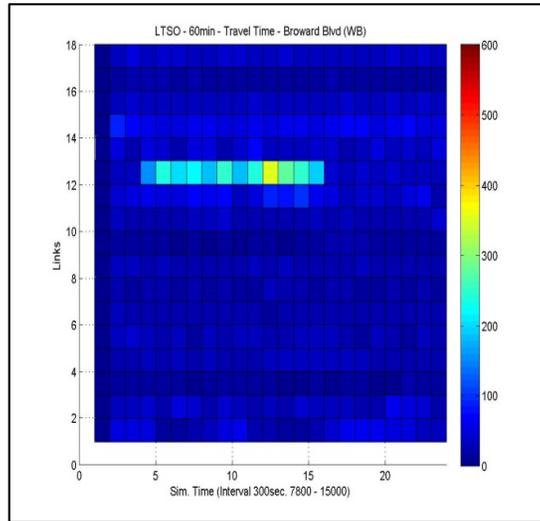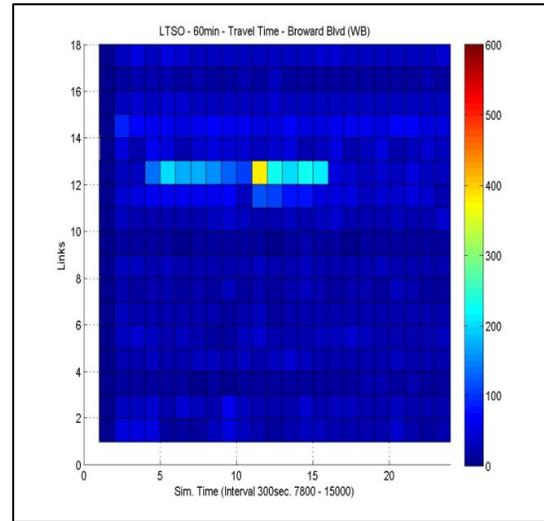
a)Base b) Scenario c) Strategy-Applied
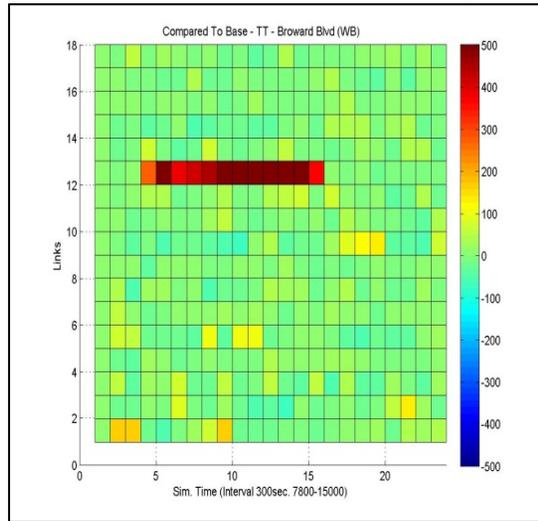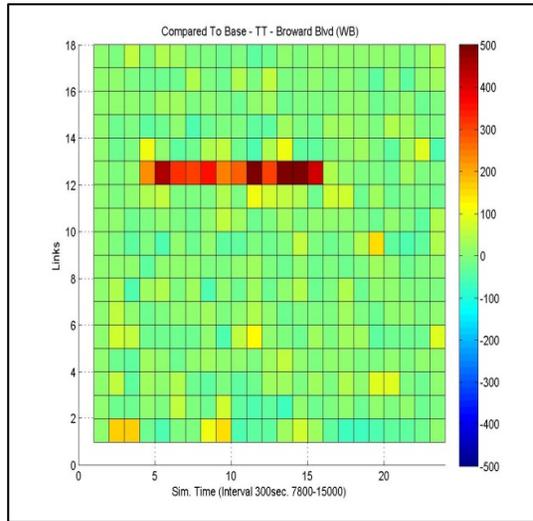
d) Scenario Compared to Base e) Strategy Compared to Base

Figure 141- Visualization of the Travel Time Performance Measure in Left Turn Spillover (60 min) Scenario
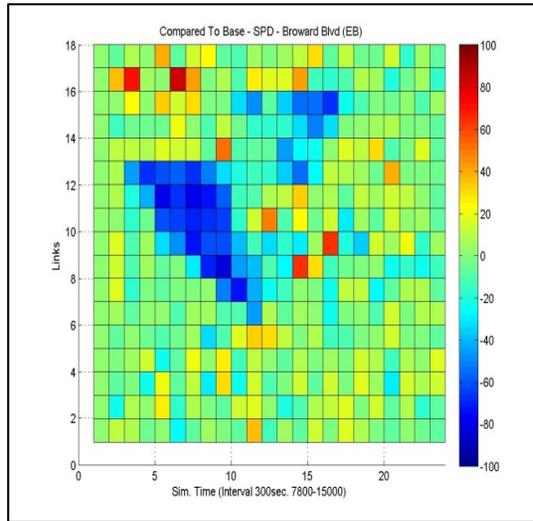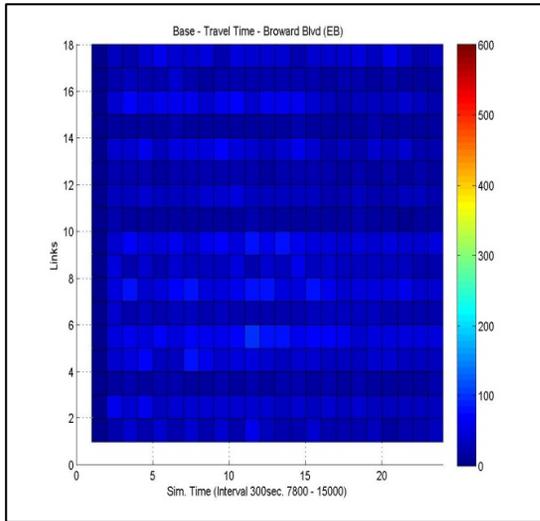
217
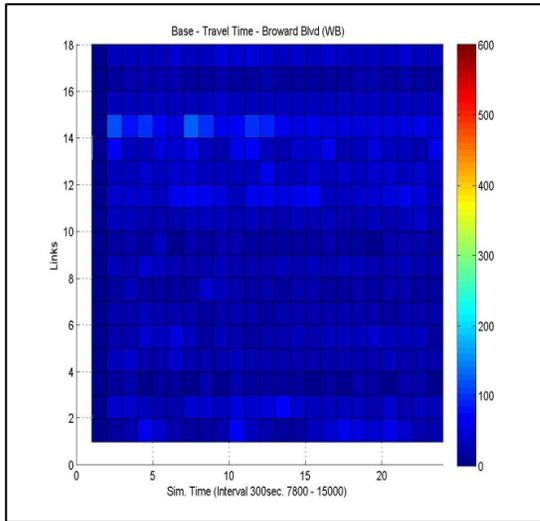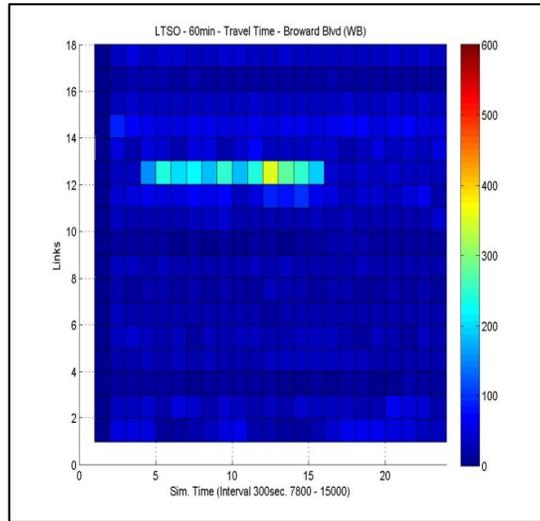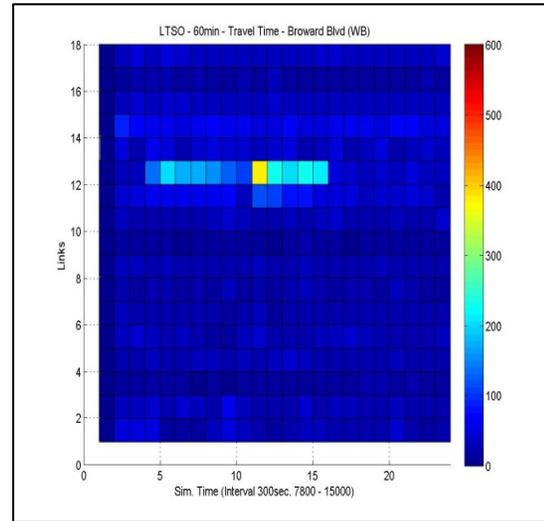
a)Base　　　　　　　　　　　b) Scenario　　　　　　　　c) Strategy-Applied
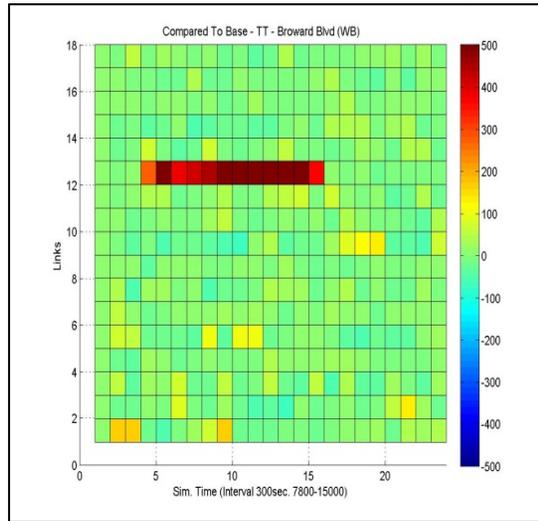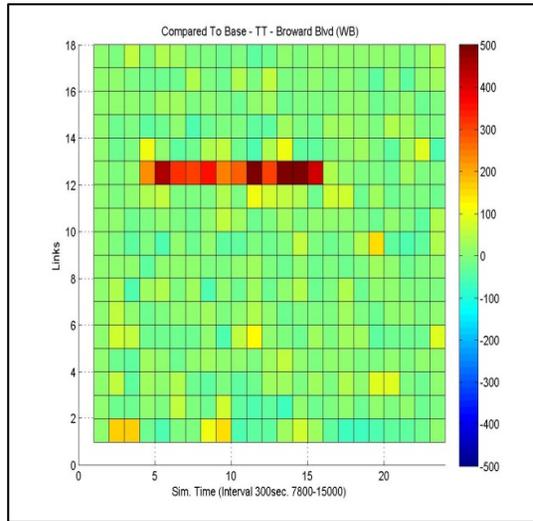
d) Scenario Compared to Base　　　　　e) Strategy Compared to Base

Figure 142- Visualization of the Travel Time Performance Measure in Left Turn Spillover (60 min) Scenario
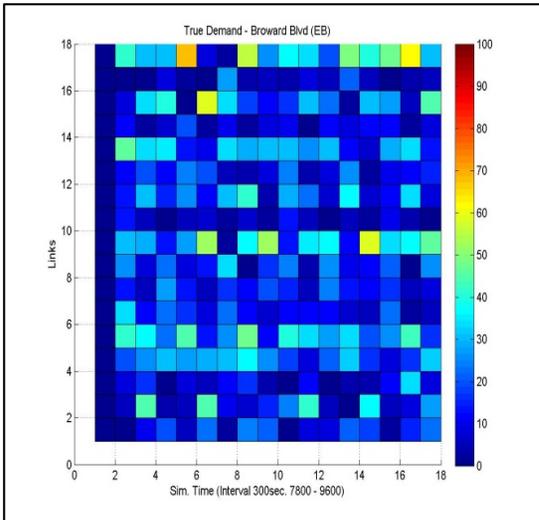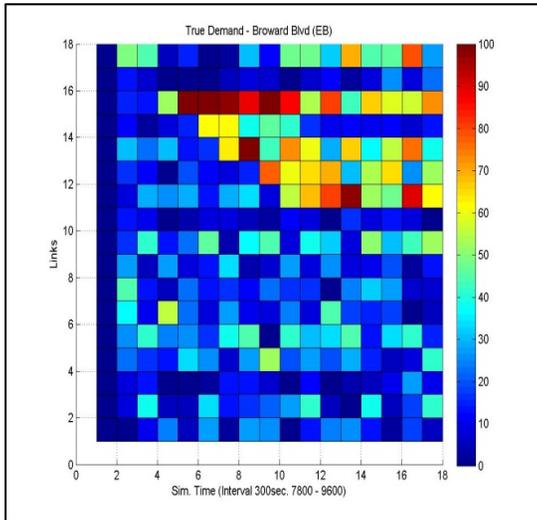
| a)Base | b) Rail Preemption (300 sec.) | c) Rail Preemption (700 sec.) |
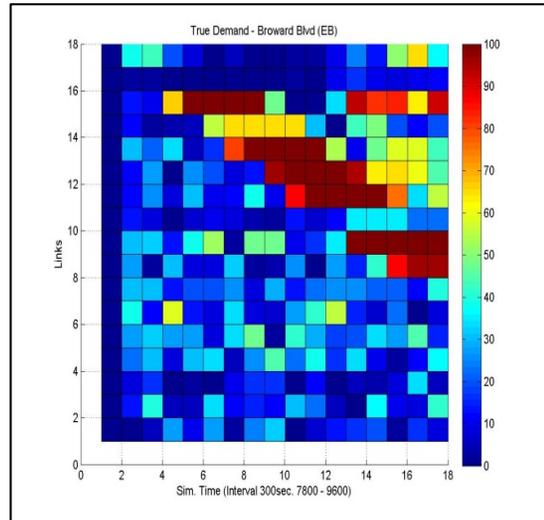
Figure 143- True Demand Under Rail Preemption
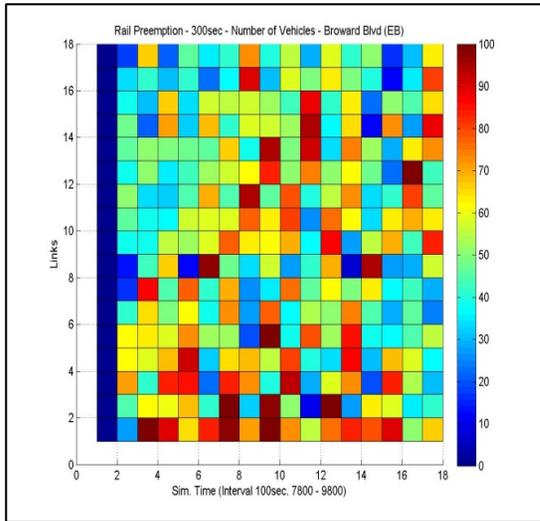
a)Base   b) Scenario   c) Strategy-Applied
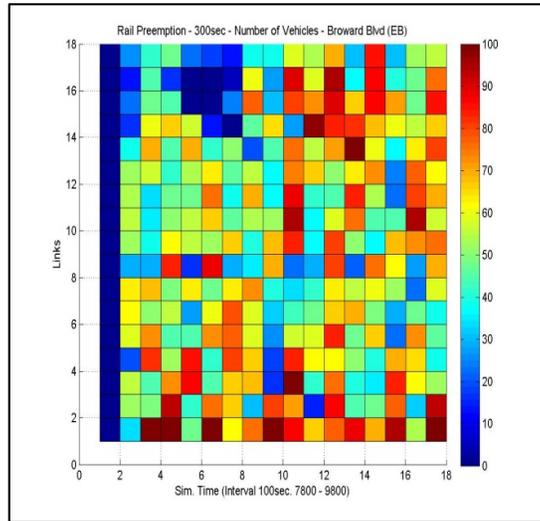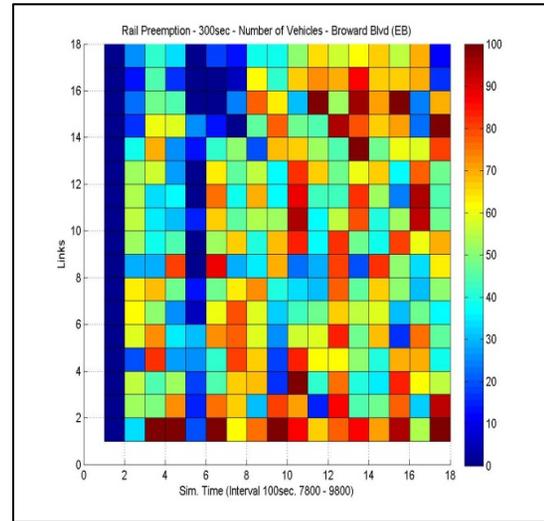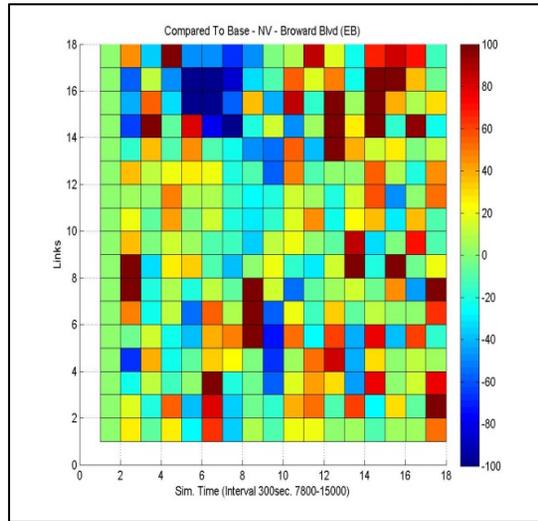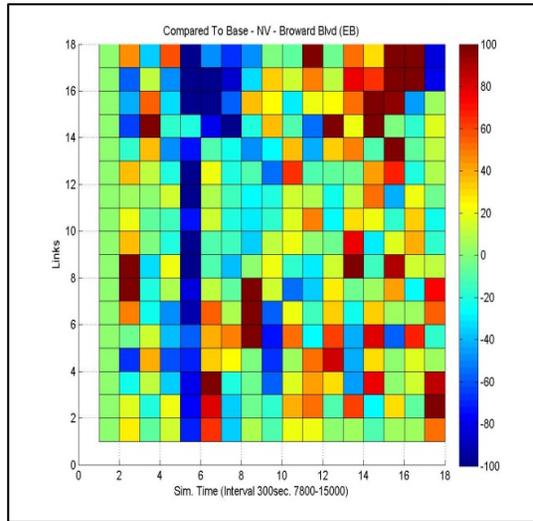
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 144- Visualization of the Throughput Performance Measure in Rail Preemption (300 sec) Scenario
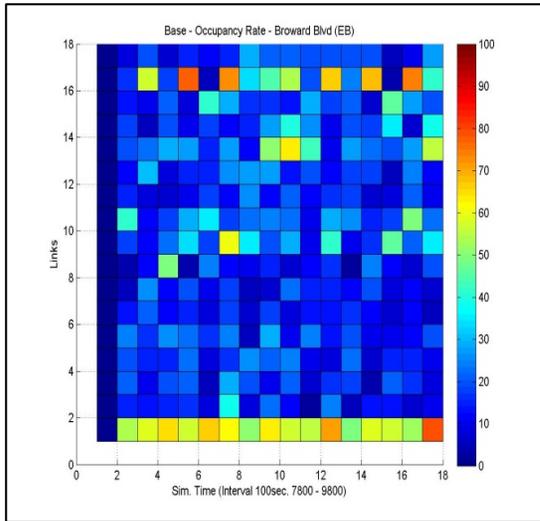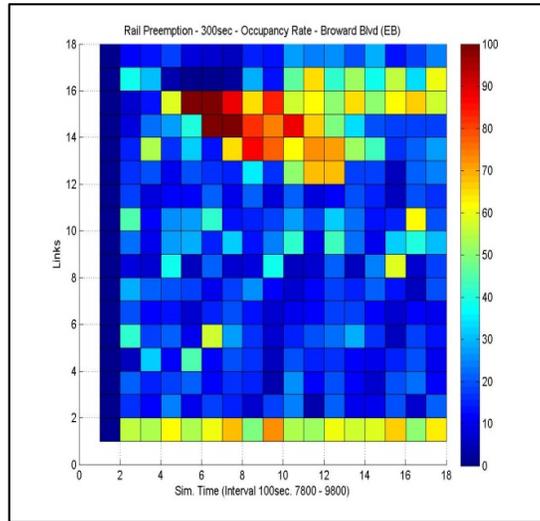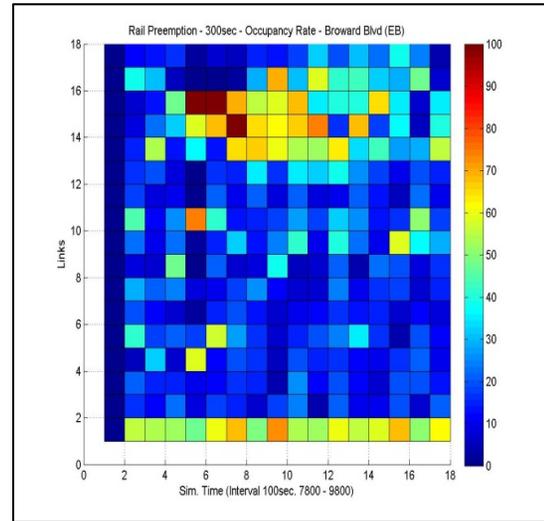
a)Base   b) Scenario   c) Strategy-Applied
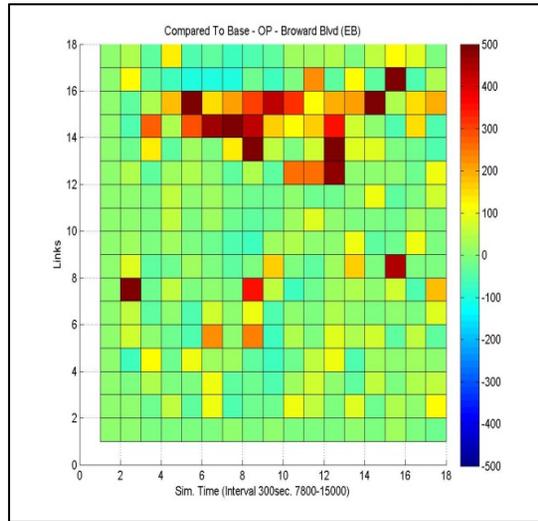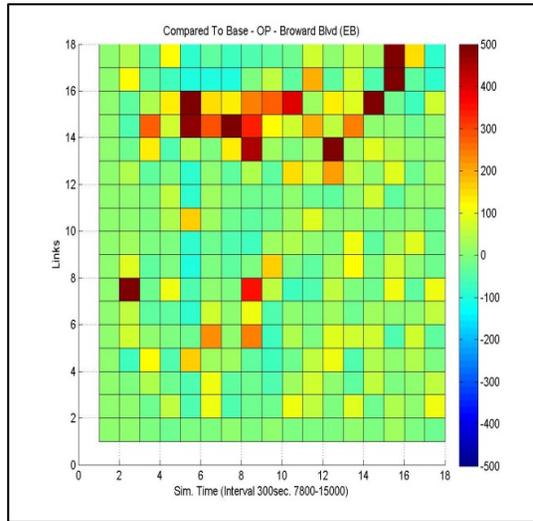
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 145- Visualization of the Occupancy Performance Measure in Rail Preemption (300 sec) Scenario
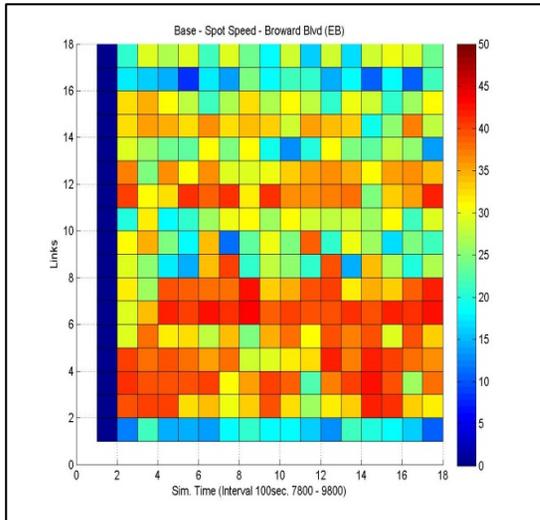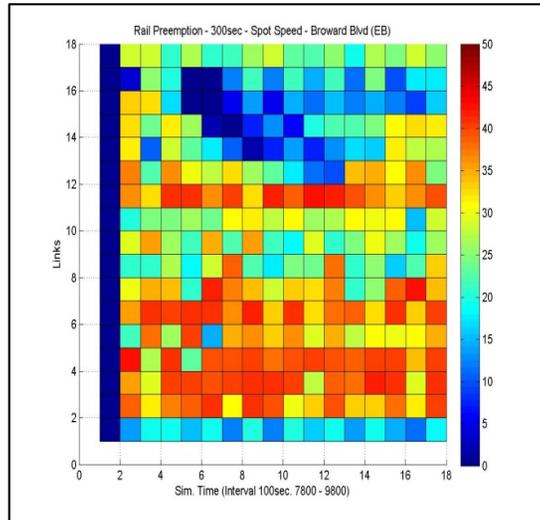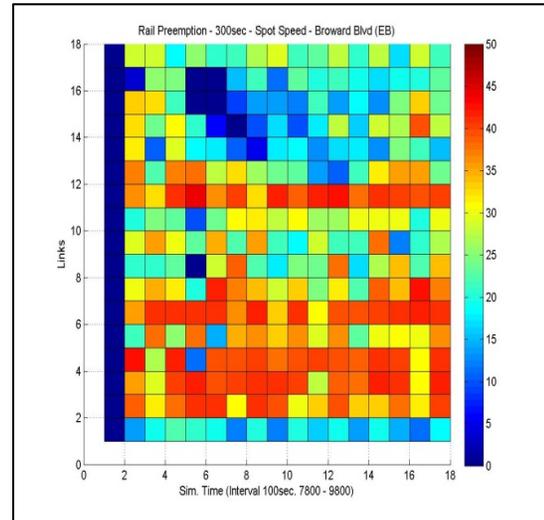
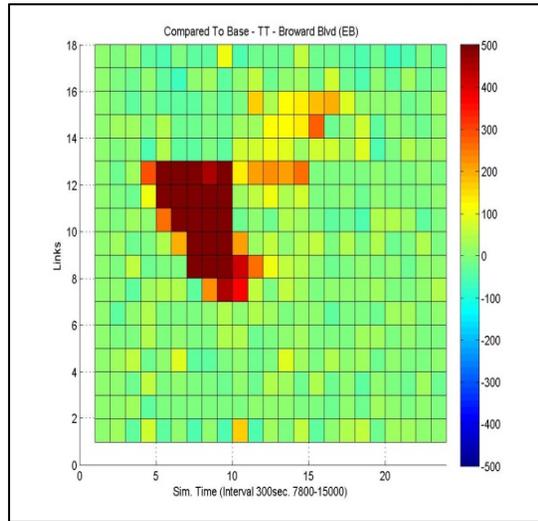a)Base   b) Scenario   c) Strategy-Applied
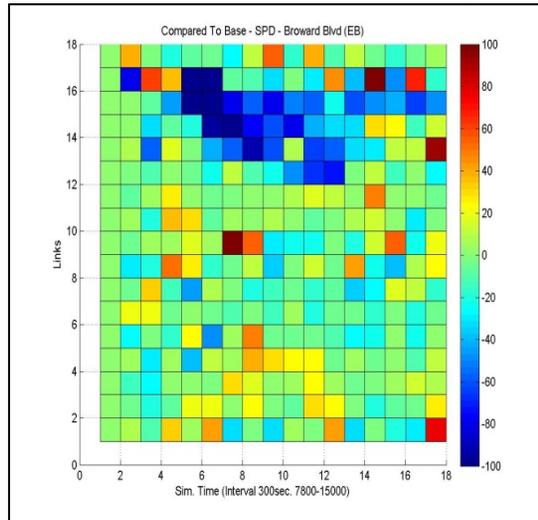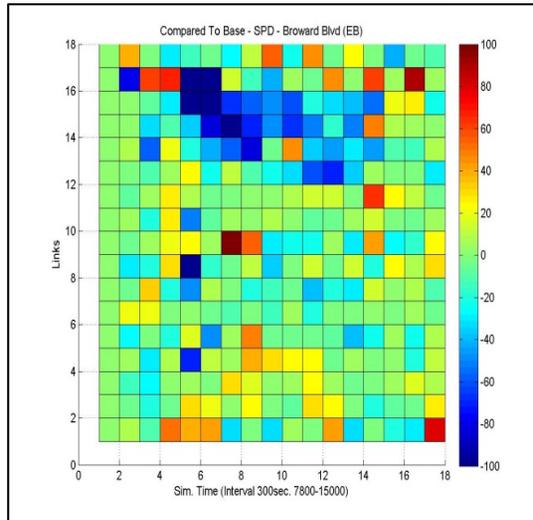
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 146- Visualization of the Spot Speed Performance Measure in Rail Preemption (300 sec) Scenario
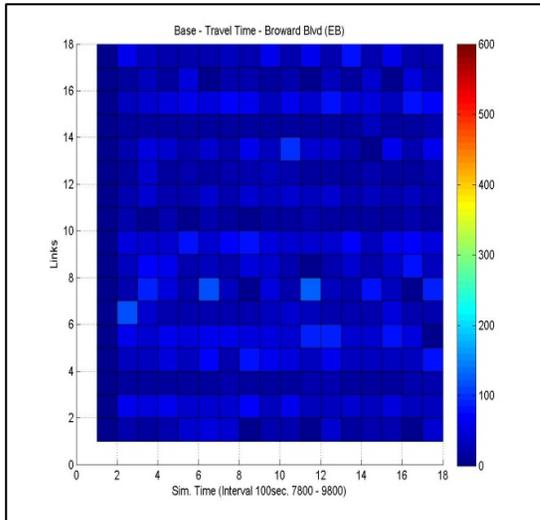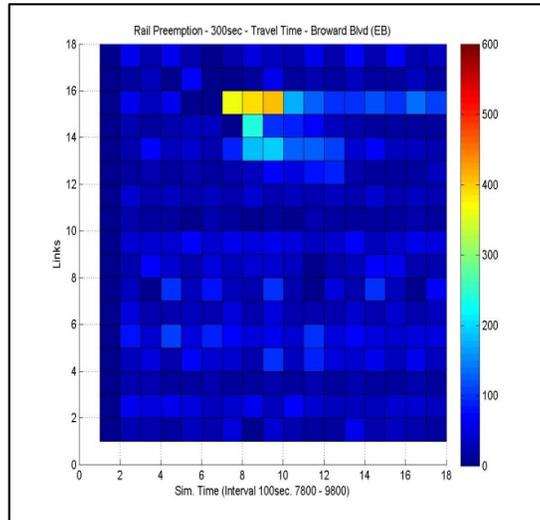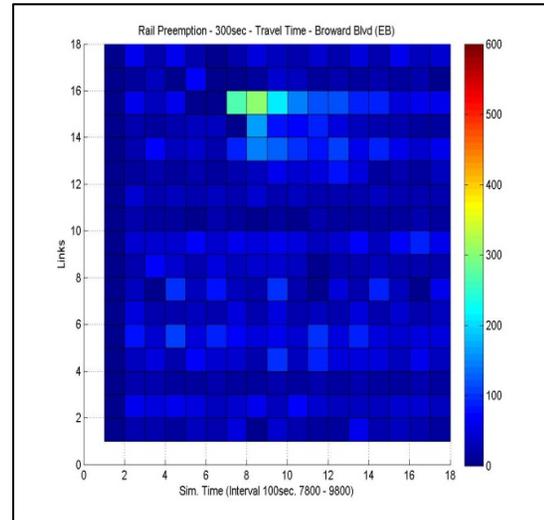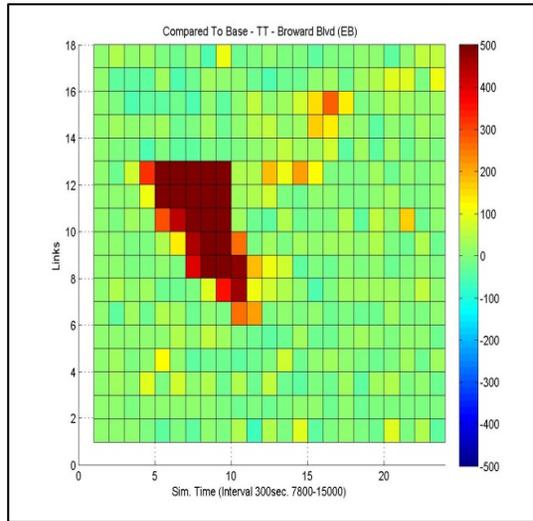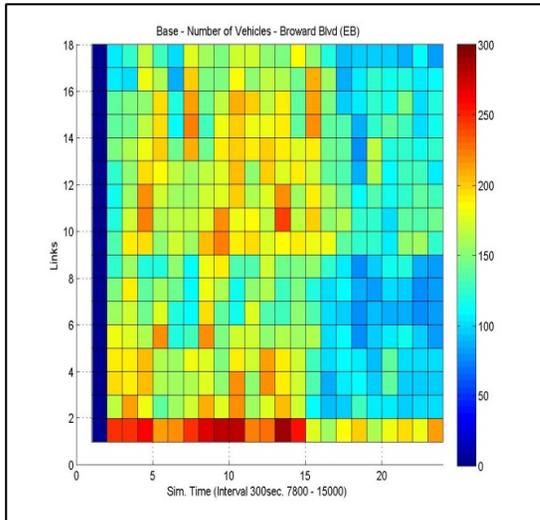
a)Base   b) Scenario   c) Strategy-Applied
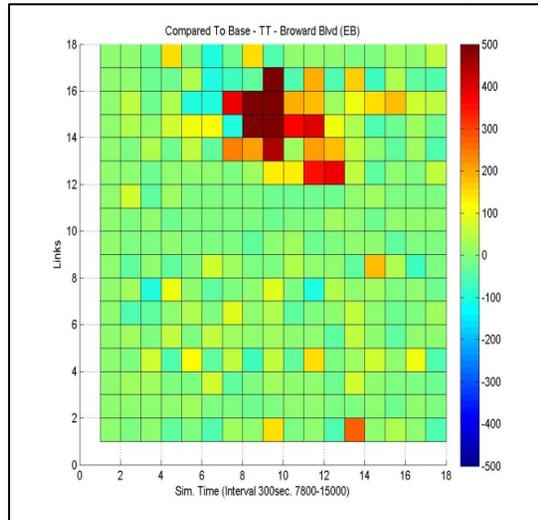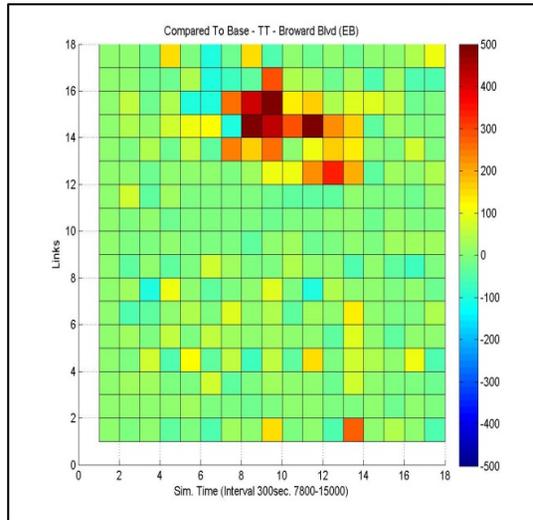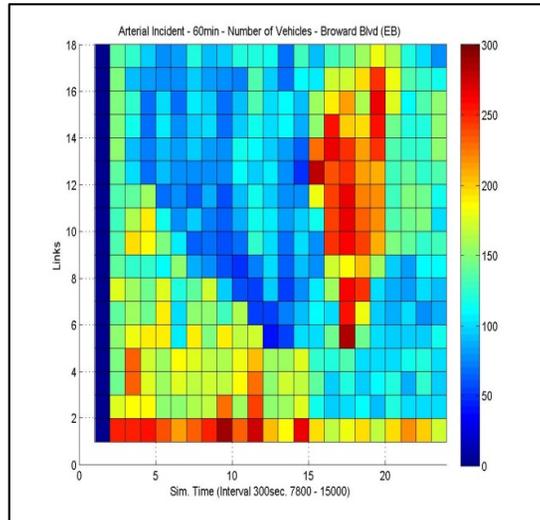
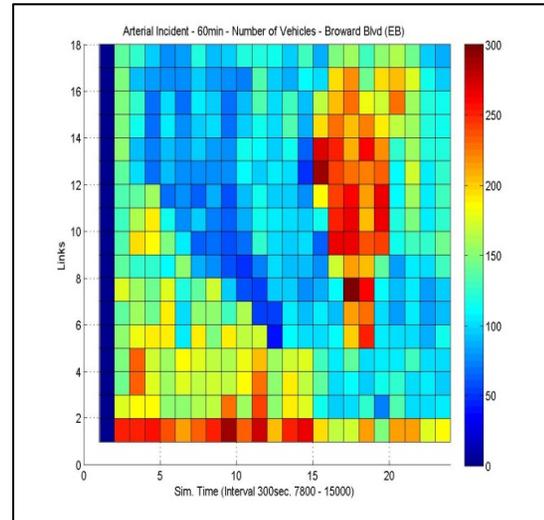d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 147- Visualization of the Travel Time Performance Measure in Rail Preemption (300 sec) Scenario
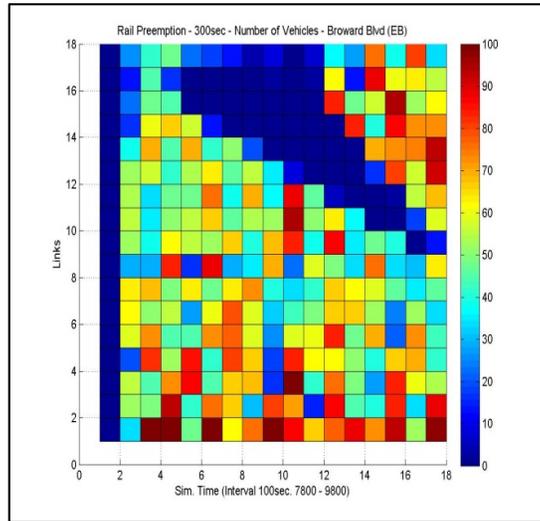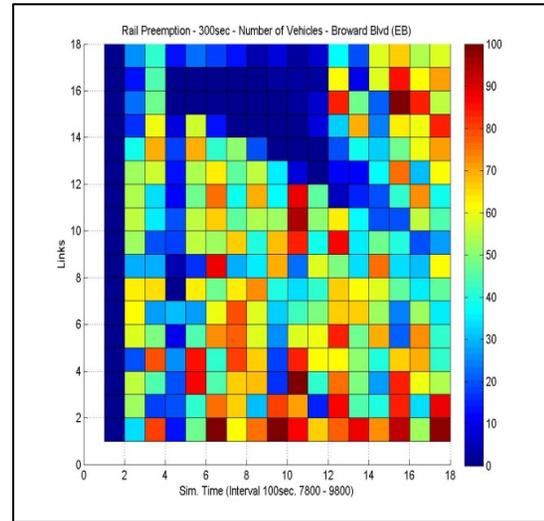
a)Base   b) Scenario   c) Strategy-Applied

d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 148- Visualization of the Throughput Performance Measure in Rail Preemption (700 sec) Scenario
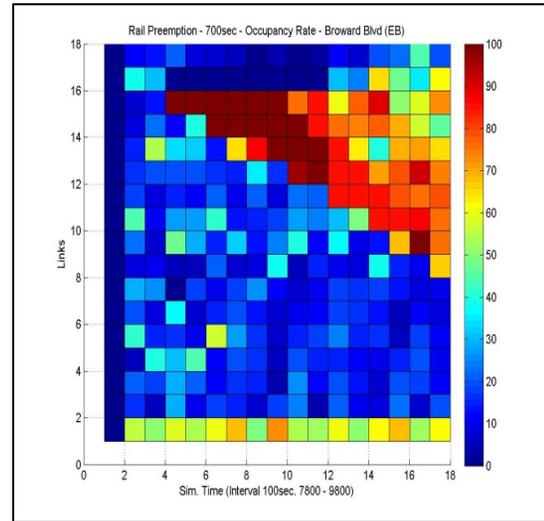
a)Base   b) Scenario   c) Strategy-Applied

d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 149- Visualization of the Occupancy Performance Measure in Rail Preemption (700 sec) Scenario
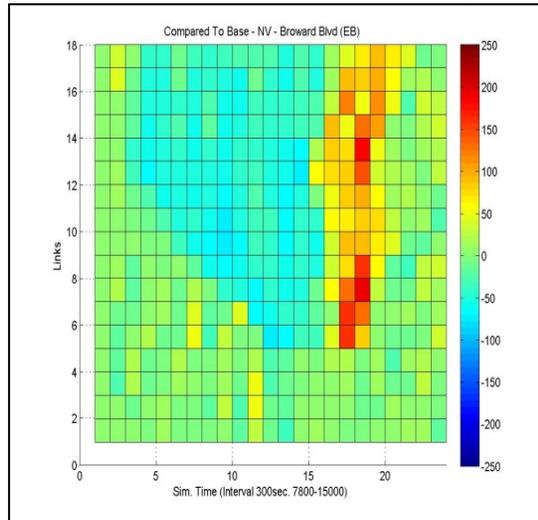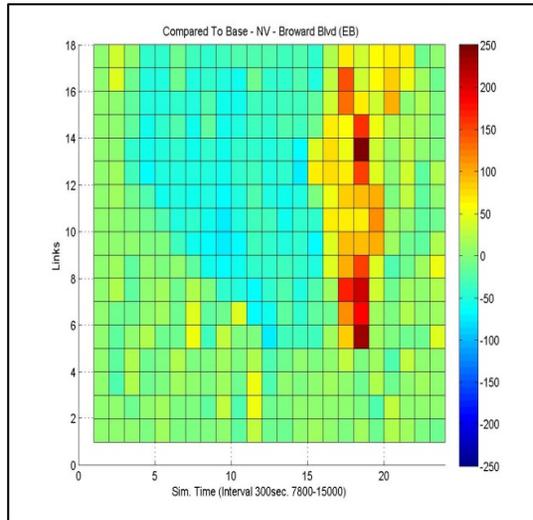
a)Base   b) Scenario   c) Strategy-Applied

d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 150- Visualization of the Spot Speed Performance Measure in Rail Preemption (700 sec) Scenario

a)Base — b) Scenario — c) Strategy-Applied

d) Scenario Compared to Base — e) Strategy Compared to Base

Figure 151- Visualization of the Travel Time Performance Measure in Rail Preemption (700 sec) Scenario

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a)Base	b) Arterial Incident- 30 min.	c) Arterial Incident- 60 min.
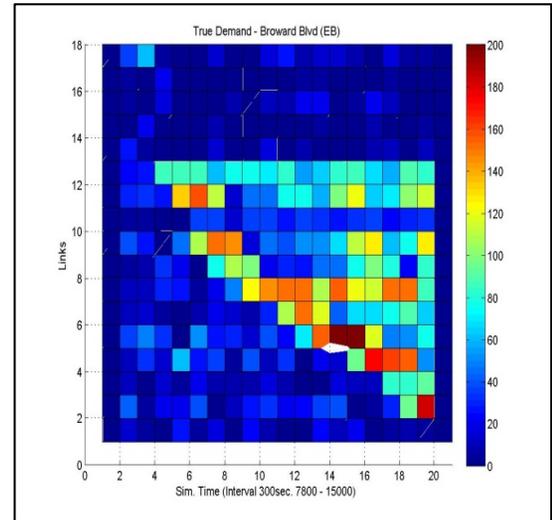
Figure 152- True Demand Under Arterial Incident

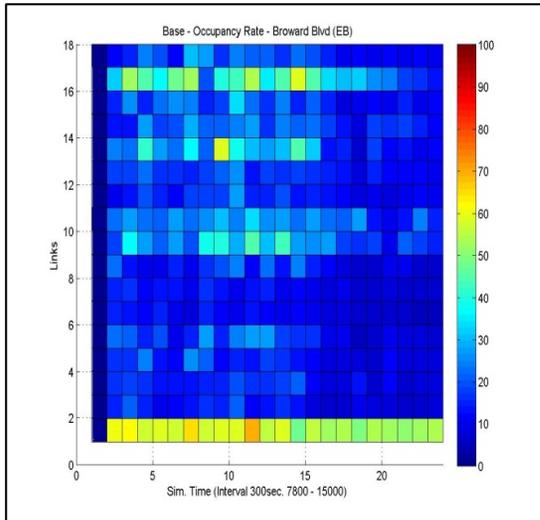a)Base   b) Scenario   c) Strategy-Applied
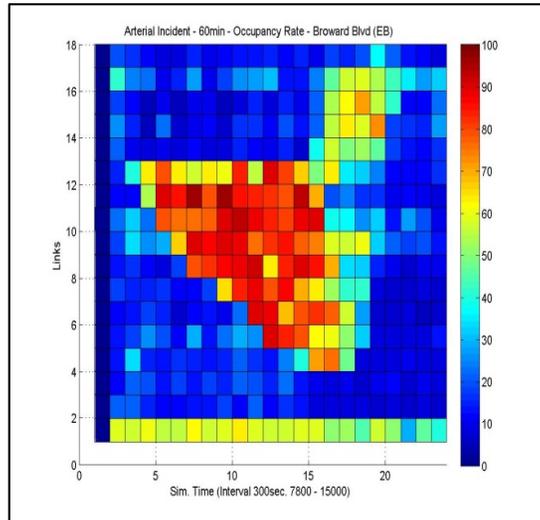
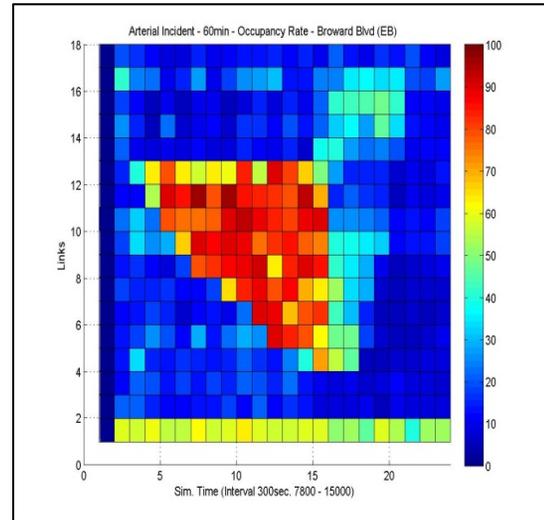d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 153- Visualization of the Throughput Performance Measure in Arterial Incident (30 min) Scenario

a)Base   b) Scenario   c) Strategy-Applied

d) Scenario Compared to Base   e) Strategy Compared to Base

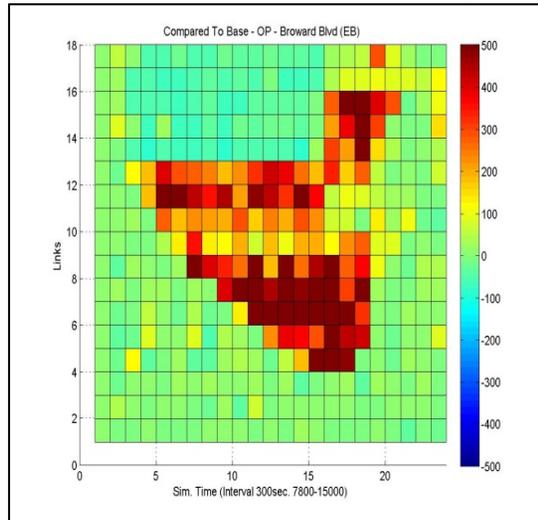Figure 154- Visualization of the Occupancy Performance Measure in Arterial Incident (30 min) Scenario
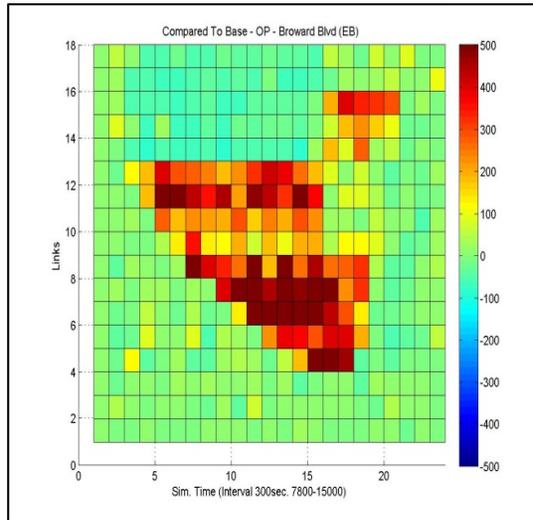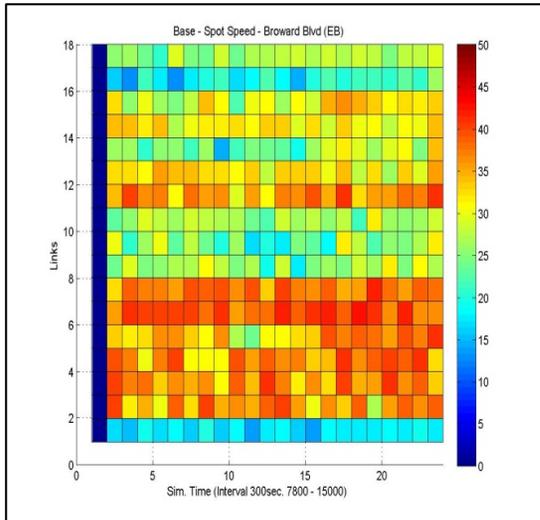
a)Base

b) Scenario

c) Strategy-Applied

d) Scenario Compared to Base

e) Strategy Compared to Base

Figure 155- Visualization of the Spot Speed Performance Measure in Arterial Incident (30 min) Scenario
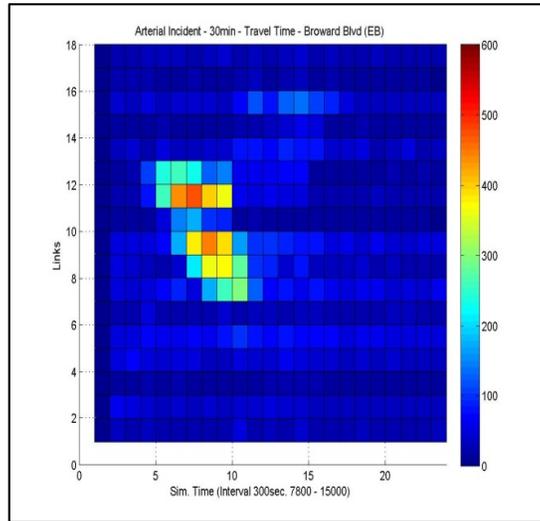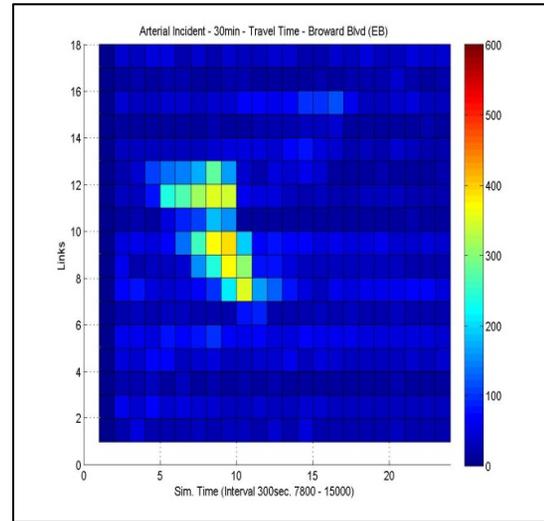
a)Base
b) Scenario
c) Strategy-Applied
d) Scenario Compared to Base
e) Strategy Compared to Base

Figure 156- Visualization of the Travel Time Performance Measure in Arterial Incident (30 min) Scenario

a)Base   b) Scenario   c) Strategy-Applied

d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 157- Visualization of the Throughput Performance Measure in Arterial Incident (60 min) Scenario

a)Base   b) Scenario   c) Strategy-Applied
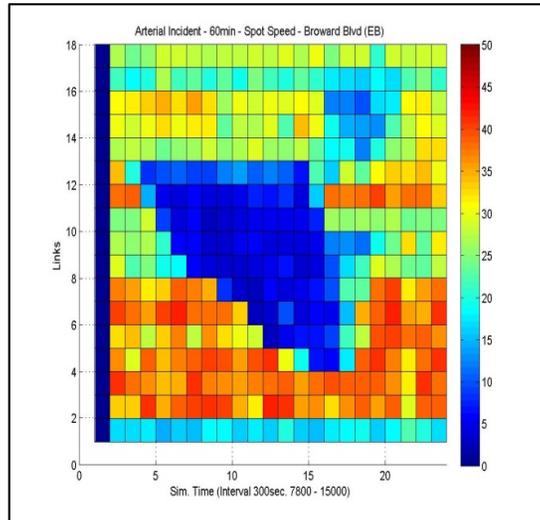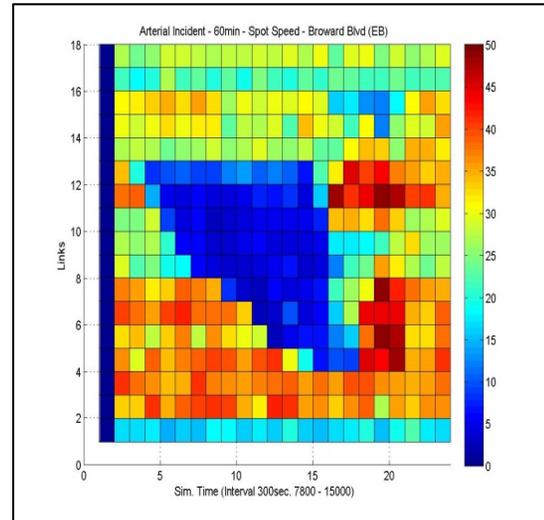
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 158- Visualization of the Occupancy Performance Measure in Arterial Incident (60 min) Scenario
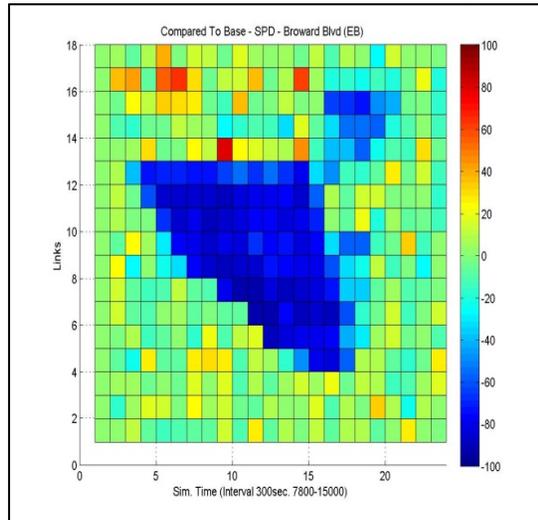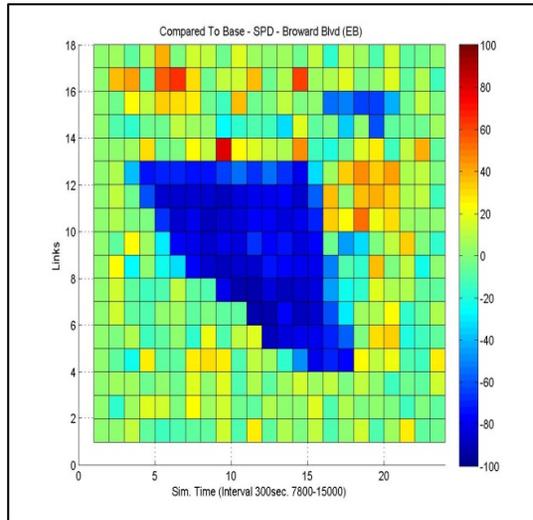
234

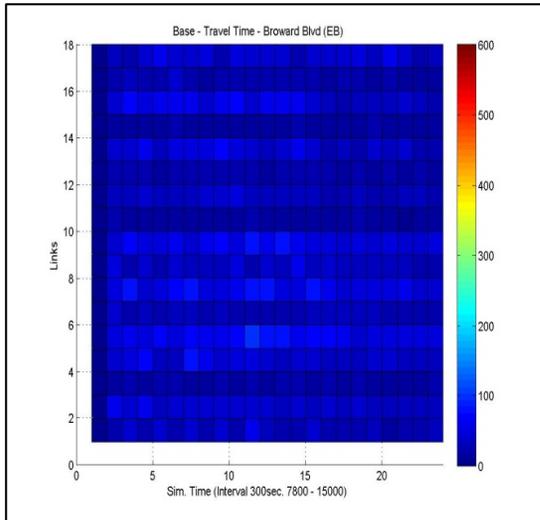a)Base   b) Scenario   c) Strategy-Applied
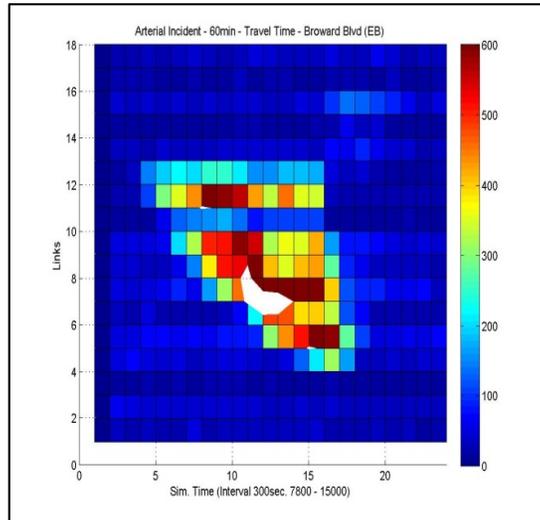
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 159- Visualization of the Spot Speed Performance Measure in Arterial Incident (60 min) Scenario
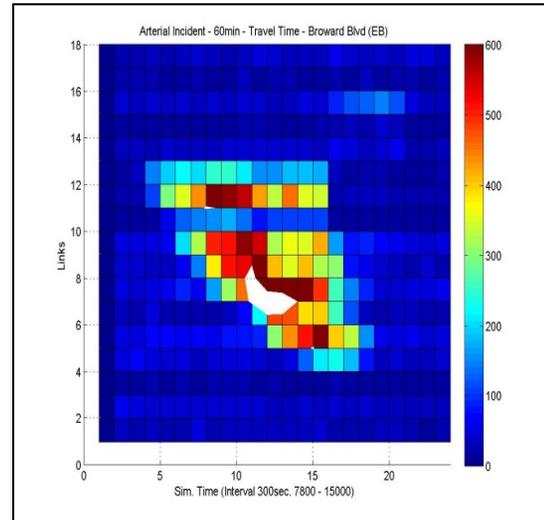
a) Base   b) Scenario   c) Strategy-Applied

d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 160- Visualization of the Travel Time Performance Measure in Arterial Incident (60 min) Scenario
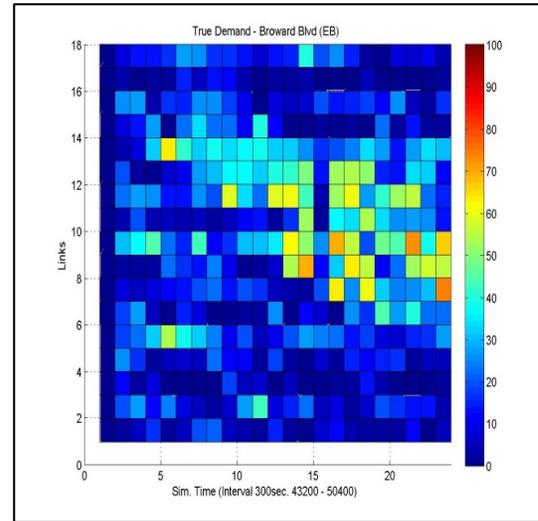
| a)Base | b) Event Traffic |

Figure 161- True Demand Under Event Traffic
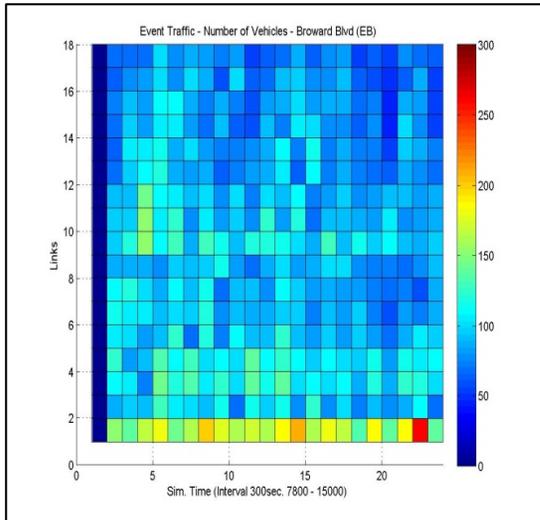
a)Base   b) Scenario   c) Strategy-Applied
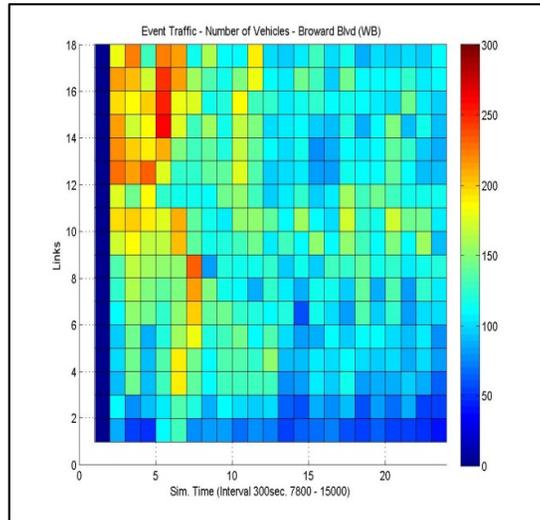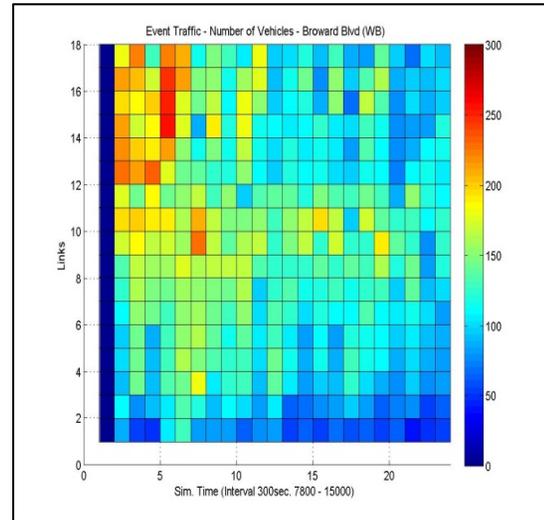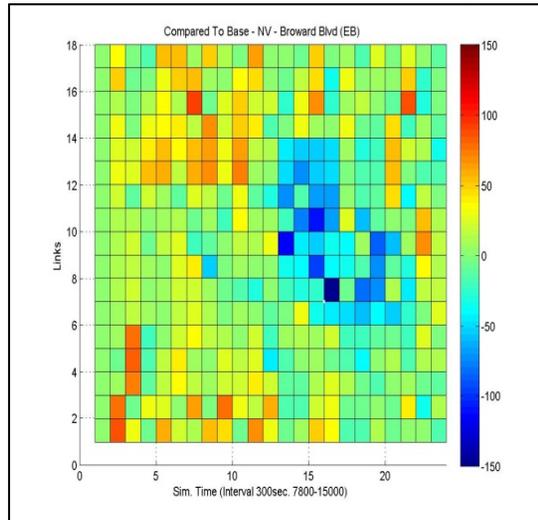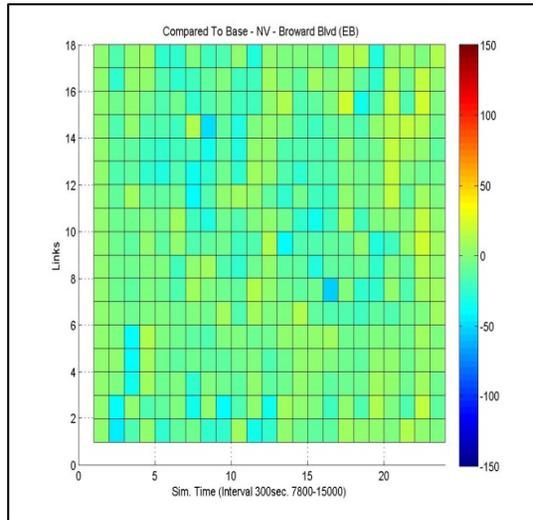
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 162- Visualization of the Throughput Performance Measure in Event Traffic Scenario
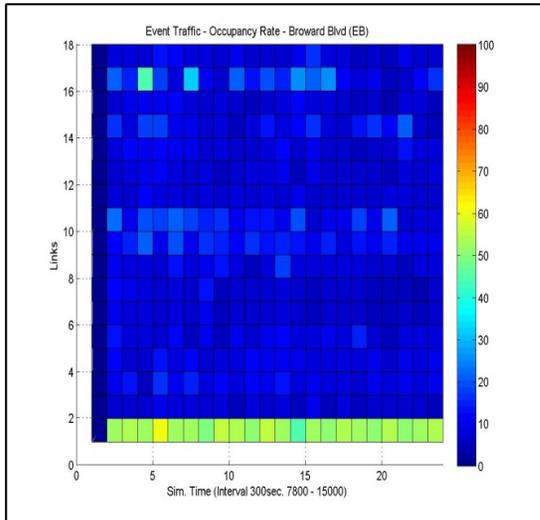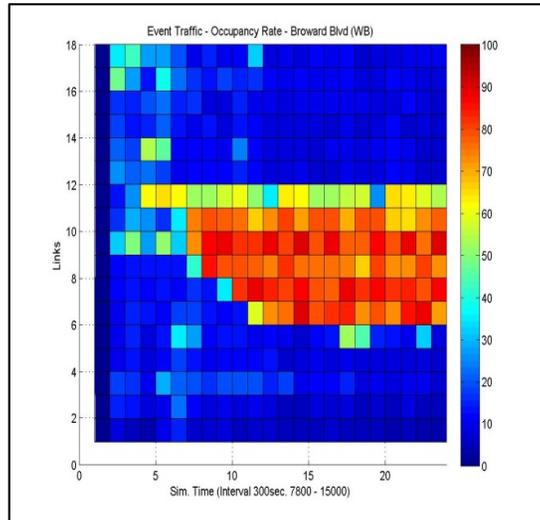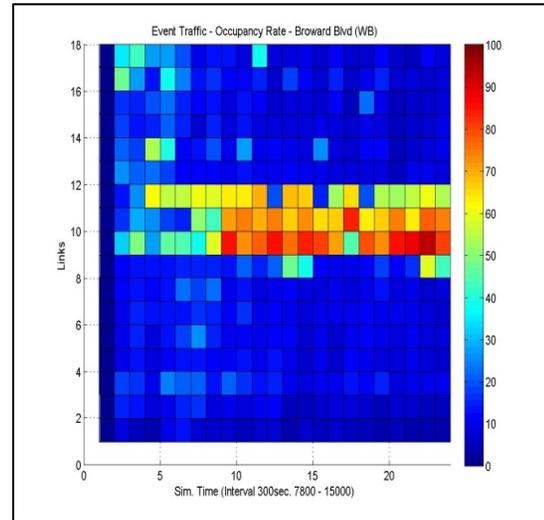
a) Base   b) Scenario   c) Strategy-Applied
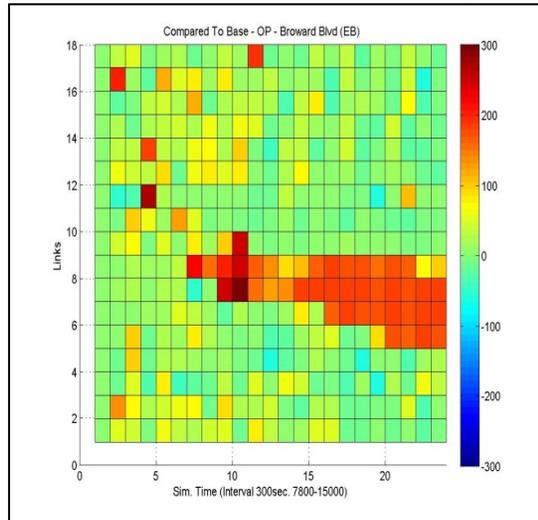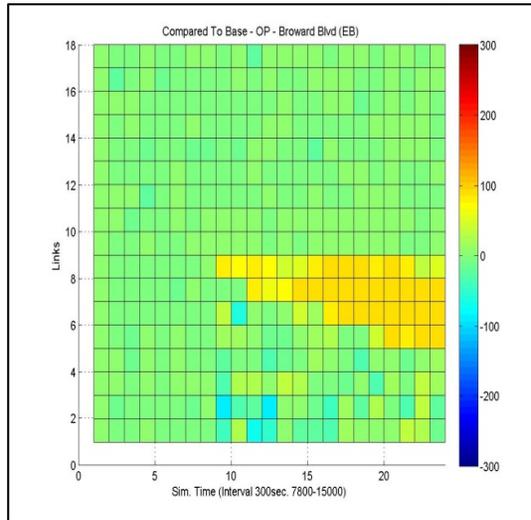
d) Scenario Compared to Base   e) Strategy Compared to Base

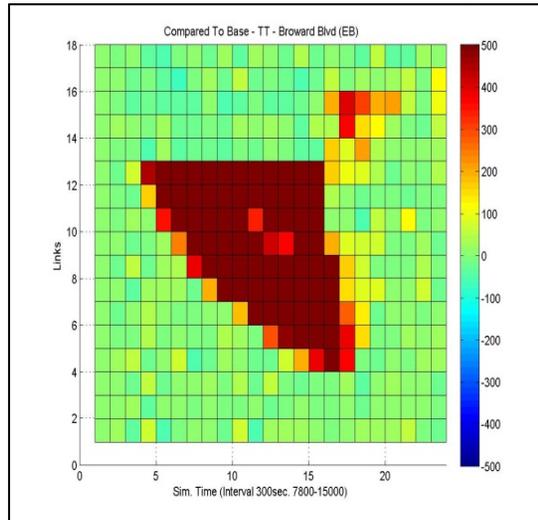Figure 163- Visualization of the Occupancy Performance Measure in Event Traffic Scenario
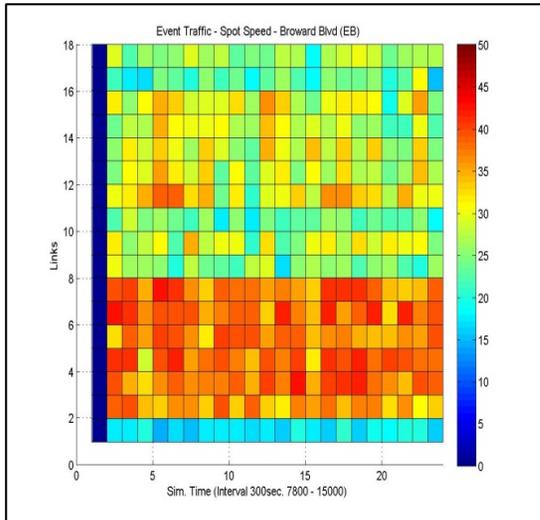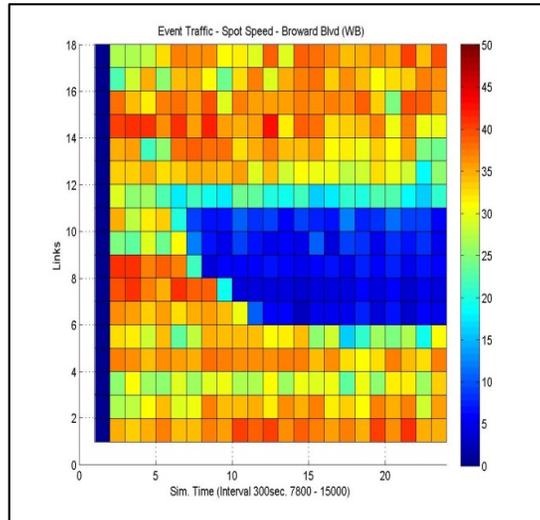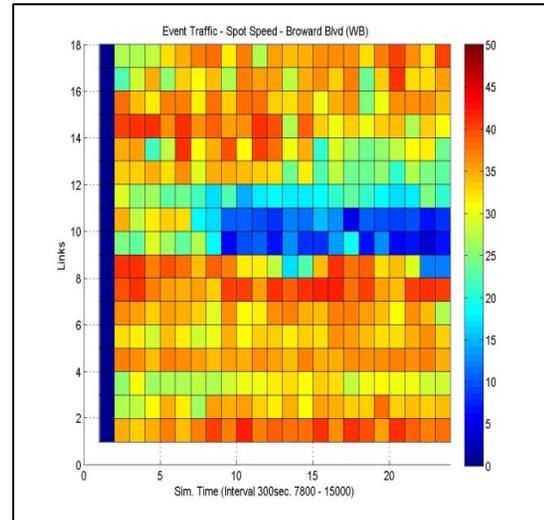
a)Base   b) Scenario   c) Strategy-Applied
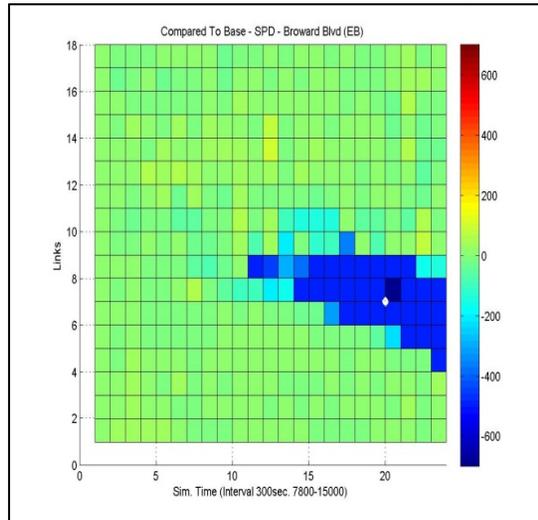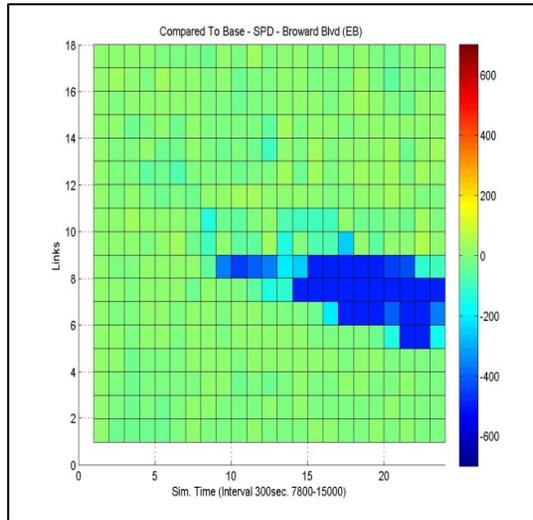
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 164- Visualization of the Spot Speed Performance Measure in Event Traffic Scenario
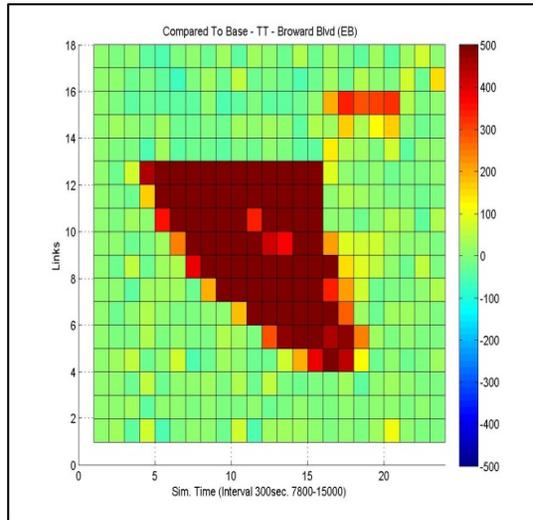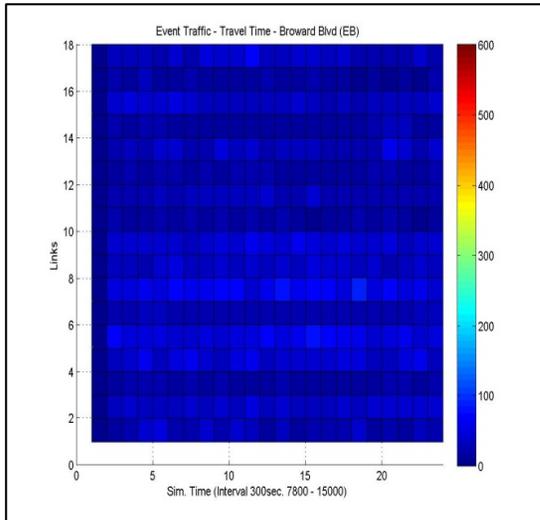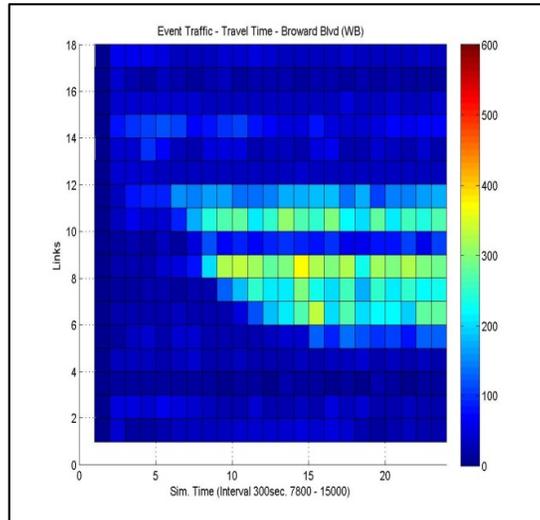
240
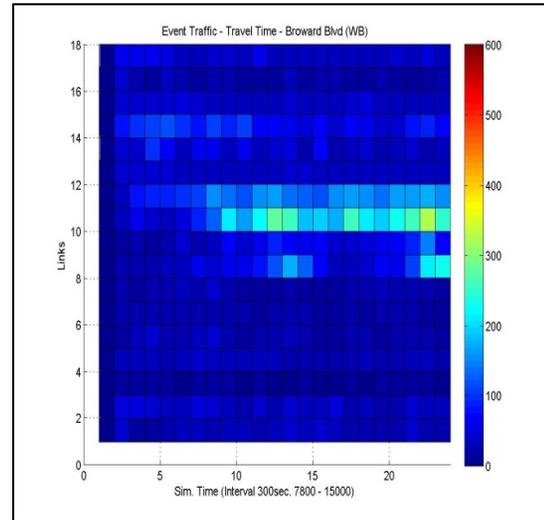
a)Base   b) Scenario   c) Strategy-Applied
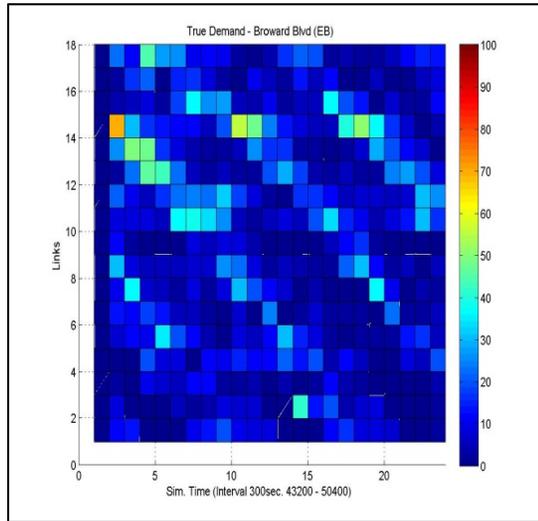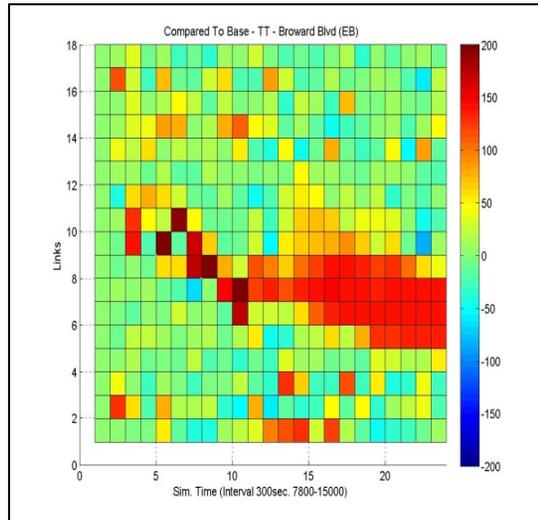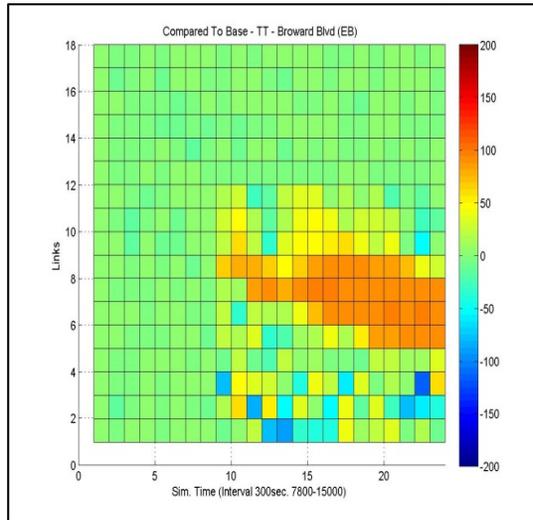
d) Scenario Compared to Base   e) Strategy Compared to Base

Figure 165- Visualization of the Travel Time Performance Measure in Event Traffic Scenario

# Guidelines

| Analysis Level	Scenario	Location	Number

OVERVIEW

This guideline represents a tool to support Traffic Management Center operators in ad-hoc decision making to control and manage several recurring and nonrecurring congestion scenarios. It is expected that through implementation of appropriate strategies this tool will help operators in alleviating traffic congestion during specific traffic scenarios. There are certain mobility benefits which result from applying these strategies. However, the strategy benefits presented below have been measured by modeling each scenario in VISSIM simulation model. Each congestion scenario is provided with the following information:

- Location: identifies the location of the scenario.
- Spatial Scope: the scenario impact area.
- Google Map: provides a quick reference for traffic operators to identify the location of the scenarios.
- Identification: depicts signature of each scenario, which guides traffic operators to identify traffic conditions. Relative thresholds are compared to the base scenario. For example, "Increase by 30%" means that the performance measure has increased by 30% compared to the base scenarios. Absolute thresholds are independent of the base scenario.
- Additional Checklist: additional factors that need to be considered by traffic operators to manage and control traffic scenarios.
- Strategy: recommended strategy for each specific scenario. The strategies are either signal retiming or traffic rerouting.
- Expected Benefits: the expected benefits of strategy application in percentage. The expected benefits are estimated by comparing before and after strategy implementation conditions.

Version	Date	Page Number

Operations	Event Management	Discovery and Science Museum	1.1

LOCATION

Discovery and Science Museum at the Intersection of Broward Blvd. and NW 5 th Ave.

SPATIAL SCOPE

- Eastbound Through Movement
- Westbound Through Movement

IDENTIFICATION

Performance Measure	Relative Threshold	Absolute Threshold	Available Sensor	Logical Statement
Throughput (vehicles)	⬆ increases to more than 50%	60	M-21	And
Occupancy (%)		⬆ 50%	M-21	And
Spot speed (mph)	⬇ decreases more than 50%	18	M-21	And
Travel Time (minutes)	⬆ increases to more than 100%	90	B-27 to B-29	

ADDITIONAL CHECKLIST

- Check event schedule (start time, end time, and duration)

STRATEGY

The alternative signal retiming plan is recommended for this scenario:

Name	Base Plan											Alt. Pattern		
	SC#	Ph1	Ph2	Ph3	Ph4	Ph5	Ph6	Ph7	Ph8	C.L.	Offset	Ph2	Ph6	C.L.
SR7	77	26	54	26	48	32	54	26	48	160	88			
SW38th Ave.	76	20	79	26	35	20	79			160	84			
SW35th Ave.	16		125		35					160	131			
SW34th Ave.	15	20	100				120		40	160	151			
SW31st Ave.	13	24	70	24	42	24	70	24	42	160	2			
Riverland Rd.	53	24	77	20	39	24	77	20	39	160	109			
SW24th Ave.	87	20	95		45	20	95		45	160	109			
I-95 SB/NB	32	20	60		25		55			160	0	100	95	200
SW18th St	70	15	103		42	15	103		42	160	25	143	143	200
SW15th Ave.	85	25	97				97		38	160	3	137	137	200
SW14th Ave.	99		130		30		130			160	134	170	170	200
NW11th Ave.	82	26	96		38	19	96		38	160	140	136	136	200
Powerline Rd.	30		123		37		123		37	160	93	163	163	200
Avenue of the Arts	71	13	71	14	38	21	71	29	38	160	104	111	111	200
NW5th St	88		106		34	20	106		34	160	78	146	146	200
NW1st Ave.	33		84		51	25	84		51	160	51	124	124	200
Andrews Rd.	54	23	63	20	43		63	30	43	160	62	103	103	200
NE3rd Ave.	43	20	63	20	47	20	63	30	47	160	129	103	103	200
US1	23	35	47	30	42	25	47	36	42	160	15	87	87	200

EXPECTED BENEFITS (SIMULATION BASED)

- Throughput: increased by 1.4%
- Occupancy: decreased by -4.3%
- Speed: increased by 9.4%
- Travel Time: decreased by 9.1%

245

Operations	Left Turn Spillover	Broward Blvd. and NW 24th Ave. WB	2.1

LOCATION

Broward & NW 24th Ave. WB

SPATIAL SCOPE

- Westbound Through Movement
- Westbound Left Turn Movement

IDENTIFICATION

Performance Measures T	Relative Threshold	Absolute Threshold	Available Sensor	Logical Statement
Throughput (vehicles)	decreases more than 30%	60	M-19	And
Occupancy (%)		30%	M-19	And
Spot speed (mph)	decreases more than 30%	20	M-19	And
Travel Time (minutes)	increases more than 30%	300	B-26 to B-25	

STRATEGY

The following signal retiming plan is recommended for this scenario:

Name	Base Plan										
	SC#	Ph1	Ph2	Ph3	Ph4	Ph5	Ph6	Ph7	Ph8	C.L.	Offset
SW24th Ave.	87	20	95->85		45->35	20->40	95->85		45->35	160	109

EXPECTED BENEFITS (SIMULATION BASED)

- Throughput increases from 1.4% to 4.3%
- Occupancy decreases from 5.1% to 6.2%
- Speed increases from 0.5% to 1.3%
- Travel Time decreases from 2.6% to 4.1%

Operations	Saturation	Entire Broward Blvd	3.1

LOCATION

Entire Broward Blvd. Corridor
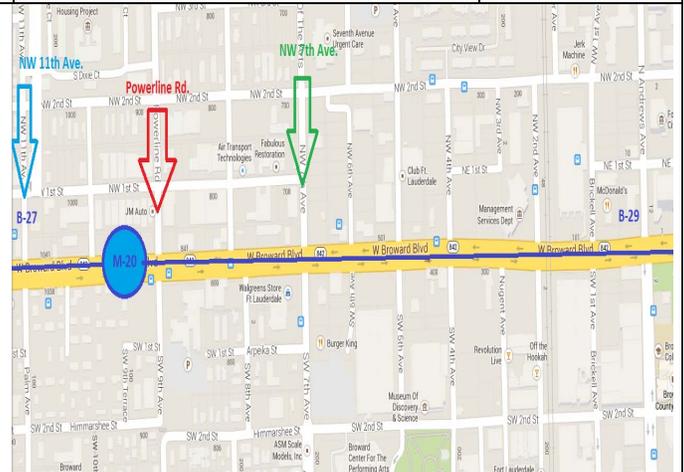
SPATIAL SCOPE

- Broward Blvd. WB
- Broward Blvd. EB

IDENTIFICATION

Performance Measures T	Relative Threshold	Absolute Threshold	Available Sensor	Logical Statement
Throughput (vehicles)	Increases more than 30%	70	M-20	And
Occupancy (%)		50%	M-20	And
Spot speed (mph)	Slightly decreases by 10%	30	M-20	And
Travel Time (minutes)	Slightly increases by 10%	120	B-27 to B-29	

STRATEGY

The following signal retiming plan is recommended for this scenario:

Name	SC#	Ph1	Ph2	Ph3	Ph4	Ph5	Ph6	Ph7	Ph8	C.L.	Offset
SR7	77	27	49	59	55	24	52	30	84	190	12
SW 38th Ave.	76	22	113	14	41	80	55			190	81
SW 35th Ave.	16		52		138					190	72
SW 34th Ave.	15	18	88				106		84	190	159
SW 31st. Ave.	13	17	96	21	56	25	88	24	53	190	129
Riverland Rd.	53	20	74	20	76	50	44	32	64	190	33
SW 24th Ave.	87	11	64		115	40	35		115	190	6
I-95 SB/NB	32	20	60		25		55			190	0
SW 18th St.	70	76	72		42	9	139		42	190	81
SW 15th Ave.	85	21	56				77		113	190	180
SW 14th Ave.	99		179		11		179			190	147
NW 11th Ave.	82	9	29		152	12	26		152	190	3
Powerline Rd.	30		92		98		92		98	190	48
Avenue of the Art	71	15	50	17	108	20	45	9	116	190	42
NW 5th St.	88		94		96	16	78		96	190	84
NW 1stAve.	33		66		124	10	56		124	190	144
Andrews Rd.	54	10	74	71	35		84	76	30	190	126
NE 3rd Ave.	43	12	100	12	66	28	84	26	52	190	3
US1	23	26	57	35	72	18	65	42	65	190	190

EXPECTED BENEFITS (SIMULATION BASED)

- Throughput increases by 3.9%
- Occupancy decreases by 6.8
- Speed increases by 11.7%
- Travel Time decreases by 15.9%

249

| Operations	Oversaturation	Entire Broward Blvd	4.1

LOCATION
Entire Broward Blvd. Corridor
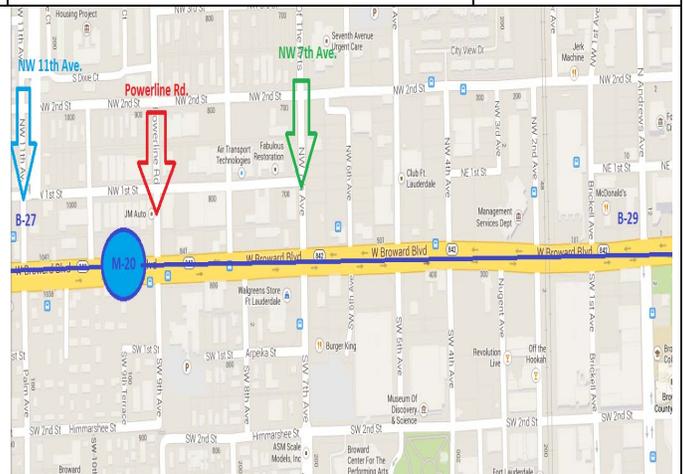
SPATIAL SCOPE
- Broward Blvd. WB
- Broward Blvd EB

IDENTIFICATION

Performance Measures T	Relative Threshold	Absolute Threshold	Available Sensor	Logical Statement
Throughput (vehicles)	Decreases more than 30%	60	M-20	And
Occupancy (%)		100%	M-20	And
Spot speed (mph)	Decreases more than 50%	20	M-20	And
Travel Time (minutes)	Increases more than 100%	300	B-27 to B-29	

STRATEGY

The following signal retiming plan is recommended for this scenario:

Name	SC#	Ph1	Ph2	Ph3	Ph4	Ph5	Ph6	Ph7	Ph8	C.L.	Offset
SR7	77	19	49	75	53	18	50	42	86	196	77
SW38th Ave	76	16	106	13	61	10	112			196	112
SW35th Ave	16		141		55					196	12
SW34th Ave	15	22	107				129		67	196	34
SW31st Ave	13	31	80	11	74	56	55	30	55	196	37
Riverland Rd	53	48	61	44	43	39	70	54	33	196	87
SW24th Ave	87	14	134		48	39	109		48	196	118
I-95 SB/NB	32	20	60		25		55			196	0
SW18th St	70	34	100		62	68	66		62	196	158
SW15th Ave	85	56	70				126		70	196	59
SW14th Ave	99		81		115		81			196	68
NW11th Ave	82	48	103		45	82	69		45	196	140
Powerline Rd	30		115		81		115		81	196	164
Avenue of the Arts	71	46	70	17	63	42	74	9	71	196	158
NW5th St	88		128		68	15	113		68	196	93
NWNW1st Ave	33		92		104	36	56		104	196	99
Andrews Rd	54	19	65	37	75		84	44	68	196	102
NE3rd Ave	43	106	37	12	41	17	126	10	43	196	140
US1	23	20	39	52	85	10	49	22	115	196	196

EXPECTED BENEFITS (SIMULATION BASED)

- Throughput increases by 15.9%
- Occupancy decreases by 20.2%
- Speed increases by 25.6%
- Travel Time decreases by 34.1%

251

Operations	Freeway Incident	Broward Blvd on ramp	5.1

LOCATION

Right after Broward Blvd. on ramp

SPATIAL SCOPE

- Westbound near I-95

- Eastbound near I-95
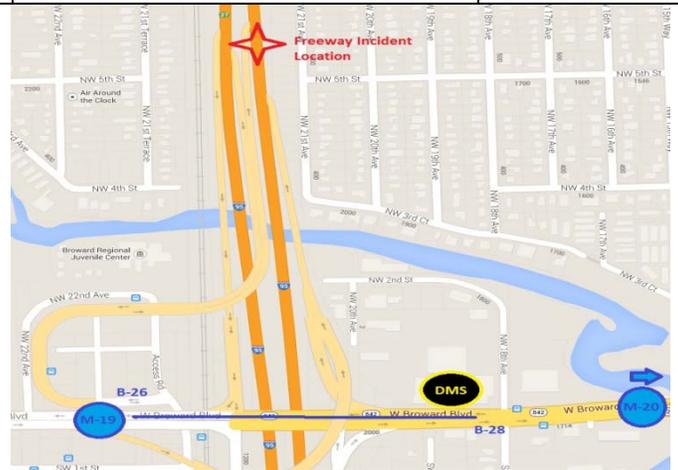
IDENTIFICATION

Performance Measures T	Relative Threshold	Absolute Threshold	Available Sensor	Logical Statement
Throughput (vehicles)	Decreased more than 30%	40	M-20	And
Occupancy (%)	30%	30%	M-20	And
Spot speed (mph)	Decreases more than 30%	20	M-20	And
Travel Time (minutes)	Increases more than 30%	200	B-26 to B-28	

STRATEGY

Change Dynamic Message Sign on Westbound to:
- Broward – I-95 (NB): 25 Minutes
- Broward- NW 27th Ave. – Sunrise – I-95 (NB): 18 Minutes

Change Dynamic Message Sign on Eastbound to:
- Broward – I-95 (NB): 25 Minutes
- Broward- NW 27th – Sunrise – I95(NB): 15 Minutes
- Broward- NW 31st – Sunrise – I-95(NB): 15 Minutes

EXPECTED BENEFITS (SIMULATION BASED)
- Throughput increases by 9.5%
- Occupancy decreases by -7.6%
- Speed increases by 9.7%
- Travel time decreases by 42.9%

253

Operations	Rail Preemption	Broward Blvd. between SW 2nd Ave. and SW 1st. Ave	6.1

LOCATION
- Broward Blvd. between SW 2nd Ave. and SW 1st. Ave

SPATIAL SCOPE
- Westbound Through Movement
- Eastbound Through Movement
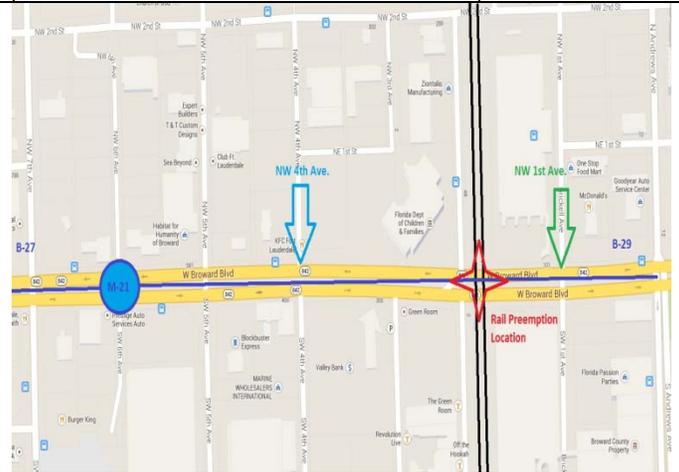
IDENTIFICATION

Performance Measures T	Relative Threshold	Absolute Threshold	Available Sensor	Logical Statement
Throughput (vehicles)		⬇ Lower than 10	M-21	And
Occupancy (%)		⬆ 90%	M-21	And
Spot speed (mph)		⬇ Lower than 5 mph	M-21	And
Travel Time (minutes)		⬆ Increases more than 500%	B-27 to B-29	

ADDITIONAL CHECKLIST
- Check train schedule to verify possible long trains.

STRATEGY

The following signal retiming plan is recommended for this scenario:

Name	SC#	Ph2	Ph6	C.L.
I-95 SB/NB	32	100	95	200
SW18th St	70	143	143	200
SW15th Ave	85	137	137	200
SW14th Ave	99	170	170	200
NW11th Ave	82	136	136	200
Powerline Rd	30	163	163	200
Avenue of the Arts	71	111	111	200
NW5th St	88	146	146	200
NWNW1st Ave	33	124	124	200
Andrews Rd	54	103	103	200
NE3rd Ave	43	103	103	200
US1	23	87	87	200

EXPECTED BENEFITS (SIMULATION BASED)

- Throughput increases from 3.1% to 5.1%
- Occupancy decreases from 3.4% to 8.4%
- Speed increases from 3.0% to 9.6%
- Travel time decreases from 6.3% to 9.1%

255

Operations	Arterial Incident	Intersection of Broward Blvd. and Powerline Rd.	7.1

LOCATION

The intersection of Broward Blvd. and Powerline Rd.

SPATIAL SCOPE

- Eastbound Through Movement

IDENTIFICATION

Performance Measures T	Relative Threshold	Absolute Threshold	Available Sensor	Logical Statement
Throughput (vehicles)	⬇ Decreases more than 50%	50	M-20	And
Occupancy (%)		⬆ 50%	M-20	And
Spot speed (mph)	⬇ Decreases more than 50%	12	M-20	And
Travel Time (minutes)	⬆ Increases more than 200%	500	B-27 to B-29	

STRATEGY

The following signal retiming plan is recommended for this scenario:

Name	SC#	Ph2	Ph6	C.L.
I-95 SB/NB	32	100	95	200
SW18th St	70	143	143	200
SW15th Ave	85	137	137	200
SW14th Ave	99	170	170	200
NW11th Ave	82	136	136	200
Powerline Rd	30	163	163	200
Avenue of the Arts	71	111	111	200
NW5th St	88	146	146	200
NWNW1st Ave	33	124	124	200
Andrews Rd	54	103	103	200
NE3rd Ave	43	103	103	200
US1	23	87	87	200

EXPECTED BENEFITS (SIMULATION BASED)

- Throughput increases from 0.6% to 2.3%
- Occupancy decreases from 9.8% to 11.0%
- Speed increases from 2.5% to 3.8%
- Travel time decreases from 5.6% to 7.1%

257