FLORIDA ATLANTIC UNIVERSITY
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in the College of Engineering & Computer Science

Multiresolution Analysis of the Impacts of Complete Streets on Efficiency, Safety, and Environment of Urban Corridors

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PREPARED FOR
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DISCLAIMER

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 comply with Section 4 of ASTM E380. (Revised March 2003)

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16. Abstract
In recent years, many DOTs and other public agencies consider implementing Complete Street designs to make our road infrastructure friendlier for multimodal users. This project developed multiresolution analysis methodologies to quantitatively assess the effectiveness and impact of Complete Street designs. Case studies were performed using the Salt Lake City (SLC) Central Business District (CBC) and the Central Broward County (CBC) networks. Both demonstrated that the partial Complete Street design that provides enhancements in signal timing without significant roadway geometric changes is more preferrable, especially considering the corridor level benefit without noticeable penalty on the macroscopic network level performance.

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EXECUTIVE SUMMARY

In recent years, many DOTs and other public agencies consider implementing Complete Street designs. Such considerations are largely motivated by the need to make our road infrastructure friendlier for multimodal users than the corridors whose primary purpose is to serve private traffic. Consequently, a large number of design and evaluation studies has been performed to identify directions for Complete Street implementations and estimate their benefits. FDOT is one of the national leaders in the adoption of Complete Street implementation. Several other activities are either completed recently or will be finished soon (Complete Streets implementation plan, Complete Streets Handbook, Design Manual, etc.). The FAU research team has reviewed the other ongoing or completed studies and identify lessons learned from those efforts. However, recent effort in analyzing and quantifying the benefits and effects of complete streets has been mostly speculative.

The process of deciding whether to implement Complete Streets is often more driven by qualitative than quantitative analysis, which leaves room for speculations on how Complete Streets would operate under many future travel demand scenarios and operational strategies. This practice does not comply with our long-term planning processes for urban network infrastructure, where future (multimodal) transportation demand levels need to be considered through macroscopic modeling of relevant scenarios. On the other hand, a realistic account of traffic operations, reflecting real-world conditions as closely as possible, requires a level of operational details and performance measures which are not attainable from the macroscopic/planning models. Such a detailed account of traffic operations is achievable only on microscopic level, which on the other hand does not provide user-friendly features to consider long-term changes in multimodal travel demand. A solution to this level-of-abstraction problem is a multiresolution analysis of Complete Streets in which macroscopic modeling is used to develop/analyze long-term travel demand forecasting scenarios whereas the microscopic analysis is utilized to investigate the impacts of operational strategies and retrieve many high-resolution performance measures (necessary for safety and environmental indicators).

Complete Street is a transportation policy and design approach that requires streets to be planned, designed, operated, and maintained to enable safe, convenient, and comfortable travel and access for users of all ages and abilities regardless of their mode of transportation. Complete Streets allows for safe travel by those walking, cycling, driving automobiles, riding public transportation, and delivering goods. Although there has been roughly a dozen of relevant studies to address qualitative benefits of Complete Streets, there are no studies which address the quantitative assessment of these streets from both operational and planning perspectives.

This research project developed a multiresolution modeling methodology which took in consideration both long-term planning aspects of Complete Streets as well as operational strategies, which may be implemented to address specific needs of its multimodal users. This

study also investigated multi-criteria costs and benefits of deploying Complete Streets in many scenarios with various ‘use-cases’ and network topologies.

Two case study networks were modeled and calibrated for real world conditions. The Salt Lake City (SLC) Central Business District (CBD) network and the Central Broward County (CBC) network represented corridor level complete street designs within a larger macroscopic network.

An existing condition, a partial complete street scenario (with only signal priority for transit but not geometric changes) and a full complete street scenario (signal priority for transit with lane reduction for private passenger cars) were considered for SLC CBD network. The difference between the partial complete street scenarios is that it has been enhanced with TSP but does not include other complete street features such as reduction in number of lanes, lower speed limits, etc.

After VISSIM simulation for all the scenarios, it has been found that for partial complete street scenario, delay has reduced for almost all parameters i.e. total delay, car delay, and person delay car; while these increased in the complete street scenario. Also, vehicle travel comparison indicates partial complete street scenario has the lowest value for maximum parameters (total travel time and car travel time). Only for bus travel time, complete street scenario has the smallest one. In addition, speed of vehicle increased in partial complete street scenario compared to the existing condition and complete street scenario for almost all parameter except the average speed of bus. This clearly justifies the partial complete street scenario as a better option than existing condition and complete street scenario.

Safety performance metrics from the SSAM analysis i.e. crossing conflict, rear end conflict, and lane change conflict show that despite the smallest number of conflict points in the complete street scenario, it has the greatest number of conflicts per vehicle. Therefore, a complete street scenario would make traffic safety less favorable than the existing condition and complete street scenario. Comparing between existing condition and partial complete street scenario, it has been observed that partial complete street scenario not only has the smaller number of conflicts but also fewer conflicts per vehicle. So, it is a clear that partial complete street scenario is the best option considering the efficiency and safety parameters.

This was further confirmed by the analysis of the macroscopic network performance. In addition, another case study was performed using two corridors (Broward Blvd. and Sunrise Blvd.) that are part of the Central Broward County network. The Broward Blvd. corridor provided enhancement for transit users while the Sunrise Blvd. corridor provided enhancement for the significant freight traffic. This also confirmed that the partial complete street scenario was effective in enhancing efficiency and safety.

To make more conclusive and holistic recommendations, we suggest expanding future analyses to include long term route choice and travel behavior changes that could arise from complete street designs on one or a few key corridors within a network.

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1. **Introduction**

1.2. Background Statement

Nowadays, many DOTs and other public agencies consider implementing Complete Street designs. Such considerations are largely motivated by the need to make our road infrastructure friendlier for multimodal users than the corridors whose primary purpose is to serve private traffic. Consequently, a large number of design and evaluation studies has been performed to identify directions for Complete Street implementations and estimate their benefits. FDOT is one of the national leaders in the adoption of Complete Street implementation. Several other activities are either completed recently or will be finished soon (Complete Streets implementation plan, Complete Streets Handbook, Design Manual, etc.). The FAU research team will review the other ongoing or completed studies and identify lessons learned from those efforts. The outcome of this research will complement other FDOT efforts and assist FDOT's decision makers on future Complete Streets implementations.

The process of deciding whether to implement Complete Streets is often more driven by qualitative than quantitative analysis, which leaves room for speculations on how Complete Streets would operate under many future travel demand scenarios and operational strategies. This practice does not comply with our long-term planning processes for urban network infrastructure, where future (multimodal) transportation demand levels need to be considered through macroscopic modeling of relevant scenarios. On the other hand, a realistic account of traffic operations, reflecting real-world conditions as closely as possible, requires a level of operational details and performance measures which are not attainable from the macroscopic/planning models. Such a detailed account of traffic operations is achievable only on microscopic level, which on the other hand does not provide user-friendly features to consider long-term changes in multimodal travel demand. A solution to this level-of-abstraction problem is a multiresolution analysis of Complete Streets in which macroscopic modeling is used to develop/analyze long-term travel demand forecasting scenarios whereas the microscopic analysis is utilized to investigate the impacts of operational strategies and retrieve many high-resolution performance measures (necessary for safety and environmental indicators).

Implementation of a Complete Street is a decision which has a long-term impact on transportation users in the entire surrounding area, not just a corridor itself. Here are a few exemplary questions that such a multiresolution analysis of Complete Streets would need to answer:

- How would pedestrian-friendly improvements of a Complete Street design impact pedestrian traffic flows at busy urban intersections? Will a number of potential conflicts (requires trajectory analysis) of pedestrians with (permitted) right-turn vehicles decrease with a Complete Street design (when compared to the previous conventional-street design)?
- How does an increased traffic flow of heavy vehicles (e.g. trucks) on a Complete Street designed mainly to aid freight traffic impact traffic emissions and energy conservation on this street? What would happen on the same corridor 10 years later if a local business area

closes (e.g. one of the planning alternatives) and a new residential complex is developed? Is the freight-traffic-driven design of the Complete Street robust enough to sustain such a change in land use?

- How do near-side bus stops with queue-jumpers, deployed as a part of Complete Street implementation, impact pedestrian walking (e.g. optimal stop from the pedestrian perspective might be on the far-side of the intersection) and extra delays for private cars? Assuming a constant increase in ride-sharing services in the future of Connected and Automated Vehicles, at what point in future does the proposed Complete Street design become obsolete (e.g. demand for bus trips drops to very low levels)?

Above are only a few examples of questions that can be translated into relevant scenarios to be analyzed in the context of Complete Street implementations. A more detailed list of relevant scenarios will be developed as one of the tasks in this project. The scenarios, networks, and modeling tools will be discussed with the FDOT staff (and potentially other stakeholders) before the FAU research team engages in any analysis.

1.3. Research Objectives

Complete Street is a transportation policy and design approach that requires streets to be planned, designed, operated, and maintained to enable safe, convenient, and comfortable travel and access for users of all ages and abilities regardless of their mode of transportation. Complete Streets allows for safe travel by those walking, cycling, driving automobiles, riding public transportation, and delivering goods. Although there have been roughly a dozen of relevant studies to address qualitative benefits of Complete Streets, there are no studies which address the quantitative assessment of these streets from both operational and planning perspectives.

This research project will fill this gap in the existing body of knowledge by addressing the following objectives:

1. Develop a multiresolution modeling methodology which will take in consideration both long-term planning aspects of Complete Streets as well as operational strategies, which may be implemented to address specific needs of its multimodal users.
2. Investigate multi-criteria costs and benefits of deploying Complete Streets in many scenarios with various ‘use-cases’ and network topologies.

These two objectives represent the major overarching purposes of this project.

1.4. Project Approach

The research approach is defined by the steps or tasks from the scope of the project. After the project kickoff teleconference, the following group of tasks was designated for development:

1) Conducting literature review

2) Defining modeling tools, networks and general scenarios

3) Building, calibrating and validating models

4) Defining and evaluating specific Complete Streets scenarios

2. Literature Review

A review of the relevant literature aims to document and describe existing practices in evaluating impact, design, costs and benefits of the Complete Streets. It also addresses methodologies for multiresolution analysis. Recent and ongoing efforts supported by FDOT are also discussed.

2.1. Approaches in Evaluating Complete Street Projects

Complete Streets are defined as streets for everyone. They are designed and operated to allow safe access for all users, including pedestrians, bicyclists, motorists and transit riders of all ages and abilities. They provide ease in crossing the street, walking to shops and bicycling to work, allow buses to run on time, and make it safe for people to walk to and from train stations. (Smart Growth America)

The Complete Streets policy by the Florida Department of Transportation (FDOT) captures three core concepts in its approach to Complete Streets:

1. Complete Streets serve the transportation needs of transportation system users of all ages and abilities, including pedestrians, bicyclists, transit riders, motorists, and freight handlers.
2. Complete Streets are context sensitive, and the approach provides transportation system design that considers local land development patterns.
3. A transportation system based on Complete Streets principles can help to promote safety, quality of life, and economic development.

(FDOT Complete Streets Handbook, 2017)

Litman summarizes various Complete Streets impacts (benefits and costs) in an excellent way (Table 1). His study provides a comprehensive discussion of Complete Streets impacts, both positive and negative (i.e., benefits and costs). He notes that, as with any project or activity, implementation affects some people positively and others negatively. For example, auto drivers can benefit from some Complete Streets elements, but can also be made worse off (Litman, 2014) as described in Table 1.

Table 1: Complete Streets Benefits and Costs (Litman, 2014)

	Improved Transport Options	**Increased Use of Alternative Modes**	**Reduced Automobile Travel**	**Smart Growth Development**
Potential Benefits	□ Improved user convenience and comfort □ Improved accessibility, particularly for	□ User enjoyment □ Improved public fitness and health □ Increased community cohesion (positive	□ Reduced congestion □ Road and parking savings □ Consumer savings	□ Improved land use accessibility □ Transport cost savings □ Infrastructure savings

	non-drivers, which supports equity objectives ☐ Option value (the value people place on having an option that they do not currently use) ☐ Increased local property values	interactions among neighbors due to more walking on local streets), which tends to increase security	☐ Reduced traffic crashes ☐ Reduced chauffeuring burdens ☐ Energy conservation ☐ Reduced air and noise pollution	☐ Open space preservation ☐ Improved aesthetics ☐ Urban redevelopment ☐ Support for local businesses
Potential Costs	☐ Planning and implementation ☐ Lower traffic speeds	☐ Additional user costs (shoes, bikes, fares, etc.)	☐ Reduced travel speeds from mode shifts ☐ Reduced parking convenience	☐ Increases in some development costs ☐ Transition costs

To understand the value of investment on Complete Streets, it is necessary to evaluate conditions and behaviors of those involved before a Complete Streets implementation and make comparisons post implementation. Evaluation of a Complete Streets site is a critical component in demonstrating to policy-makers and constituents the benefits that Complete Streets provide, when trying to garner future support for Complete Streets policies and projects (Broward Complete Street Evaluation Toolkit, 2015). Different approaches in evaluating and analyzing impact, costs and benefits of complete streets are investigated by a number of studies so far. In this section, several of them are discussed.

2.1.1. Efforts supported by the Florida Department of Transportation (FDOT)

The Florida Department of Transportation (FDOT) put much effort into the evaluation of Complete Street Implementation such as the Complete Streets implementation plan, Complete Streets Handbook, Design Manual, etc. This part of the Literature Review focuses on those endeavors taken on by FDOT.

The Complete Streets Handbook by Florida Department of Transportation (FDOT) provides a menu of potential project evaluation measures based on Complete Streets best practices. This list was prepared from industry best practices, including the latest guidance and research from FHWA, such as the FHWA Guidebook for Developing Pedestrian and Bicycle Performance Measures. The list is shown in

Table 2.

Table 2: Evaluation Measurements by Mode (FDOT Complete Streets Handbook, 2017)

Vehicular	**Freight**	**Transit**	**Bicycle**	**Pedestrian**
• Vehicular LOS (refer to the ***Q/LOS Handbook***) • Volume-to-capacity ratio • Estimated potential crash reduction utilizing crash modification factors (CMFs) • Travel-time reliability • Peak and off-peak travel time between key origins and destinations • Project cost and cost effectiveness	• Travel-time reliability • Ability to serve freight origins and destinations • Peak and off-peak travel time • Project cost and cost effectiveness	• Transit LOS (refer to the ***Q/LOS Handbook***) • Number of ADA-compliant transit stops • Travel time • Travel time reliability • Percent of population within the study area that are within a 1/2 mile network distance from a transit stop • Project cost and cost effectiveness • Weekday span of service	• Bicycle LOS (refer to the ***Q/LOS Handbook***) • Bicycle level of stress analysis • Percent of roadway served by an exclusive bicycle facility • Estimated potential crash reduction utilizing CMFs • Percent of roadway with bicycle facilities meeting current standards for roadway context • Bicycle delay at intersections • Travel time • Project cost and cost effectiveness	• Pedestrian LOS (refer to the ***Q/LOS Handbook***) • Pedestrian level of stress analysis • Percent of sidewalk coverage/ linear feet of sidewalk • Average or range of distances between marked pedestrian crossings • Percent of ADA-compliant pedestrian crossings • Average or range of pedestrian delay at intersections • Presence of pedestrian refuge islands • Sidewalk continuity along the roadway and throughout the surrounding network • Presence of shade • Adequate pedestrian-level street lighting • Estimated potential reduction in crashes utilizing CMFs

				• Travel time • Project cost and cost effectiveness

In addition to the evaluation measures listed in Table 2, the following measures could be applied over the length of a roadway or at an area-wide level.

- Person throughput (i.e. the total capacity for a roadway based on vehicular, transit, bicycle, and pedestrian throughput)
- Network completeness (i.e. the continuity of sidewalk and bicycle facilities)
- Street connectivity
- Person-miles traveled
- Access to jobs, housing, retail, civic facilities, and recreational facilities
- Mode split

According to the guidebook evaluation measures should justify to project's purpose, needs, and objectives. They are represented in the following table, Table 3.

Table 3: EVAL Linkage to Project Purpose (FDOT Complete Streets Handbook, 2017)

Purpose	**Needs**	**Objectives**	**Evaluation Measures**
Serve anticipated future travel demand	An additional 10,000 vehicular trips are projected along the roadway in 20 years	Increase capacity for regional trips	Peak-hour travel times from point A to point B
Provide safe travel options along roadway	Number and percent of rear-end crashes in the last five years is higher than statewide averages of similar facilities	Decrease rear-end crashes	Potential reduction in rear-end crashes
	Number of fatal and serious injury crashes in the last five years is higher than statewide averages of similar facilities	Decrease the severity of automobile crashes	Potential for reducing the severity of crashes
	Number of fatal and serious injury pedestrian crashes in the last five years is higher than statewide averages of	Decrease number and severity of pedestrian crashes	Linear feet of roadway with adequate levels of pedestrian lighting

	similar facilities		
Provide multimodal mobility options that support local economic development goals	Ten percent of households in the study area do not have access to an automobile	Increase mobility through walking and bicycling	Percentage of roadway with sidewalks and bicycle facilities meeting current standards for context classification
		Increase ease of transit use	Number of ADA-compliant transit stops
			Percent of population reached within 0.25 miles of improved transit stops
	A new activity center along a major state roadway will introduce an additional 3,000 new daily vehicular trips	Maintain vehicular mobility	Overall street connectivity
			Intersection LOS
			Travel-time reliability
Support freight access to businesses	Retail and restaurants along the corridor require daily deliveries	Allow efficient local area delivery	Presence of loading and unloading zones near businesses

During the M2D2: Multimodal Development and Deliver workshop series, members of the Complete Streets Implementation Team were concerned about how the department measures a successful transportation system compared to how residents, businesses, and transportation system users measure a successful system. They incorporated criteria into decision-making that evaluate the qualities people want from their transportation system – convenience, safety, comfort, access, reasonable travel times, low cost, and reliability – while also reflecting the broader role of the transportation network in contributing to regional competitiveness and quality of life. (Complete Streets Implementation Plan – 2015)

According the plan a Complete Streets framework for measuring performance involves:

- Moving beyond measures of capacity and mobility toward measures of access based on context by assessing whether residents have safe, reliable, and affordable ways to reach important destinations such as employers, healthcare, schools, and other daily needs;
- Evaluating the quality of the travel experience for all modes of transportation as well as safety for all modes of transportation;
- Assessing the completeness of the transportation network for all modes of transportation, including transfers between modes; and

- Evaluating whether transportation investments are contributing to broader state and community goals articulated in planning documents such as those related to future growth and development, environmental protection, and health.

A key step in the evaluation process is to identify performance measures that can help FDOT assess whether transportation investments are meeting the needs of all residents and achieving other Complete Streets goals at the project scale, corridor scale, and network scale. They consider a variety of measures to incorporate into FDOT's practices, which are included in

Table 4. Some of these measures gauge outputs over which FDOT has direct control (such as the continuity of sidewalks along a corridor), while others measure outcomes – the ways in which projects contribute to changes in the broader environment (such as changes in walking rates along a corridor, or changes in chronic disease). Both types of measures can play an important role in evaluating success.

Table 4: Complete Street Measures (Complete Streets Implementation Plan, 2015)

Complete Streets Goal	**Performance Measures to Consider**
Safety for All Transportation System Users	• Crashes, fatalities, and serious injuries by mode and type (counts and rates per capita or per vehicle mile traveled) • Traveler surveys with safety ratings for different modes • Presence of adequate lighting • Number of violent and non-violent crimes • Crime prevention through environmental design (CPTED)
Access to Destinations	• Measures of travel-time reliability and person delay on foot, on bicycles, on transit, and in vehicles • Combined household expenditures on housing and transportation as a percentage of household income • Emergency response times • Transit access, measured by percent of persons living within a set distance from transit stops • Walk score, bike score, and transit score • Sidewalk continuity • Bicycle facility continuity • Presence of pedestrian facilities in proximity to transit stops • Percentage of bus stops that are ADA-compliant • Percentage of children walking and bicycling to school • Number of residents using carpool and vanpool services

	- Number of residents with telecommuting options
Economic Competitiveness	Measures of community economic vitality: - Alignment of transportation projects with local and regional land use and economic development plans and visions - Level of private investment in adjacent properties - Changes in vacancy rates for adjacent properties - Changes in retail vibrancy (retail and restaurant sales, numbers of customers, etc.) Measures of environmental degradation or preservation (outcomes): - Air quality and emissions - Stormwater runoff - Land and habitat preservation
Environmental Sustainability	Measures of transportation facility sustainability (outputs): - Impervious surface area - Presence of vegetation - Energy efficiency of transportation facilities Measures of environmental degradation or preservation (outcomes): - Air quality and emissions - Stormwater runoff - Land and habitat preservation
Public Health	- Rates of active transportation (ex. walking and biking trips as a portion of total trips in a community) - Rates of chronic disease - Exposure to contaminates - Travel time and reliability from residential areas to health facilities
Social Equity	- Access to economic opportunities and other daily needs by gender, age, income, race, ethnicity, and disability status - Combined household expenditures on housing and transportation as a percentage of household income by gender, age, income, race, ethnicity, and disability status - Relative impact of other measures by gender, age, income, race, ethnicity, and disability status
Quality of Life	Measures of travel experience quality: - Quality of automobile trips (pavement conditions, traveler survey results, etc.) - Quality of the transit experience (transit LOS,

	frequency of service, quality of accommodations for passengers at stops, accessibility of information for passengers, etc.) • Quality of the bicycle environment (bicycle LOS, width of facilities, pavement condition of bicycle facilities, presence of bicycle wayfinding, etc.) • Quality of the pedestrian environment (pedestrian LOS, sidewalk widths, sidewalk continuity, crossing distances and times, wait times at intersections, widths of medians, etc.) Measures of community vibrancy: • Alignment with local and • regional visions and plans • Support for local "placemaking" efforts • Presence of shade, scenic views, seating, etc.

According to Complete Streets Design Guidelines – Miami Dade County, county should evaluate the designation of multimodal transportation corridors as "Activity Corridors" on the Land Use Plan Map, Land Use Element and Transportation Element. The evaluation should address the following objectives:

- Allowed uses
- Development density and intensity
- Urban design guidelines
- Multimodal components

The complete street policy implementation should be evaluated using the following performance measures:

- Total miles of on-street bikeways defined by streets with clearly marked or signed bicycle accommodation
- Total miles of streets with pedestrian accommodation
- Number of missing or non-compliant curb ramps along City streets
- Percentage of tree canopy along City streets
- Percentage of new street projects that are multi-modal
- Number of alternative modes of transportation available
- Total number of people (instead of cars) moved on street rights-of-way
- Number and severity of pedestrian-vehicle and bicycle-vehicle crashes
- Number of pedestrian-vehicle and bicycle-vehicle fatalities
- Number of residents diagnosed as overweight or obese (data collected at the County level)
- Number of residents engaging in physical activity (moderate/vigorous) three times per week (data collected at the County level)

(Miami Dade County Complete Streets Design Guidelines, 2016)

The Broward Complete Streets Guidelines includes evaluations of how well the project performed by asking the following questions:

- Did the project meet the commonly-held community vision?
- Important projects that benefit all members of the community are the first to be built. Did those built reflect the community's priorities?
- Did the project provide long-term benefits to all people?
- Did the process allow for adequate time to respond to plans?
- Were there any legal actions or complaints about the public process that could have been reduced or eliminated?
- How can the public process improve?

According to these guidelines, good land use planning and urban and architectural design are best measured by how complete street fulfill the community's vision for the specific place. Also, how the daily lives of their residents and users were enhanced by the Complete Street implementation. Additionally, other qualitative and quantitative metrics were considered that could be used to evaluate the effectiveness include the following:

- Jobs within a 15-minute commute by public transportation, bicycle, or walking
- Convenient shopping within comfortable walking or biking distance
- A school or park that a child can walk to from home
- Useful transit within a 10-minute walk from home and/or work
- Clear zoning standards or design guidelines that help assure planning and design will be implemented as envisioned by the community
- Increased land values coming from the effective melding of transit, land use, and design
- The creation of great streets or places that people want to spend time in or live near
- Rates of diseases and health conditions associated with isolation, sedentary lifestyle, and air quality

(Broward Complete Streets Guidelines, 2012)

Broward Complete Streets Evaluation is aimed to measure the benefits and impacts of a Complete Streets project through five best practices. The first approach was to collaborate with others by establish working relationships with partner agencies and organizations to collection of data for evaluation. One of the evaluation techniques was to look for percent changes to show the changes from baseline to evaluation pre- and post- Complete Streets implementation. Establishing baseline data was another approach, so that it could serve as a reference point from which to compare evaluation metrics to better illustrate success. Evaluations regarding the reflection of goals and objectives of the Broward County Long Range Transportation Plan was one of the practices. Being clear about measuring outputs versus outcomes is another important evaluation approach, as having a clear picture of the outputs (changes made during implementation) and outcomes (changes resulting from implementation) can help understand the benefits of a successful Complete Streets project or program is important. The outputs and outcomes measured in the Complete Streets Evaluation Toolkit are presented in

Table 5 (Broward Complete Street Evaluation Toolkit, 2015).

Table 5: Outputs and Outcomes Measured in Complete Streets Evaluation Toolkit

Outputs	**Outcomes**
• More multimodal amenities • More amenities for persons with disabilities • More countermeasures implemented, resulting in less crashes • More trees planted • More green infrastructure implemented	• Increased transit ridership • Increased user satisfaction • Decrease in crash-related injuries and deaths • Increased number of pedestrians and bicyclists • Increased property values • Decrease in vacant parcels • Increase in sales volume • Reductions in annual fuel usage • Savings in annual fuel costs • Reduction in carbon dioxide emissions • Savings in daily and annual healthcare benefits

2.1.2. Approaches followed by different studies

Several studies have been performed to investigate the impact of Complete Streets. Studies evaluated the impact of Complete Streets based on safety, mobility, access, economic vitality, health impact, etc., in general. Among the evaluation factors whether some of the study were focused on overall benefit, as some of them were mainly focused on economic vitality.

A guide published by Smart Growth America and AARP provided a comprehensive set of outcomes and measures to evaluate Complete Streets projects, this work provided seven performance goals. Each of them with a set of measures can be used to evaluate how well a project meets a particular goal. The seven goals include: Access, Economy, Environment, Place, Safety, Equity and Public health. (AARP, Smart Growth America, and NCSC, 2015)

The Center for Inclusive Design and Environmental Access and GOBike Buffalo developed outcomes which are used to measure the impact of Complete Streets projects on citizens, businesses, and the environment to assist in the evaluation of Complete Streets initiatives and to assist communities in creating an evaluation plan for their individual Complete Streets policies or programs. They focused on the outcomes represented in Table 6. (Ranahan et al., 2014)

Table 6: Common Approaches to Measuring Complete Street Outcomes

Outcome Category	**Related Indicators (units)**	**Measurement Approach**
Bicycle/pedestrian activity	Mode share (# of bike/ped trips per total # of trips) Usage (# of bicyclists/pedestrians per unit time)	Inductance loops Infrared sensors: active/passive Magnetometer Manual observers Pneumatic tubes

		Pressure sensor/pressure mat Seismic sensor State/municipal DOT Video imaging: automated or manual
Citizen feedback	Perceived safety, satisfaction, comfort, quality of life	Context-sensitive survey that can be administered via phone, mail, or in-person. Neighborhood Environment Walkability Scale (NEWS), 2003, U.S.
Economic impact	Commercial property values (\$/ft^2) Foreclosure data (foreclosure risk rating) Residential property values (\$/ft^2) Retail sales (\$/ft^2; \$/yr)	County property tax database **www.foreclosure-response.org** Sales tax receipts Surveys of business owners
Environmental impact	Air Quality Index (# of days with AQI>100) Asthma (prevalence per 1000, ER visits for asthma-related cases) Transportation emissions VMT per capita (miles) VMT per household (miles)	EPA AirNow Air Quality Index report Local air, soil, and water quality agencies State/local departments of health
Health impact	Asthma (incidence, prevalence, acute episodes) Diabetes-type 2 (incidence, prevalence) Chronic disease (incidence, prevalence) Obesity (incidence, prevalence) Physical activity (duration, frequency)	Electromechanical measures of physical activity (accelerometers, GPS) Hospital records Observation of physical activity (corridor and pedestrian counts) Self-report measures of physical activity (surveys, interviews) State/local departments of health
Multimodal LOS	MMLOS	Complete Streets LOS Sustainable Transportation Analysis and Rating System (STARS)
Safety	Accident/collision (auto crashes/1000 drivers; bicycle crashes/1000 cyclists; pedestrian	Citizen surveys on perceived safety Hospital records Police department/DOT

	collisions/1000 pedestrians) Emergency room visits Injury/fatality (injuries/1000; fatalities/1000) Self-reports of perceived safety	accident records

Guidance from the National Complete Streets Coalition encourages to evaluate Complete Street based several performance measures from New Hope Minnesota (COMPLETE STREETS policy analysis 2011). The performance measures includes the following:

- User data (bicycle, pedestrian, transit, and traffic)
- Crash/safety data
- Use of new projects by mode
- Compliments and complaints received
- Linear feet of pedestrian accommodations built
- Number of ADA accommodations built
- Miles of bike lanes or trails built/striped
- Number of transit accessibility accommodations built
- Number of street trees planted
- Number of exemptions from the policy approved

The Complete Streets Implementation Resource Guide for Minnesota Local Agencies stated typical evaluation approaches. The guideline mentioned about informal observation and feedback, an approach that relies on designers to informally observe how the completed project is functioning as well as feedback from project users. Another approach was before-and-after studies, which measure multimodal conditions before and after implementation of a project. Typical measures includes mode volumes and shifts, vehicle speeds, and crashes. The other evaluation approach (goal attainment measurements) can measure to what extent an agency is meeting its stated complete streets goals. This approach may take the form of measuring miles of sidewalks or bikeways, calculating the completion percentage of a planned network, or user surveys regarding satisfaction and perceived safety (Michael et al., 2013).

In 2001, the City of Orlando in the project aiming to improve safety on a dangerous 4-lane road, a redesign of Edgewater Drive in Orlando, FL, (Orlando, FL: Measuring multimodal access) created nine “Measures of Effectiveness,” to help evaluate if the project met its objectives. (AARP, Smart Growth America, and NCSC, 2015). The measures of effectiveness include:

- Safety: Safety was measured by crash and injury rate and frequency of crashes. A three-year average of pre-project crash and injury data and four months of post-project crash and injury data were utilized. The crash and injury rates are calculated based on the number of million vehicle miles of travel on the corridor. The frequency of crashes and injuries are reported as the number of crashes or injuries occurring per day.
- Speeding: Speeding was measured as part of traffic counts at three locations (northern, center, and southern segments) along the corridor during “typical” autumn days when a certain percentage of drivers exceed speeds of 36 miles per hour.

- Daily automobile traffic volumes: The volume was counted by mechanical counters at 11 midblock locations on Edgewater Drive. The counts for each location were then averaged to determine daily traffic volumes from the redesigned segment. These mechanical traffic counts were validated by manual turning movement counts at signalized intersections.
- Parking utilization: To calculate the utilization rate, on-street parking and side and rear-parking use during morning, mid-day, and evening periods were counted, and these counts were then totaled and compared to the total number of available parking spaces on the corridor.
- Bicycle counts: Bicycle and pedestrian counts were manually conducted to measure the total number of people on bicycle traveling north/southbound or east/westbound at 18 locations for seven hours on a typical autumn day.
- Pedestrian counts: This was measured by the total pedestrians traveling north, south, east, and west at 18 locations for seven hours on a typical autumn day.
- Corridor travel times for drivers: Travel times and delays were conducted during peak commuting windows (7–9 AM and 4–6 PM) by linking a device (a JAMAR TDC-8 Traffic Data Board) to the axle of a vehicle traveling at least 10 times along the area with the greatest density of traffic signals. The change in time is calculated separately for the AM and PM commuting windows for both northbound and southbound vehicles. The time is reported in minutes.
- Transit use and operations: This was measured by bus operator surveys to estimate the average delay (in seconds) to board LYNX-run buses serving the corridor.
- Property values: Property values were measured by the growth rate in property values for residential and commercial properties within the designated boundary.
- Resident and merchant satisfaction: The satisfaction was measured through statements collected through feedback forms for residents and merchants.

A study by Southwest Region University Transportation Center, University of New Orleans Transportation Institute and Texas State University, sought to evaluate the extent to which complete streets policies are being adopted and implemented at the MPO level through a national survey of the 385 metropolitan planning organizations (MPOs) around the country. (Merritt et al., 2015)

They evaluated various documents relating to the Complete Streets policy and/or the key elements of implementation including ordinances, resolutions, internal policies or executive orders, official planning documents, and design manuals or guides. Survey responses were also reviewed, and knowledgeable stakeholders were contacted via phone or email to discuss these findings in greater detail and provide additional contextual information.

The survey questions targeted basic descriptive characteristics of policy implementation and extent, along with potential reasons for full or limited implementation of key Complete Streets policy metrics. Survey results were compiled and analyzed using SPSS (a software package used for statistical analysis). The survey resulted a wealth of data for analysis, descriptive statistical findings, and selected highlighted relationships. The New Heaven Complete Streets Design Manual, 2010, focused on the measurement and evaluation of both objective and subjective data. (John et al., 2010).

The volume of users, the number and rate of traffic accidents, travel speeds, and the demographics of roadway users were considered as objective data. Various methods and sources including manual counts, automated counts, user surveys, and accident reports can be utilized to obtain objective data. It should be ensured that traffic counts include automobile counts, pedestrians, cyclists, and transit users. Also, it is important to make use of objective performance measures for each major mode of transportation, including automobile, bicycle, pedestrian, transit, and multimodal levels of service (LOS).

As objective measures cannot always capture that users' experiences of the transportation system, user surveys should be administered at regular intervals and integrated with the city's transportation planning and engineering projects. Surveys can be conducted in different ways including intercept surveys, take-home surveys, and web-based surveys. This subjective data focuses on the attitudes and beliefs of those individuals using the transportation system includes:

- Purpose of trip
- Choice of travel mode
- Choice of route
- Level of satisfaction with existing service/facilities
- Perceived gaps or deficiencies
- Desired improvements
- Barriers to transportation
- Reported modal split

The New York City Department of Transportation's guidebook, "Measuring the Street: New Metrics for 21st Century Streets," pointed out various performance measures which can be used for Complete Streets evaluations (NYCDOT 2012). The measures are summarized in Table 7.

Table 7: Complete Street Evaluation (NYCDOT, 2012)

Goals	Strategies	Metrics
• Safety • Serve all users • Create great public spaces	• Design safer streets • Provide safe and attractive options for all street users • Build great public spaces for economic value and neighborhood vitality • Improve bus service • Reduce delay and speed to allow for faster and safer travel • More efficient parking and loading to improve access to businesses and neighborhoods	• Pedestrians, cyclists and motorist crash rates • Vehicles, bus passengers, bicycle riders, and other street user volumes • Optimal traffic speeds. • Economic vitality, including retail activity growth • User satisfaction • Environmental and public health impacts

One of the study documented performance measures to evaluate multimodal conditions before and after the implementation of a project by analyzing some Complete Street projects. On their road diet projects, the Seattle Department of Transportation (SDOT) conducted before and after evaluations of mode shift, volumes, and crashes. The Charlotte Department of Transportation (CDOT) conducted performed before and after evaluations of volumes, speeds, and crashes. New York City has developed an extensive process for matching Sustainable Streets goals and measures. Each of the Sustainable Streets goals was accompanied by many benchmarks for measuring success—including improved safety and mobility, good maintenance of infrastructure, well-developed placemaking policies, and the incorporation of sustainability objectives into projects, among others—that are to be measured annually. (Barbara et al.)

A study by NRPC, funded by the HNH foundation, considered guidance provided by "Model Local Ordinance on Complete Streets" (MLOCS) for data collection and public input to evaluate the effectiveness of the ordinance and assesses the local populations' needs (NRPC and HNH foundation, 2014). In this study, five short subsections were considered which identified the responsible entities and process to quantify and monitor how Complete Streets:

- Serve all users,
- Enable users to travel in safety and comfort,
- Ensure public participation in policy decision making, and
- Evaluate and mitigate impacts of proposed projects.

According to the study, Complete Streets elements are more likely to be evaluated and implemented on future projects by establishing an agency or agencies to be responsible for data collection, measurements, and enforcement.

To measure how streets are currently serving each user dataset, one must include latent demand, existing levels of service for different modes of transportation and users, collision statistics, and bicycle and pedestrian injuries and fatalities. Also, the data sets should inform the development of specific performance standards that can help a community establish benchmarks and timeframes. An example of performance standards includes indicators such as transportation mode shift, miles of new bicycle lanes or paths and sidewalks, percentage of streets with tree canopy, low design speeds, and public participation rates.

Additionally, they considered other research such as a literature review, interviewing, empirical research and conducting community surveys, and creating focus groups to explore more.

The National Complete Streets Coalition by Smart Growth America found in one study that the Complete Streets projects tended to improve safety for everyone, increased biking and walking, and showed a mix of increases and decreases in automobile traffic based on data collected directly by local transportation and economic development agencies. While discussing how the Complete Streets approach can yield transportation and economic benefits, they mentioned using existing data and information to evaluate projects. According to Smart Growth data, mode counts, automobile travel time or delay, and collisions can be used to set baselines at the beginning of projects and evaluate the conditions after the Complete Streets completion of work. Also, the selected measure of performance should account for all users and capture the multiple benefits of Complete Streets projects. They suggested using a broad range of metrics to assess how the roadway changes are affecting all people traveling on it. They consider auto-oriented measures like level-of-service as most valuable one. Also, they suggested to consider additional factors like overall travel speed and time for automobiles, the number of people walking, bicycling and riding transit, and overall comfort and ease of travel. Metrics that account for changes beyond the right-of-way, connecting Complete Streets work to broader community goals like health, equity, and economic development were suggested to take into accounts as well. (Smart Growth America and NCSC, 2015)

A demonstration project of Smart Growth America by City of Orlando, FL, in collaboration with Orange County staff and local elected official on a commercial arterial (with a history of crashes involving people walking and biking that spans both the city's and county's jurisdictions), transformed a five-lane speedway into a three-lane Complete Street with protected cycle tracks and a mid-block crossing. They used a combination of online tools and in-person engagement to find out the impact of this transformation among people. In the first two weeks of the demonstration, the Orlando team received 142 emails, of which 39 percent were satisfied with the change while 61 percent were opposing it (people who expect to travel at a high speed) (Smart Growth America, 2018)

One study by the University at Buffalo created and utilized six survey tools to capture various impacts (streetscape quality; street usability and satisfaction for drivers, bicyclists, and pedestrians; traffic volume for vehicles, pedestrians, and bicyclists; accidents and injuries; economic vitality; and health impact). Although the survey for three stakeholder groups (resident, merchant, and streetscape user) were designed to contain fundamentally similar content and response options, it includes some additional question based on their individuality. (James et al., 2016)

A study by Zhu et al., evaluated the impact of Complete Street on travel behavior and street users' exposure to traffic-related air pollutants. Two empirical study designs: a natural experimental design (using before after comparisons) and a quasi-experimental design (using a spatial difference-indifference (DID) approach) were utilized throughout the process. The first study analyzed and conducted a neighborhood survey for the volume of motorized vehicles, cyclists, and pedestrians as well as exposures to fine (PM2.5) and ultrafine particles (UFP) among drivers, cyclists, and pedestrians before and after Complete Street implementation. Another study selected six pairs of diverse roads based on types and land use contexts comprised of one complete street and one parallel incomplete street. PM2.5 and UFP concentrations as well as traffic, pedestrian, and cyclist volume on each pair of streets were measured to investigate the difference between complete and incomplete streets. Also road-side intercept surveys were conducted at these six sites to assess street users' perceptions of the streets. (Zhu et al., 2016)

Another study was conducted to evaluate Complete Street implementations by exploring the development of typologies of intersections and by examining how these typologies relate to traffic safety. They performed the study on the five-mile segment (or approximately 8 km) of urban arterial on Santa Monica Boulevard running from the western border of West Hollywood to its intersection with Highway 101 in the City of Los Angeles. Santa Monica Boulevard is a state route that acts as an urban arterial in Los Angeles. Multiple indicators of environmental features were collected in 2012 and were included in a latent analysis. Latent classes were analyzed as a predictor of the number of pedestrian injuries/fatalities and injuries/fatalities for all modes in separate models using negative binomial regression and controlling for exposures. Six years (2009-2014) of injury and fatality data were used. Additionally. the role of alcohol has been examined. The study identified two distinct classes of intersections: One class was more complete with respect to pedestrian features but was also associated with indicators of increased potential conflict and was predictive of higher overall injuries/fatalities for all modes. Another class also had higher pedestrian volumes but was not predictive of higher pedestrian injuries/fatalities in the final models. The alcohol involvement in crash injuries at these locations positively associated with injuries and fatalities for all modes and with severe/fatal injuries for pedestrians in the final models although did not differ by intersection class. (MacLeod et al., 2018)

In the City of Pasadena, California, a newer multimodal level of service measures and metrics were used in comparison to the existing (and more traditional) measures. This multimodal level of service measures how well it helps the city meet its transportation and mobility objectives. Four categories of measures were considered: accessibility, sustainability, livability, and user experience. Through the process of selecting the new metrics, a strategy was adopted that maintain some present measures to provide continuity and adds metrics that respond to community expectations (Dock et al., 2012).

The California Department of Transportation (“Caltrans”) worked with researchers at the University of California, Berkeley, to propose new measures to gauge progress in meeting Complete Streets objectives. Their focus was on pedestrian and bicycle safety and mobility along urban arterials (Sanders et al., 2011).

A project by the Local Research Board with the Minnesota Department of Transportation (MnDOT) aimed to evaluate the safety and operations impacts of complete street. Eleven sites had been reconstructed with features of complete street. To evaluate safety, two methods were considered at each site. One method was a simple before-and-after analysis, which calculates the percentage difference between the number of crashes before and after implementation of the Complete Streets project. Another one is an empirical Bayes analysis, which incorporates data from similar sites in this calculation. In general, the empirical Bayes analysis is preferred for a realistic safety analysis, as it overcomes the regression-to-the-mean effect in which the small number of crashes at any one site can make statistically insignificant changes appear to be significant trends (MnDOT and LRRB, 2014).

A study by the New York City Department of Transportation was interested in finding new and better ways to measure the effects of sustainable Complete Street projects by evaluating economic benefits of seven Complete Street case studies. They considered benefits including safety, access and mobility, livability and quality of life, public health, environmental quality, and economic vitality. The NYC DOT evaluated many potential measures of local economic vitality such as the number of businesses, property values, employment, retail sales, and visitor spending. They found retail sales – specifically, reported sales for street-level retail and restaurant/food service businesses – to provide the most direct and reliable indicator of the health of local businesses. As a result, they selected retail sales tax filings as the measure they would use to evaluate the case studies. The corridors before and after the implementation of Complete Streets elements were studied and compared to similar yet non-Complete Streets corridors nearby. As retail sales tax filings are difficult to acquire, the aggregated quarterly data were used in this study provided by New York City Department of Finance (NYC DOT, 2015).

One of the projects of the Florida Department of Transportation (FDOT) by the University of South Florida evaluated the economic benefit of Complete Streets based on several case studies. The chosen case studies represented a wide variety of Complete Streets applications from a business district in Gainesville, Florida, to a beach community in Fort Myers Beach, to a larger urban city up north (Cleveland, Ohio) with a major transit investment. (Perk et al., 2015)

Based on the compiled information, a set of quantitative measures which comprise employment data and land values has been identified to estimate economic benefits. Perk et al considered employment information from the businesses adjacent to the Complete Streets corridor to assess economic vitality. Information about employment was available directly from the businesses and also available Longitudinal Employer-Household Dynamics (LEHD) data provided information on the location on jobs as well as wage ranges. Data on market values, sale prices, and property taxes paid were utilized to constructed measures such as tax yield per acre, tax receipts as a percentage of project cost, and a ratio of speeds and property values. These data were collected from county property appraiser databases.

One study by Shapard and Cole evaluated Complete Streets by comparing the costs of Complete Streets projects and “incomplete” streets projects, using Charlotte, North Carolina, as a case study. Only slight increases in costs were observed due to the various Complete Streets elements. The staff at the Charlotte Department of Transportation calculated the costs of three different, typical urban street cross-sections: a two-lane street, a three-lane street, and a four-lane, median-divided street. They assumed each project was constructed in an open field condition without impacts to adjacent properties, buildings, or existing land uses for the evaluation purpose and exclude real estate costs from their calculation as cost of real estate varies based on location and land uses associated with each parcel (Shapard et al., 2013).

Another study by Vandegrift and Zanoni investigated whether Complete Streets policy adoption impacted facility values for local residents by analyzing the link between Complete Streets policy adoption and housing prices using a difference-in-differences matching procedure (DIDMP) developed in Heckman et al. (1997) and Heckman et al. (1998). This estimator calculated the change in the outcome variable (housing prices) for each observation (i.e., municipality) between the pre-period and the post-period and made comparisons across treated and untreated groups conditioned on the variables that determine selection into treatment. The analysis uses municipality characteristics to determine selection into treatment (i.e., a Complete Streets policy) and pre-period housing price changes to estimate propensity scores. (Vandegrift and Zanoni., 2018)

Yu et al. conducted a pre-post and intervention-control comparison to explore the changes in property values before and after a Complete Streets implementation during the housing market boom (2000–2007) as well as to examine the effects of Complete Streets on the resilience of property values during the housing market downturn (2007–2011) in Orlando, FL. The year 2000 was chosen for the study design, as it is one year before the intervention and set as pre-intervention year. 2007 and 2011 were chosen as two post-intervention points to represent the peak and bottom of the housing market to better capture the effect of Complete Street designs on a dynamic housing market (Yu et al., 2017).

As the first set of intervention control, the researchers compared the residential single family (SF) housing exposed within 800 m of treatment area with those in the adjacent, non-exposed area (between 801–2000 m away from treatment area). This study also tested the change in property values for SF housing units within the exposed area (intervention group within 800 m around treatment area) and within 800 m around the control roads as the second set of intervention controls. The study considered three criteria (described in the next paragraph) to make the final selection of the control roads.

For housing values, this study used appraised values rather than sales prices, as sales data for resident housing is not made publicly available. For a pre-post comparison, time-series values were required to investigate the change of housing value from 2000 to 2011. Appraised values were evaluated and certified by county appraisal district for property taxation, and appraisers are required to assess a property's appraisal value at 100% of market value. The total assessed value includes the sum of improvement value and land value. This total value was compared with sales data to estimate the ratio to market value and make corresponding adjustments.

This study used propensity score matching (PSM) to match single-family houses one by one for two sets of intervention-control groups. For the purpose of matching intervention and control groups, covariates from building attributes (i.e., housing age, total living area, number of stories, number of bathrooms, number of bedrooms, and inclusion of a pool) were used to match intervention and control groups.

2.2. Methodologies for Multiresolution Analysis

Multiresolution analysis, or modeling, is the combination of three classes of modeling approaches – macroscopic, mesoscopic, and microscopic, which are all considered essential components in multi-resolution analysis modeling (MRM) methodology (FHWA, 2012a).

One study by Davis et al. (1998) gives various definitions for MRM: building a single model with alternative user modes involving different levels of resolution; building an integral family of two or more mutually consistent models of the same phenomenon at different level of resolution; or the combination of both. Each model serves different purposes based on the project demand.

The Federal Highway Administration (FHWA, 2012a) considered MRM an effective method for linking analysis tools with different resolutions to enhance dynamic traffic assignment (DTA). Overall analysis results were improved and consistency between model assumptions is maintained within MRM framework by feeding one model to another in an iterative process. This document classified MRM into partial MRM and full MRM as shown in Figure 1. According to the FHWA document, a full MRM utilizes three modeling levels. It relies on the interaction between demand forecasting model to mesoscopic simulation-based DTA models and mesoscopic simulation-based DTA models to microscopic models. Partial MRM relies on either the interaction between demand forecasting, model-to-mesoscopic-simulation-based DTA models, or demand forecasting model-to-microscopic models.

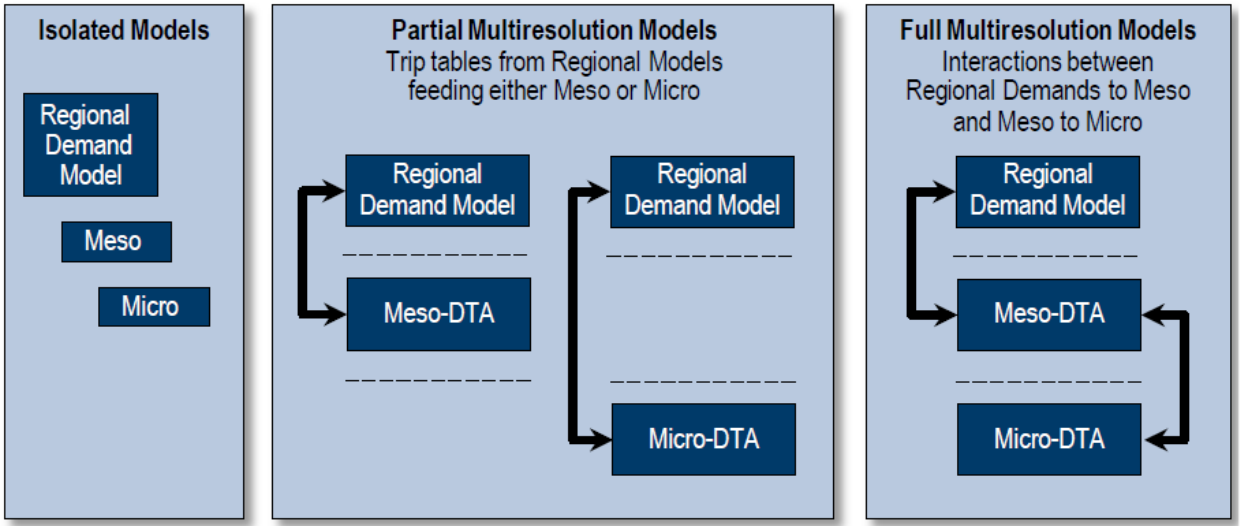


Figure 1: Multi-Resolution Modeling Frameworks (FHWA, 2012a)

Fox (2008) expressed that for the majority of transport assessments, there is strong evidence that a pure microsimulation approach is inappropriate. For most cases, seamlessly integrate macro, micro and meso modeling together allowing the best approaches to be combined effectively. A MRM of Complete Streets can be utilized where macroscopic modeling is used to develop and analyze long-term travel demand forecasting scenarios, whereas the microscopic analysis is utilized to investigate the impacts of operational strategies and retrieve many high-resolution performance measures (necessary for safety and environmental indicators).

Holyoak and Branko (2009) revealed a range of theoretical and practical issues about integration between macro-demand forecasting models and microsimulation. To utilize the concept of MRM, it is mandated one use a combinations of tools with different functionalities, resolutions, and capabilities, as overcoming these integration issue will lead to modeling solutions that will benefit the transport planner with an integrated approach to representing transport operations at different scales.

Sbayti et al. (2010) considered multi-resolution modeling (macro, meso, and micro) as the future of current modeling practice. They found that, to make MRM approach successful, it is necessary for the integration process to transfer data seamlessly between software platforms. Required data for all levels of modeling would be stored in a common data repository for extraction and processing by a given model and the results would be returned to the repository for use by the next model in the overall process. A multi-resolution modeling process was used to evaluate the peak-hour conditions. At first the travel demand (macro) model was to a DTA (meso) model which generated the time-dependent equilibrium conditions. Then, in turn, those were fed into a microscopic simulation model to accurately assess the actual dynamics of the system.

Shelton and Chiu (2009) have utilized full MRM in practices. They used a combination of the DynusT mesoscopic tool and Vissim microscopic tool. They converted a regional travel demand model into DynusT network. Then, a subarea was defined and cut from a calibrated large DynusT network. To aid the process, a tool called DVC (Dynus-T Vissim Converter) (CIITR, TTI, 2010), developed by researchers from TTI and UA, was utilized to convert DynusT inputs and outputs to VISSIM inputs. This tool read files from DynusT inputs and outputs and generate the corresponding network and demands in the format required by Vissim. Figure 2 represents the MRM framework used by Shelton and Chiu.

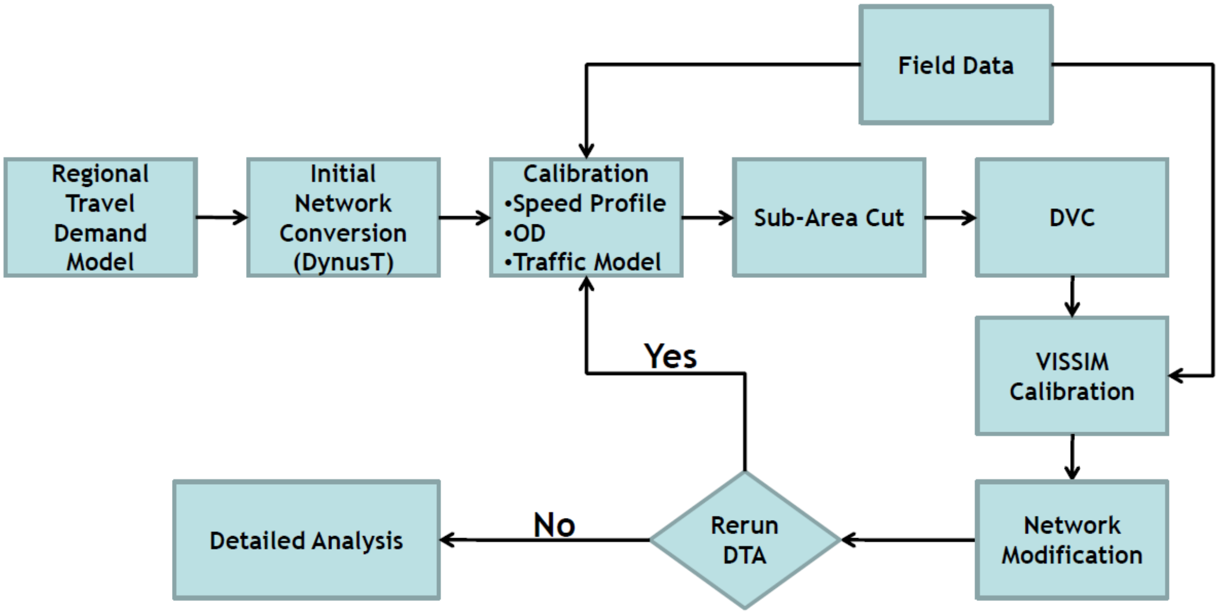
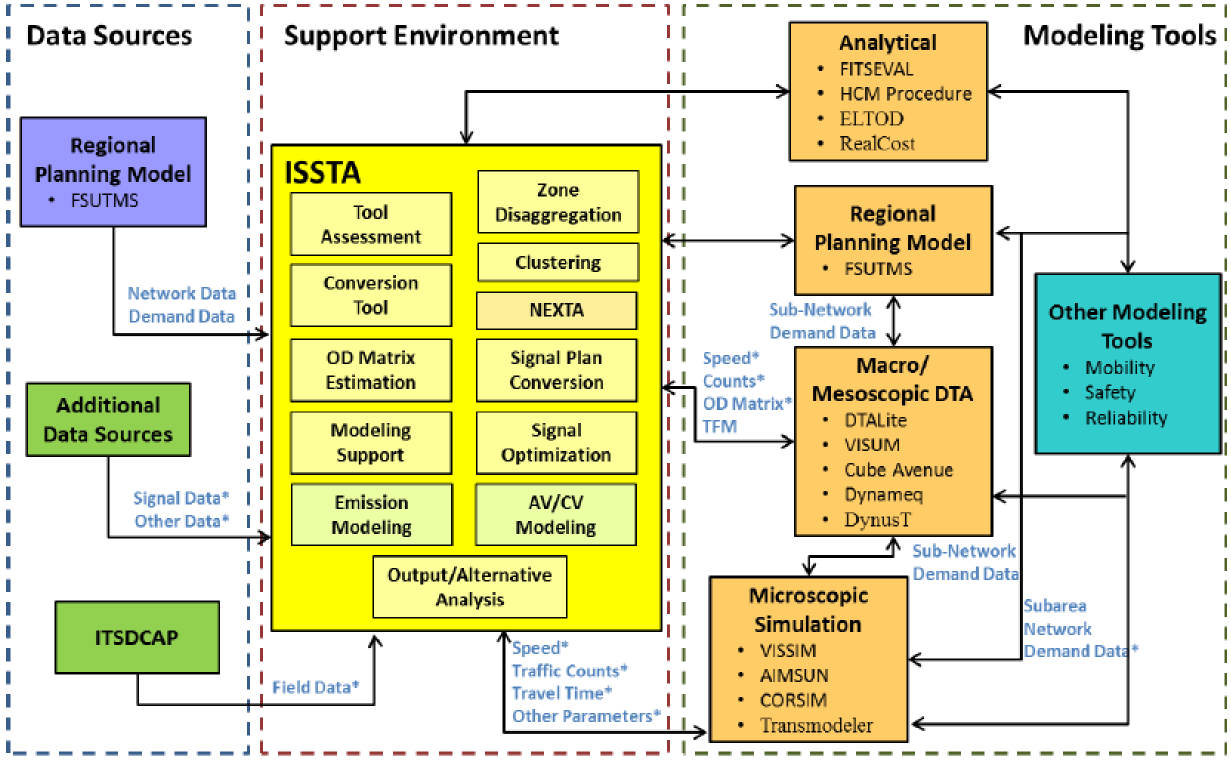


Figure 2: Multi-Resolution Modeling Frameworks (Shelton and Chiu, 2009)

Martin et al. (2011) utilized the MRM concept in the three levels of models while the modeling basis and outputs from the top levels serve as the input and basis for the next levels. In level one, the researchers used regional, four-step static models for mapping land use pattern into origin-destination trips and link/turn volumes by trip purposes; in level two, regional dynamic traffic assignment (DTA) models were developed for the screening and evaluation of various projects and scenarios. In level three, the researchers developed corridor network micro simulation models for selecting the most promising improvement plan from a reduced number of candidates in level two. In the process of implementing MRM, a travel demand forecasting model was implemented in Visum as additional network detail was added to the model in the corridor area to facilitate a data exchange with the microscopic model in future. The sub-network generator in Visum cut the sub-area of interest without loss of the reference to the original region model, which includes the time-varying boundary path flows and the path flows within the sub-network. The sub-network was then exported into the ANM format, which was then imported directly into Vissim as initial simulation network.

Duthie et al. (2012) stated that multi-resolution traffic assignment integration for each individual model will allow to be strengthened by using beneficial output from the other models. They utilized MRM concept by achieving the integration between TransCAD (macroscopic traffic assignment), Vista (mesoscopic DTA), and Vissim (microsimulation).

Hadi et al. (2016) proposed a multi-resolution modeling framework consisting of three components: data sources, supporting environment, and modeling tools. The data sources and tools allow the utilization of data from multiple sources to support modeling tasks. The supporting environment assists modelers in developing, calibrating, and processing the results of the selected modeling tools; modeling tools of different types and resolution levels allow the estimation of various performance measures. Their MRM framework is represented in Figure 3.



*: The data files are interfaced through the csv format.

Figure 3: Multi-Resolution Modeling Frameworks (Hadi et al., 2016)

Zhang et al. (2017) represented MRM by using a triangular framework (macro, meso, and micromodel were its vertexes) as a means of fusion-technology-based different resolution simulation models. Integration type, integration strategy, integration direction, and integration consistent are the cores of different resolution simulation models in optimization process. The framework is illustrated in

Figure 4. They proposed a novel multiresolution traffic simulation model through an asynchronous integration strategy (different granularity models that can run simultaneously in a certain space or time which is parallel execution strategy) based on Set Theory, which can explain the characteristics of traffic system, such as behavioral characteristics, time characteristics, spatial characteristics, performance characteristics, granularity level, and internal structure.

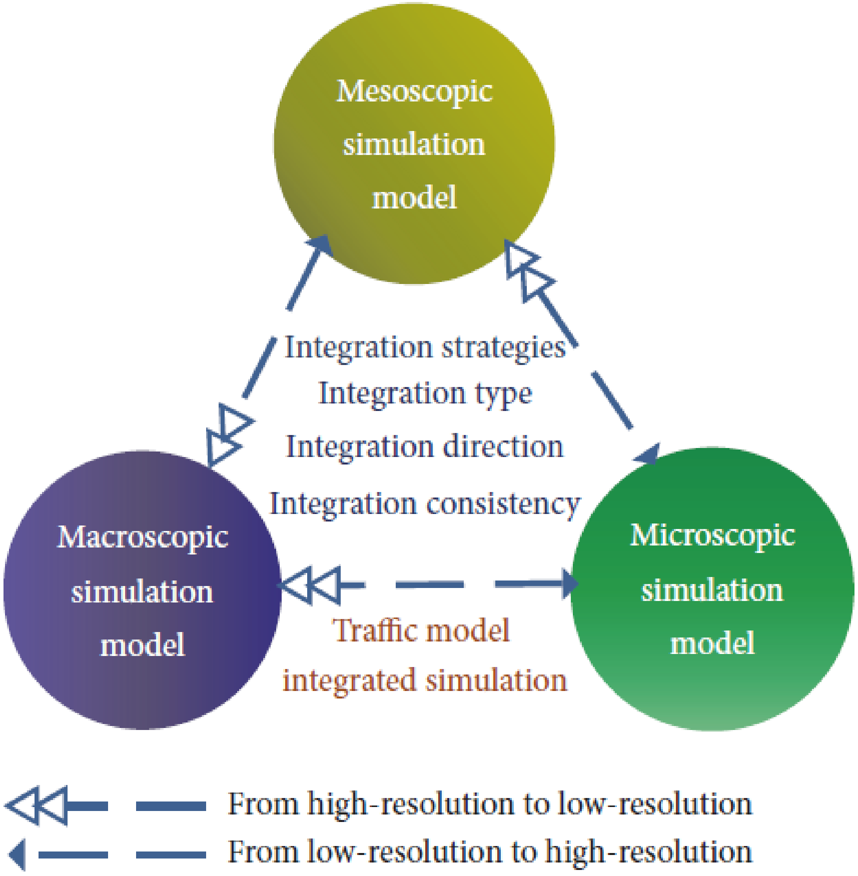


Figure 4: Triangular Framework of MRM (Zhang et al., 2017)

2.3. Lessons Learned

From the above literature it is evident that researchers utilized different approaches and performance measures to evaluate Complete Street. In general, most of the studies dealt with qualitative benefits of Complete Streets.

Some studies considered access, economy, environment, place, safety, equity and public health as performance measures to evaluate the impact of Complete Streets. Some studies also considered daily automobile traffic volumes, speeding, parking utilization, bicycle/pedestrian counts, transit use and operations, mode volumes, rate of traffic accidents, volume of users and corridor travel times for drivers. Other than these studies, there are studies which were dealt with travel behavior as well as street users' exposure to traffic-related air pollutants and relationship between topologies and safety. To evaluate the economic vitality of Complete Street, researcher considered measures like number of businesses, property values, employment, retail sales, visitor spending, housing price, and change in property value before and after implementation of Complete Street etc.

In terms of methodology most of the studies utilized before-and-after studies to evaluate the Complete Street Projects. Many studies also used various types of surveys by utilizing a combination of online tools and in-person engagement to find out the impact of this transformation among stakeholders groups as well as users. Some studies utilized documents relating to the Complete Streets policy and/or the key elements of implementation including ordinances, resolutions, internal policies or executive orders, official planning documents etc. Even informal observation and feedback from project users were also utilized for the investigation of Complete Street performance. Also some studies came up with ideas to utilize various statistical analysis such as latent analysis, empirical Bayes analysis etc.

As these findings are based on qualitative or anecdotal data. It can be very difficult to identify the operational and planning perspectives of Complete Streets elements. Thus it is leaving room for speculations on how would Complete Streets operate under a number of future travel demand scenarios and operational strategies. This project will fill a gap in the existing body of knowledge by: 1. Developing a multi-resolution modeling methodology which will take in consideration both long-term planning aspects of the Complete Streets as well as operational strategies which may be implemented to address specific needs of its multi-modal users; and 2. Investigating multi-criteria costs and benefits of deploying complete Streets in a number of scenarios with various Complete Street ‘use-cases’ and network topology.

3. Modeling Tools, Methodology, Network and General Scenarios

In this task the FAU research team has investigated modeling tools which can be used to accomplish the necessary evaluation tasks. These tools, their interfaces, and inputs and outputs were combined in a step-by-step methodology which describes flow of the data (and relevant outputs) of the modeling processes.

In order to include both long-term planning processes and operational scenarios for urban network infrastructure it is necessary to develop a multiresolution analysis of Complete Streets. In such an approach future (multimodal) transportation demand levels need to be considered on a macroscopic level whereas a realistic account of traffic operations (reflecting real-world conditions as close as possible) needs to be modeled in microscopic simulation environment. The microscopic analysis is especially necessary to investigate impacts of operational strategies and retrieve a number of high-resolution performance measures (necessary for safety and environmental indicators).

3.1. Categories of Multiresolution Traffic Analysis Tools

Macroscopic simulation models: Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. Macroscopic models have considerably fewer demanding computer requirements than microscopic models. They do not, however, have the ability to analyze transportation improvements in as much detail as the microscopic models.

Mesoscopic simulation models: Mesoscopic simulation models combine the properties of both microscopic (discussed below) and macroscopic simulation models. As in microscopic models, the mesoscopic models' unit of traffic flow is the individual vehicle. Their movement, however, follows the approach of the macroscopic models and is governed by the average speed on the travel link. Mesoscopic model travel simulation takes place on an aggregate level and does not consider dynamic speed/volume relationships. As such, mesoscopic models provide less fidelity than the microsimulation tools, but are superior to the typical planning analysis techniques.

Microscopic simulation models: Microscopic models simulate the movement of individual vehicles based on car-following and lane-changing theories. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network over small time intervals (e.g., 1 second or a fraction of a second). Typically, upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulations runs that can be completed.

3.2. Selection of the Modeling Software Tools

The appropriate analytical tool selection is a key part towards fulfilling the project objectives. There are many software packages for macroscopic, mesoscopic, and microscopic simulation.

Their main differences, relevant from the perspectives of this project, are based on the data requirements that they use for the travel demand forecasting process for macroscopic tools and the approach used by both macroscopic and microscopic tools in generating traffic assignments.

Criteria used to determine the ability of various software tools to serve the purposes of this project included:

- Size of the network - number of nodes and links that can be handled
- Support of the traditional four-step travel demand model
- Available traffic assignment routines
- Potential to export inputs/outputs of a macro-simulation software to a microsimulation software
- Number and variety of performance measures produced
- Price of the software (discounts, academic versions, technical support)
- User interface
- Peer reviews on the weaknesses and advantages of the software

Following the criteria given above, a detailed review of the applicable software was conducted (demo versions and company product brochures). Finally, VISUM & VISSIM were selected as the modeling tools based on how well they satisfied the given criteria, in relation with the other software packages.

Among all other advantages of VISUM and VISSIM, these software were mainly selected due to the fact that there is a good interface between the two. This feature gives the modelers an opportunity to use compatible traffic models for planning and operation levels of traffic analysis.

3.2.1. The Basic VISUM Characteristics

The VISUM is a macroscopic multimodal traffic assignment software. It is a module of the Planung Transport Verkehr AG (PTV AG) software package that also contains other modules for the travel demand forecasting process.

VISUM represents traffic assignment software, and it requires completion of the previous three steps of a traffic demand forecasting process (trip generation, trip distribution and modal split). The results of the three previous steps are represented in the form of OD trip table. This table represents number of trips, during certain period, between each pair of zones in the region. The VISUM ‘reads’ the table and assigns the trips on the available road network following parameters given by a modeler.

The traffic assignment depends on the capacity of each link in the network, its free flow speed and impedance (which can be set by the modeler). After these inputs are provided, VISUM uses one of its several algorithms to assign the trips on the available links in the network. The modeler can define the assignment procedure. Usually, the calibration process requires a modeler to try all available assignment procedures in order to get link volumes as close as possible to real traffic loads on the links. Once the VISUM assigns traffic to the network links it provides a modeler with many tools for calculation of the transportation system metrics.

3.2.2. The Basic VISSIM Characteristics

The VISSIM is a microscopic multimodal traffic flow simulation software package developed by PTV Planung Transport Verkehr AG in Karlsruhe, Germany. VISSIM is part of the PTV Vision Traffic Suite which also includes PTV VISUM (traffic analysis and forecasting) and PTV VISTRO (signal optimization and traffic impact).

The VISSIM allows you to simulate traffic patterns exactly. Motorized private transport, goods transport, rail and road related public transport, pedestrians and cyclists and it displays all road users and their interactions in one model. Scientifically sound motion models provide a realistic modelling of all road users.

The software offers flexibility in several respects: the concept of links and connectors allows users to model geometries with any level of complexity. Attributes for driver and vehicle characteristics enable individual parameterization. Furthermore, a large number of interfaces provide seamless integration with other systems for signal controllers, traffic management or emissions models.

The VISSIM provides traffic assignments routines which are calculated based on the iterated simulation. Thereby the modeled road network is simulated not only once but repetitively. The drivers choose thereby their paths through the network based on their experiences from the preceding simulations.

The VISSIM also provides an opportunity to execute traffic assignments through its mesoscopic simulation model. This option is especially handy for mid-sized networks with simulation accelerated by a factor of +/-50 compared to microscopic simulation while at the same time studying the effects of phenomena such as impact of traffic congestion on travel times. On the performance-evaluation side, the reduced depth of detail is reflected in the use of a simplified car-following model. Another advantage is the fact that mesoscopic simulation provides a convenient way to calibrate networks due to the limited number of parameters.

3.3. Selection of the Networks

The network definition is closely tied with development of general Complete Street scenarios. Two networks have been identified, so far, as good candidates for the Complete Street scenarios: Salt Lake City Central Business District network and Central Broward County Network.

3.3.1. Salt Lake City (SLC) Central Business District (CBD) Network

The SLC CBD network consists of heavily traveled arterial streets, multiple public transportation systems, including an intermodal transit hub (regular and express bus service, LRT, Commuter rail, future streetcar), bicycle transportation with an increased deployment of bike lanes and the shared bike program, as well as heavy pedestrian traffic. The other areas represent major corridors that lead in and out of the SLC CBD and the University of Utah, characterized by heavy traffic and where the right-of-way is shared among different users. This CBD network has a strong potential for deploying innovative multi-modal solutions that would benefit all transportation modes. Figure 5 shows the google map with the highlighted line representing some of the potential improvements along the suggested SLC CBD corridors.

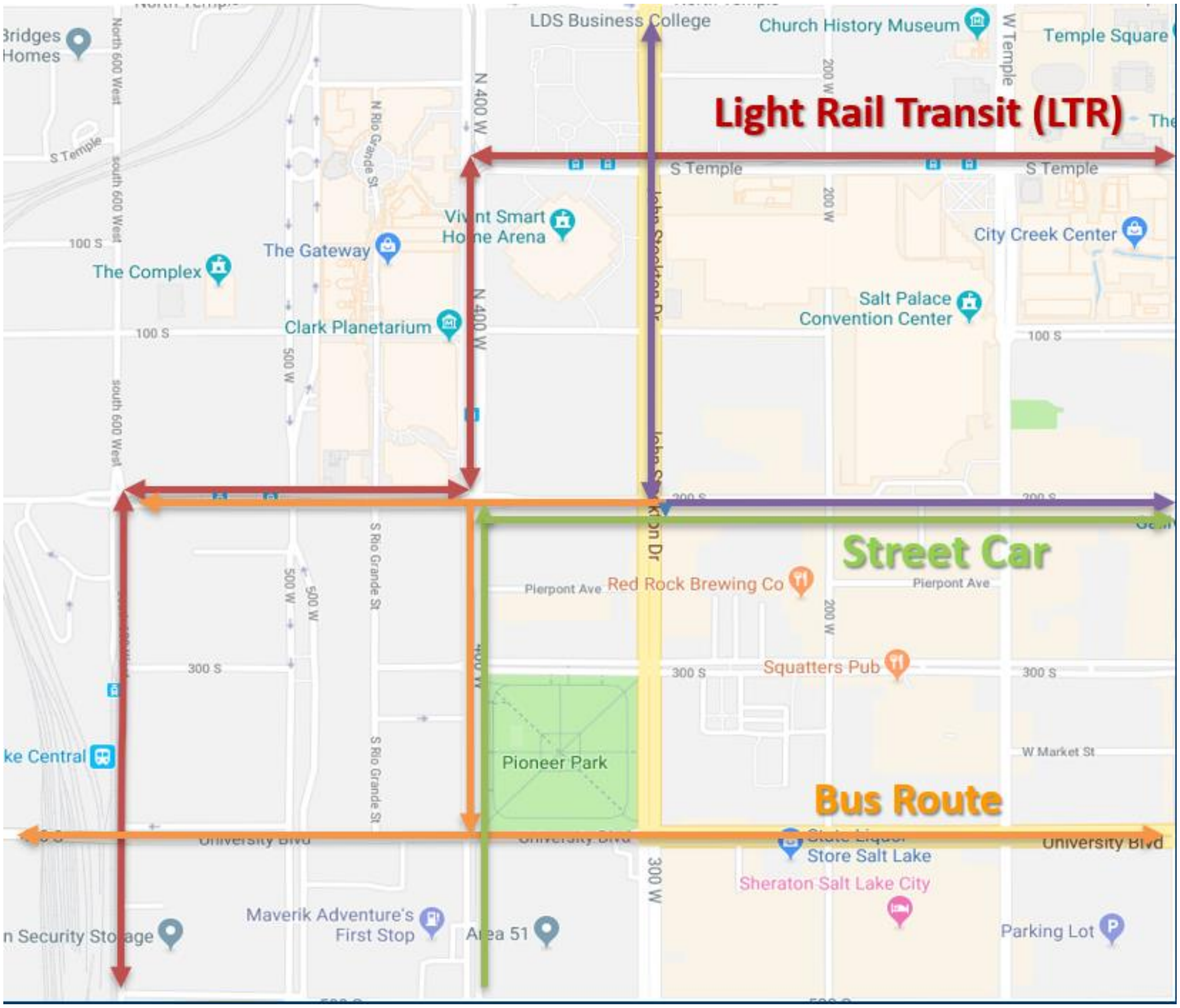


Figure 5: Google Map of Utah SLC CBD subarea

Scenarios that are planned for investigation are centered around a number of multimodal alternatives which include, high-capacity transit modes (Light Rail Transit (LRT)) exclusive and shared bicycle lanes, pedestrian traffic facilities and similar. Thus, availability of such multimodal plans have directed our attention to consider this network as a suitable candidate to achieve the project objectives.

We can classify the corridors of SLC CBD network into four types as follows:

- Carry significant transit ridership along some segments and characterized by low LOS during peak hours for all modes.
- Carry a lot of vehicular traffic, but they have also several transit routes and higher ridership.
- Mostly car-oriented corridors, but they are also favorable for bicyclists.
- Multimodal corridors that are being planned for a complete overhaul in the oncoming years.

According to the bullets above, alternative analysis and comparison with geometric and operational improvements for vehicular, transit and bicycle modes are needed to consider both long-term planning aspects of the Complete Streets as well as operational strategies which may be implemented to address specific needs of its multimodal users. Analyzed alternatives with improvements will include exclusive bus and bicycle lanes, potential road narrowing, and complex traffic control (e.g. Transit Signal Priority (TSP)) along some of the network routes. A comprehensive planning approach is needed for this corridor in the long term.

For corridors with a lot of vehicular traffic in this network the goal would be to make them more favorable for transit and non-motorized modes, e.g. potentially by applying exclusive bus and bicycle lanes. Special attention needs to be given to bicycle traffic along this corridor because of the high demand for this mode which keeps increasing.

3.3.2. Central Broward County Network

Broward County is located in southeastern Florida, in the center of the Miami-Fort Lauderdale-West Palm Beach metropolitan area. A majority of the developed land in Broward County follows a low-density, suburban development pattern, with concentrations of denser urban development primarily to the east of Interstate 95 in the cities of Fort Lauderdale, Hollywood, and Pompano Beach.

The beachfront areas of Broward County are popular tourist destinations, and many of these visitors may not have access to private transportation. The need for safe, multimodal streets is further confirmed by Broward's tourism industry, its countywide bike sharing network, and expected population increases.

In 2012, residents and city leaders embarked on an ambitious plan to ensure the long-term safety and accommodation of all road users throughout the county and to address local problems including increasing traffic, an incomplete network of sidewalks and bike lanes, and less-than-ideal public health conditions. The aim of the plan, called the Broward Complete Streets Initiative, is to develop healthier and safer streets for multi-modal transportation use, which includes walking, biking, use of wheelchairs or assisted walking devices, and/or the use of public transportation throughout Broward County. Finally, current projections indicate that by 2040, Broward County's population will grow by 250,000 people, which means all municipalities will need to identify ways and means to move more people beyond private automobiles. Following

Figure 46 is the FDOT context classification where the Broward County comes under the C4-Urban general to C5-Urban center.

Figure 6: FDOT Context Classifications

A majority of Broward residents currently travels with a car due to limitations in alternate forms of transportation. According to participants, there are currently not enough places to bike or walk safely or nearby public transportation options. A majority of the public workshop participants consistently reported high levels of interest in expanding sidewalks, adding public transit near their homes, marked bicycle lanes, more destinations within walking or biking distance, and a sense of safety while commuting without a car.

Many corridors on Broward County will be improved to satisfy the County’s endeavors. Oakland Park Blvd. represents one of the most important corridors in Broward County and is a center to many businesses, entertainment, and attraction areas. Figure 7 shows a Google aerial view of the Central Broward County and the highlighted lines show the major and minor arterial roads.

The highest number of multimodal improvements, based on the documentation received from FDOT D4, includes bus shelters, transit signal priority, queue jumps, bike lanes and sidewalks on the Oakland Park Boulevard. This corridor has a variety of operational issues, poor Level of Service (LOS), transit needs, and general congestion issues, among others. All major transportation and planning agencies in the Broward metropolitan area have begun working together towards the improvements of the corridor for all modes of transportation.

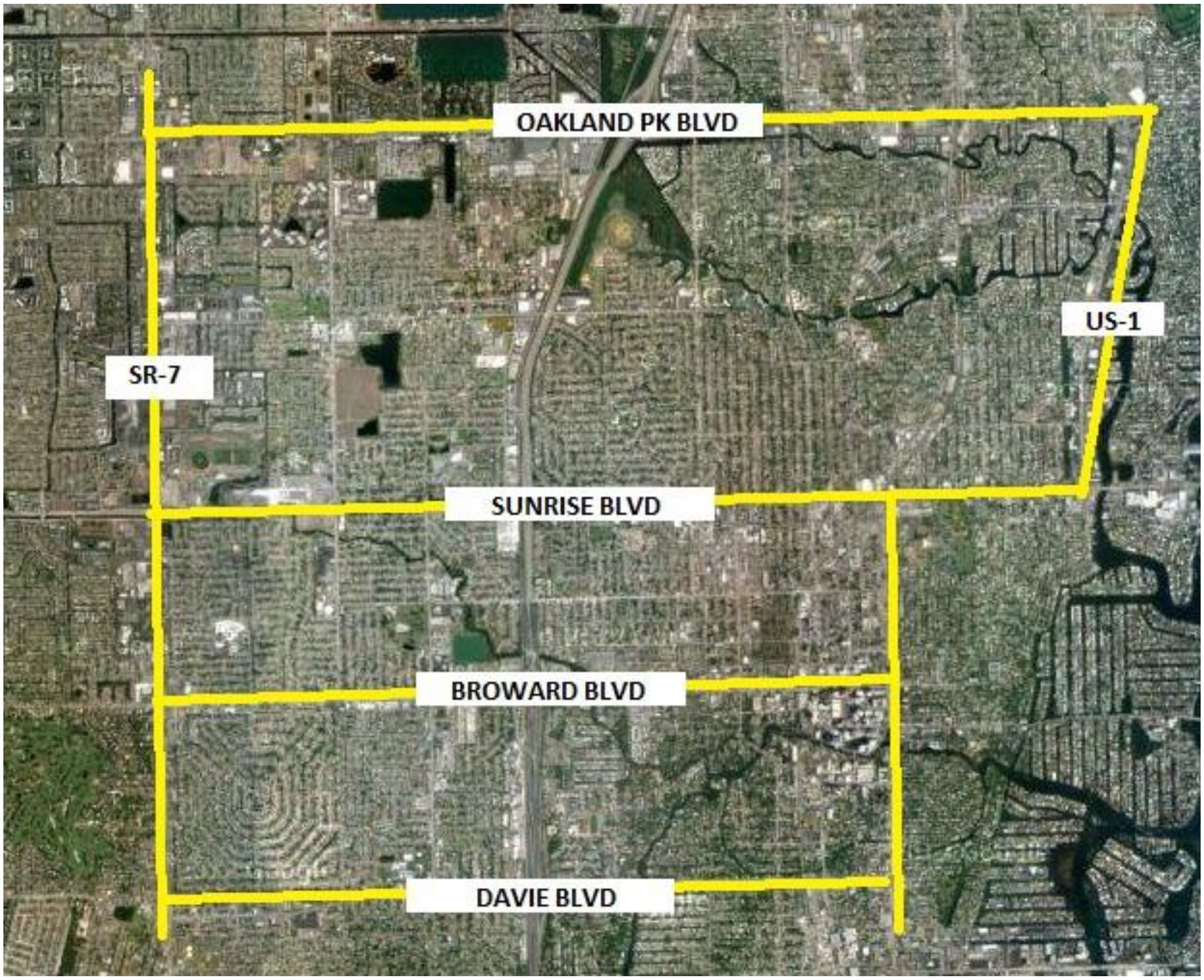


Figure 7: Google Map of Central Broward Area

The FAU research team has made inquiries to FDOT, Broward County and consulting companies who did any recent studies in this area to obtain as much data as possible. As a result of this effort the FAU research team was able to find a list of major improvements from Production Books for both Complete Streets and all active projects programmed in the FDOT D4 5-year Work Program in Broward County. The improvements could be classified as follows:

- Bus shelters, transit signal priority, queue jumps
- Bike lanes/sidewalks
- Widening the existing lanes to provide 5’ bike lane with 2’ buffer on both sides of the road
- Road construction and interchange improvement in freeways
- Intersection lighting and intersection improvements
- Crosswalks
- Intersection improvements
- Traffic signals

The existence of many proposed improvements for the Central Broward County network helps the FAU research team to choose among a variety of modeling scenarios which will be used to: 1. investigate multi-criteria costs and benefits of deploying complete Streets, and 2. predict the impact of both long-term planning aspects of the Complete Streets and operational strategies on efficiency, safety and environment of Urban Corridors.

3.4. Proposed Methodology

This section presents an overview of the proposed methodology and tasks throughout this study. The methodology has developed to be as model-agnostic as possible and it essentially follows sequential steps to achieve the goal and objectives of this research. The two networks selected for this project are the large Central Broward County network and the small SLC CBD network, as explained in detail in the previous section.

Figure 48 shows the overall framework of complete street methodology.

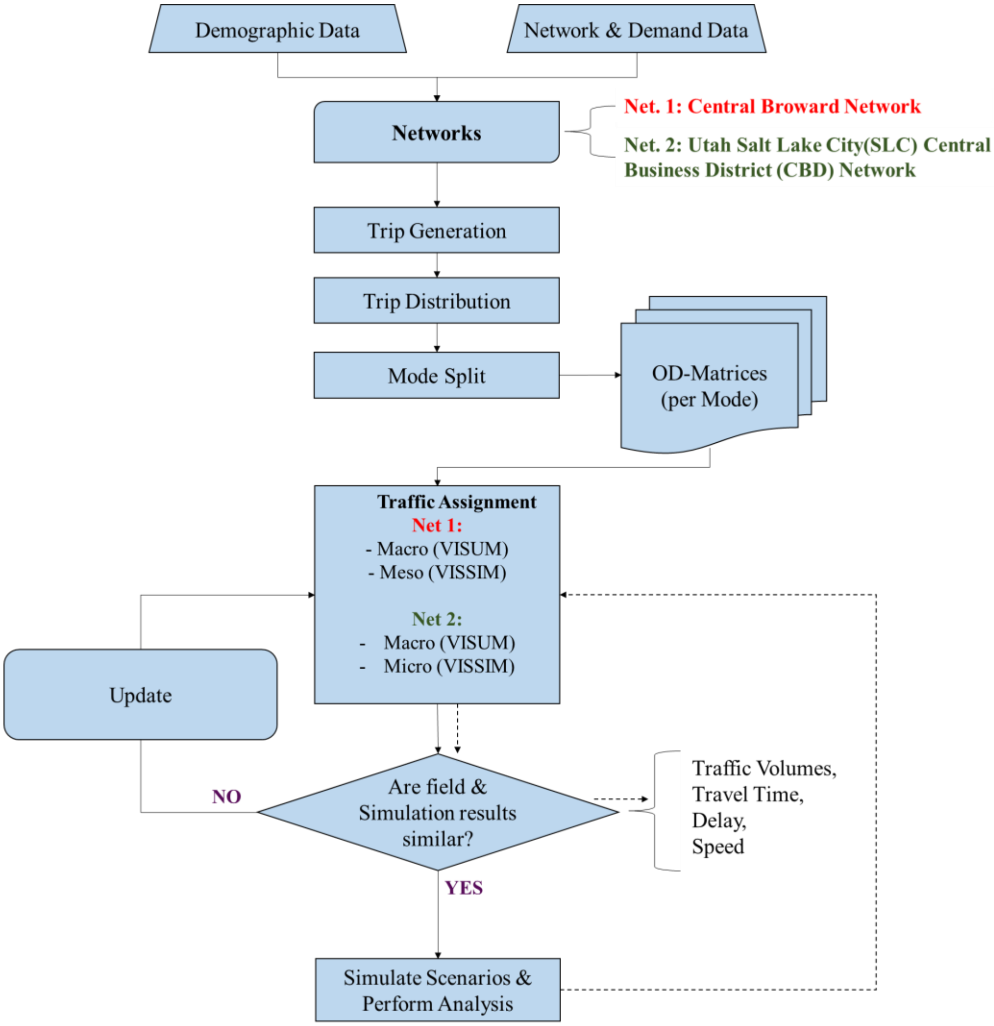


Figure 8: Overall framework for complete street methodology

3.4.1. Network Model from Demographic, Demand and Network Data

The first step is the data acquisition for macro-simulation/transportation planning software tool (in this case VISUM). It is essential to define free flow speeds, capacities, origin-destination zones, the number of lanes, traffic control at intersections, turns as network data, etc. The additional planning data like travel pattern data, land use data, socio-economic data, signal data, field traffic data, etc. will be obtained from multiple sources and agencies like Metropolitan Planning Organizations (MPO), Departments of transportation (DOT), Open Source Data (OSD), and other available data repositories (e.g. websites). Data from multiple sources and agencies will be collected and processed to develop and calibrate models. The extraction of a selected Broward subarea network will be done from Central Broward County MPO and the demand forecasting model will be coded in the transportation planning software (VISUM). Also, for Utah SLC CBD network will be extracted from the Wasatch Front Regional Council (WFRC) network. The extracted network, including the geometry and the origin-destination travel demand, will need to be further adjusted and converted in the models of different aggregation levels. Further, the modified network will be corrected for coding errors and geometrical details, not included in the demand model, will be added.

3.4.2. The Four Step Process in Transportation Planning Model (VISUM)

After preparation of the network infrastructure (supply side), the next step is preparation of the networks for modeling. Different traffic patterns were identified for modeling to represent different demands and congestion levels. Macroscopic and microscopic simulation models will be prepared for each network. These simulation models will be loaded with travel matrices during the peak hours for passenger cars, bicycles, pedestrians, transit and train in the forecasted state. For a macroscopic models, the study networks will be first divided into zones, the number of zones and their size is already determined by the purposes of the models and the MPO data. Core of the transportation planning model (VISUM) is a traffic assignment model that requires completion of the three steps of a traffic demand forecasting process (trip generation, trip distribution, and modal split). Based on the type of data available, the FAU research team may decide (in consultation with FDOT) to use modal OD matrices which already contain data pre-processed through the previous modeling stages such as trip generation, trip distribution, and mode split. Following three sections describe steps that will be done if such modal OD tables are not available.

3.4.2.1. Trip Generation

The trip generation is the process of determining the number of trips that began/end in origins (e.g. home-work) or destinations (e.g. shopping-home) of trips in each zone, as a function of land uses and demographics, and other socio-economic factors within the study area. For example, a home to University trip would be considered to have a trip end produced in the home zone and attracted by the University zone. For the two networks in this project we will determine number of trips originated and attracted by each zone. Transportation planning software (VISUM) calculates trip generation figures for a number of separate purposes (e.g. person group combinations). Trip attractions and productions are calculated on the basis of zonal characteristics. If the output matrices (with defined properties) do not exist in the model, they will be automatically generated during a procedure in VISUM. If such matrices already exist, their matrix values will be overwritten. On the other hand, the matrices can be used in other procedures, although they are only generated during the calculation process.

3.4.2.2.Trip Distribution

The trip distribution procedure is part of the 4-step procedure with sequential calculation of the steps. The trip distribution calculates proportions of the total travel demand between each pair of the zones based on how good a transportation ‘connection’ is between the zones. The connection quality is often measured by travel time or a similar impedance function. From the both networks (Central Broward County and SLC CBD), OD matrices for all modes of transportation will be calculated (in a single trip table).

3.4.2.3.Mode Split

The mode split computes the proportion of trips between each pair of zones that use a particular transportation mode. This procedure contains a sequential calculation of the steps where single-step mode choice breaks down the total demand (total demand matrix) into the individual transport modes per demand stratum (for example private (PrT), public (PuT)) based on mode-specific impedance skims (for journey time, costs, etc.). For the two networks in this study we will have a single OD-matrix table for each mode of transportation.

3.4.2.4.Traffic Assignment

Traffic assignment calculates how the traffic will distributed on the links of the road network. This includes both private car and public transportation vehicles, bicycles, pedestrians, etc. The assignment of trips to the network is the final step of the 4-step modelling process and becomes the basis for validating the model’s ability to replicate observed traffic, for the base year. Results of such a scenario are then used to evaluate impact of changes in the transportation system, modeled for any future traffic demand or the other scenarios on the network supply side. The traffic assignment can be done on multiple levels. On macroscopic level, traffic assignment will be used to distribute trips through the network and model any future traffic demand. This will be done to ensure that there is a basic level of understanding where the extra capacity exist and ensure that any large capacity shortages are detected before the process is transferred to higher-resolution modeling levels (e.g. meso and micro).

3.4.3. Evaluations of Scenarios

After the traffic assignment processes are completed for each of the defined scenarios, transportation planning software (VISUM) and traffic operations analysis software (VISSIM) will output a variety of results which will be used to evaluate such scenarios (e.g. densities, delays, speeds, volumes, travel times, queue lengths, etc.). Some of these results (such as traffic volumes, travel times, speeds etc.) will be used to calibrate and validate both planning (macroscopic) and operations (microscopic) models. Once the field and simulation results achieve appropriate match, various scenarios will be simulated, and the analysis will be performed for the selected performance measures. These performance measures are chosen to measure impact of the given complete streets scenarios on safety and efficiency of the transportation systems. If the simulation outputs do not properly match the field data, further adjustments will be made to make their outputs more realistic.

While Figure 8 shows a general methodology to prepare the models for the Complete Streets experiments, Figure 9 (given below) shows a more detailed process with data flows and tasks that need to be performed.

The process starts with selection of a network to analyze and given travel demand (contained within OD tables for current/recent year and year 2030). Once the network and demand have been defined it is necessary to select one of the proposed scenarios for the given network. The scenario (e.g. multimodal infrastructure or ITS (Intelligent Transportation Systems)) improvements are done directly in the microscopic model. Then, the model is run and proposed (efficiency and safety) Measures of Effectiveness (MOEs) are retrieved. Once the microscopic modeling is done, similar scenario-related modifications are made in the transportation planning macroscopic model. Then the relevant MOEs from the macroscopic model are retrieved without modifying any travel demand aspects of the macroscopic model (such as modal split or similar). In the next step the outputs from both micro and macro models are compared to revalidate results of the macro model. It is essential to point here that this steps are necessary to ensure that the transportation planning model (macro) has a right ‘sense’ of the impacts made by the particular Complete Street scenario (implemented originally in the microscopic model). If the results are matched fairly the process can continue with the next steps; otherwise, a ‘recalibration’ is needed to adjust the macroscopic model to properly reflect impact of the Complete Street scenario.

Once the match between results of the micro and macro models is confirmed, a modal split process will be executed again – now with an objective to see how many trips (if any) would be realized through a different mode if the Complete Street scenario offers some better multimodal options. This would require a direct adjustment (by the process itself) of the modal OD tables, which would be followed by a multimodal traffic assignment. Once a new traffic assignment is executed it would inevitably (where it makes sense) redistribute the traffic on the network, thus affecting the traffic demand levels in the microscopic model. For this reason, it would be necessary to readjust traffic volumes, pedestrian counts, and similar inputs in the microscopic model and repeat simulation runs of the microscopic Complete Street scenario. Once this step is done the loop is closed and the results from both models are ready to be used in the subsequent Cost-benefit analysis. Then, the entire process should be repeated for a new traffic demand level (e.g. 2030). Then, the other Complete Street scenarios will be considered for the same network (by repeating the entire process for two travel demand levels). Finally, this process would be repeated for the second network scenario. Such an extensive analysis of Complete Street scenarios, in both micro and macro models, would create a large number of cases, which would increase reliability of the Cost-benefit results.

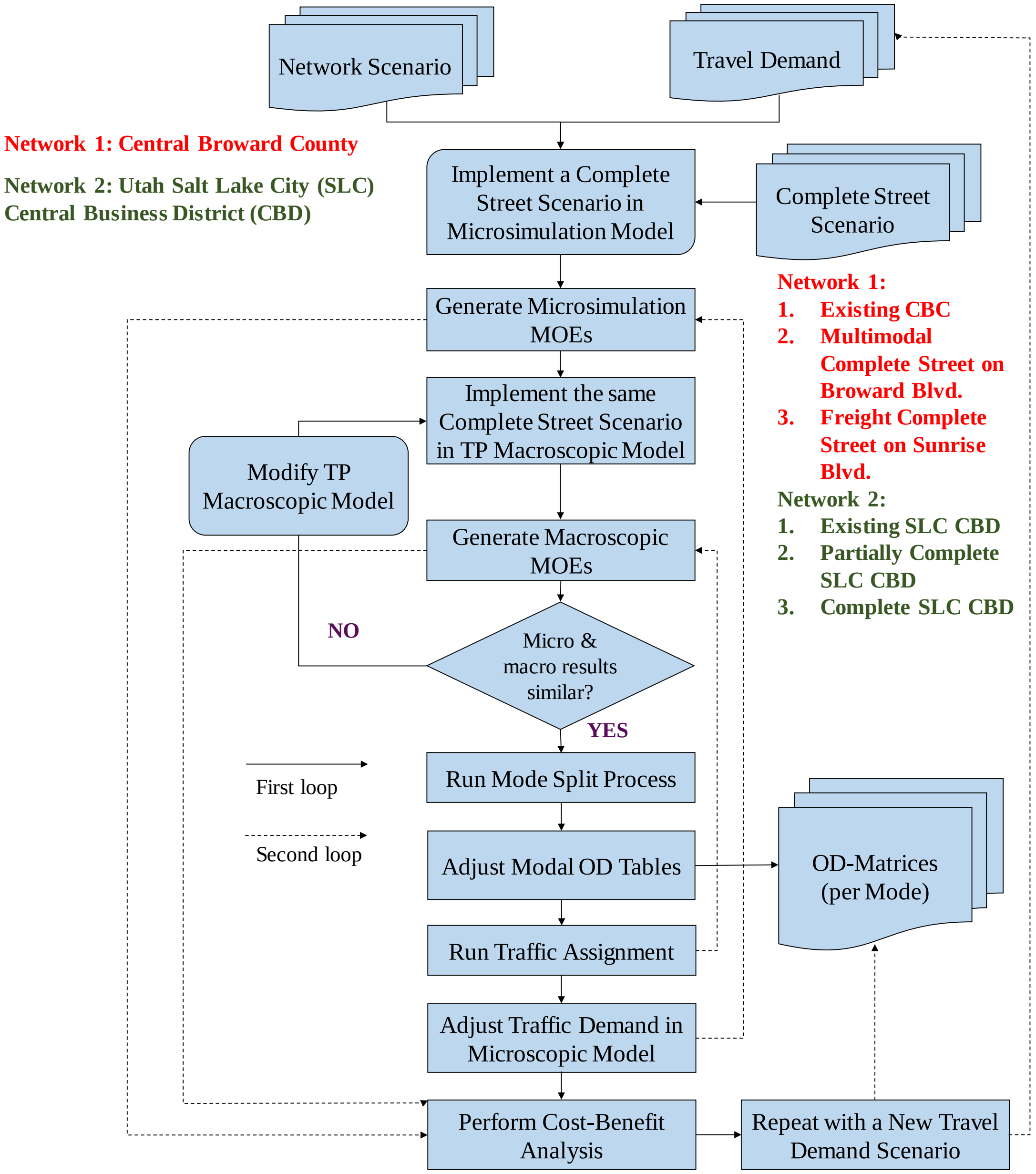


Figure 9: Overall framework for complete street methodology

3.4.3.1.General Scenarios

The simulated scenarios will be developed in coordination with FDOT. However, it is envisioned that they will depend on the operational and background conditions of a particular Complete Street network, and other factors. A few exemplary scenarios are supposed to answer potential questions:

- What happens with a Complete Street if one out of four lanes at an intersection/corridor with potential freight traffic converts to a dedicated truck lane? How will this affect regular traffic at that corridor?

- What happens with efficiency, safety and environmental indicators of a Complete Street if people change their travel mode due to increased taxes for use of private vehicles?
- How the traffic demand and network performance (in terms of efficiency, safety of all users) will change if a 2+2 arterial / collector road needs to be turned to 1+1 road where the two inner lane will be turned into areas aimed for pedestrians / public transport.

The improvements like bus shelters, transit signal priority, queue jumps & bike-lanes/sidewalks, etc. are expected to be developed in future years in the both networks. The performance measures calculation for the current transportation system for both networks, a timetable-based assignment should be performed for one of the peak periods (e.g. morning). To meet the objectives of this research, various scenarios will be sequentially developed and evaluated. The Central Broward County network and SLC CBD network will be focused on following general scenarios which will be categorized in different sub-scenarios later in task 3.

General Scenarios for SLC CBD Network

SLC CBD network, already having multiple multi-modal services, is a good test-bed for additional multi-modal Complete Street considerations. On the other hand the SLC CBD is not as urban/active as some other CBDs around the country. The same amount of urban space in other metropolitan areas attracts many more people every day (and creates more ‘alive urban environment) than the SLC CBD. From that perspective, it would be interesting to see how various travel demand levels would change traveling experiences in multi-modal CBD such as one in SLC. Thus, we propose to make a full assessment of the streets that constitute the SLC CBD network and investigate what would be needed to make every street in the SLC CBD to be a Complete Street (thus making the SLC CBD a “Complete CBD”). From that perspective we propose to model two travel demand scenarios (Existing Demand and Future Demand (where 2030 is used a Future Demand year). These two travel demand scenarios will be coupled with following three network supply scenarios:

- Existing SLC CBD – current field conditions including all of the existing multi-modal amenities including pedestrian and bicycle facilities, Light-Rail Transit, bus lines, etc.
- Complete SLC CBD – where every street in the CBD is made to be a Complete Street from multi-modal perspective; thus giving pedestrians, bicyclists, public transit riders, and motorists an equal access to any parts of the CBD.
- Partial SLC CBD – which represent a ‘half-way’ scenario between the two extremes from above; in this scenario we would add some multi-modal amenities which are not currently present in the field but the multi-modality would not be omnipresent in the SLC CBD.

General Scenarios for Central Broward County Network

Similarly, for Central Broward County network there are variety of improvements on the arterial corridors which could be taken in consideration. Examples of these are geometrical changes of the street alignment, addition of: new bike lanes, transit lanes, number of stops, sidewalks, transit signal priorities etc. Such infrastructural alterations will be analyzed in terms of average traffic volumes and transit capacities due to the fact that some of the investigated scenarios may attract new transit passengers and similar.

The major characteristic of the Central Broward County Network are large arterial roadways which connect various sub-urban areas with some of the CBD transitional areas (on east side) or remote sub-urban areas of the county (on west side). From that perspective this network seems to be a good testbed for a number of various Complete Street scenarios – from those where multi-modal facilities are improved to support non-motorist transportation modes to those that may favor special freight transportation alternatives, considering proximity of the major seaports and airports in the Southeast Florida. Similarly to the SLC CBD case, we propose to model two travel demand scenarios – for Existing Travel Demand and Future Travel Demand (where 2030 is used as a representative year for Future Traffic Demand). These two travel demand scenarios would be coupled with three network supply scenarios:

- Existing Central Broward County – current field conditions including all of the existing multi-modal facilities and other amenities.
- Central Broward County with a Multi-modal Complete-Street Corridor – Broward Boulevard will be modeled as an example of Complete Street (possibly with a number of multi-modal options including pedestrian sidewalks, bicycle lanes, improved public transit, etc.). In this case the FAU research team will follow some of the recommendations of the Central Broward East-West Transit Study, which was conducted by the Broward County MPO. Following some of the recommendations from this study ensures that the modeled scenario will have a connection with a relevant real-world considerations.
- Central Broward County with a Freight Complete-Street Corridor – Sunrise Boulevard will be modeled as an example of a full Complete Street for freight traffic (e.g. with ‘truck priority’ at signalized intersections and the other considerations for freight traffic). Similarly to Broward Boulevard, some considerations have been made (by FDOT) to enable Sunrise Boulevard to better support freight traffic. Our research team will work along the same general guidelines to execute realistic traffic scenarios on the Sunrise Boulevard.

3.4.3.2. Signal Priority Scenarios

Transit Signal Priority (TSP)

Transit signal priority is an acclaimed and commonly used strategy, applied to prioritize bus movements for improving their reliability, punctuality, speed, and cost-effectiveness. The main advantages of TSP are the little impacts that the strategy has on the rest of the traffic network and its low cost that makes it very competitive with the automobile. It is used extensively around the world, providing priority to transit vehicles that are detected on an arterial network and request priority to cross a signalized intersection.

TSP is a traffic operation strategy that provides priority to the movement of transit vehicles on signalized intersections. It is usually confused with the preemption strategy that facilitates the right of way at and through a signal for the most important classes of vehicles such as fire trucks. Preemption is different from signal priority, which alters the existing signal operations to shorten or extend phase time settings to allow a priority vehicle to pass through an intersection. The preemption strategy always interrupts the normal traffic operations of a signalized intersection, while signal priority tries to facilitate specific types of vehicles without completely interrupting the coordination for the signalized intersection. The main purpose of TSP is to improve the schedule adherence and the transit travel time efficiency while minimizing the effects to normal traffic operations.

Transit Signal Priority Strategies

Transit signal priority shall be given in various ways to the arterial networks. Passive, active, and real-time goals are the most common strategies. Passive transit signal priority is a continuous process that does not interfere with the information in real-time. In particular, the passive priority does not include any prioritization detection system, since it relies on predictable transit operations.

Active priority for the transit signal is the reverse passive priority strategy. The function of the active priority depends on a device that uses detectors at a signalized intersection for the transit vehicles to request priority. Green extension and the early green are the most widely used active approaches. The green extension policy gives transit vehicles priority by extending the green time period. Among the other priority approaches, the green extension strategy has the most preferred because it eliminates the delay in that direction without the need for extra clearance periods and disruption of network coordination.

The early green strategy, on the other hand, works in contrasting ways different from the green extension strategy. This form of strategy is triggered when the headlight on the opposite approach of the one that asked for priority is green. Consequently, the preceding step finishes earlier than it should be, and the strategy implemented by the priority request turns green to promote priority movement.

Freight Signal Priority (FSP)

Freight transportation holds a key role for the satisfaction of the economic system’s demand in the US. The movements of products across the country are based on trains and trucks. The volume of freight movement was growing rapidly over the past few decades and it will continue growing for the years come.

The achievement of providing smoother operation of freight movements along arterial corridors is significant for the economy on a state and national level due to the importance of freight transportation on mobility and congestion.

Furthermore, the impact of trucks on traffic flows is detrimental to arterial corridors and especially on signalized intersections, where their steady flow might be interrupted by the traffic lights. The negative impacts of freight vehicles are due to their large size, large weight, slow dynamics, and high levels of emissions.

Consequently, a truck needs more time for recovering its previous speed and longer distance for decelerating and stopping at a red light in comparison to the passenger vehicles. The result of the above truck needs affects directly, and on a high scale, the overall traffic delay and congestion that is generated by truck stops, compared to the traffic delay generated by passengers' vehicle stops.

For traffic light control purposes, today's traffic operations consider all traffic movements as passenger vehicle movements, without taking into consideration the trucks along an arterial corridor. However, the rapid growth of the freight transportation system around the world has led engineers to focus on planning an improved freight service in urban areas. Freight signal priority is a traffic operation that is able to improve freight transportation worldwide and the efficient operation of the traffic and road network in total.

Specifically, a freight signal priority strategy is designed to give priority to truck movements along a corridor near a freight facility. By using this strategy, the travel time of freight vehicles will potentially be decreased and consequently the cost of freight movement as well. In addition, the reduction of truck stops arriving at an intersection at the end of the green phase has safety benefits due to the reduction of red-light running. The elimination of traffic delays of passenger vehicles and the transit system is another advantage of the reduction of prioritizing truck movements, as well as the elimination of truck emissions, noise, and pavement damage. Finally, FSP could be applied for assigning truck drivers specific routes that they need to follow.

3.4.4. Performance Measures (Key Performance Indicators)

Following performance measures, given in Table 8, are identified as the key parameters for the proposed methodology, calibration and validation of the simulation models, and scenario evaluation efforts. The FAU research team has taken into consideration, when selecting these performance measures, needs of both macroscopic modeling for a long-term planning and the microscopic modeling for a realistic account of traffic operations. Also, following three primary categories of cost-benefit analysis were taken into account to ensure that the selected performance measures can consequently be used in the proposed cost-benefit analysis. Table 8 summarizes how these performance measures can be retrieved from various types of simulation models.

1. Travel time savings
2. Vehicle operating cost savings
3. Safety benefits (accident cost savings)

Table 8: Performance measures for efficiency, safety, and environment aspects

Aspect Simulation Model	Efficiency	Safety
Macroscopic	1- Total vehicle-miles [mile] 2- Total travel time [sec/veh] 3- Vehicle hours of delay	Number of accidents
Mesoscopic	1- Delay per node 2- Travel time 3- Speed	Type of conflict and the quantity of each type (SSAM)
Microscopic	1- Delay per node 2- Travel time 3- Speed	Type of conflict and the quantity of each type (SSAM)

The following section provides details for each performance measure based on the resolution of a simulation model:

3.4.4.1. Macroscopic Performance Measures

Efficiency:

Total vehicle-miles or vehicle miles of travel (VMT), total travel time, and vehicle hours of delay (VHD) will be calculated for the corridor of interest.

Safety:

Number of accidents and analyze them can be done using the customized GIS-based modules in transportation planning software (e.g. Add-on module “SAF” in VISUM), to geo-locate and analyze safety blackspots and individual accidents.

3.4.4.2. Mesoscopic Performance Measures

Efficiency:

Delay per node, which is a modeling component (geographic boundary) that must be defined based on the shape of a field intersection. Travel times & speeds are available in similar options as in microscopic simulation, e.g. by node, link, and individual vehicles.

Safety:

For safety outputs from microsimulation models the FAU research team will utilize vehicular trajectories (e.g. from VISSIM) which will be post-processed by the

Surrogate Safety Assessment Model (SSAM) of the Federal Highway Administration Research and Technology of the U.S. Department of Transportation. SSAM provides an opportunity to estimate number of conflicts (near trajectory misses) for three types of conflict (Rear-end, Crossing, and Lane-change).

3.4.4.3. Microscopic Performance Measures

Efficiency:

Delay per node or link. Travel times & speeds are available for different scales, e.g. node, link, and individual vehicle.

Safety:

Similarly to mesoscopic simulations, vehicular trajectories will be exported to the SSAM which will process the data and output frequencies for each type of the conflict types (Rear-end, Crossing, and Lane-change). It should be noted that pedestrian trajectories can also be used but it will be crucial to model risk-prone pedestrian behavior.

3.5. Cost-benefit Analysis

One can consider four primary categories of user benefits for cost-benefit analysis utilizing the output from simulation and available data: (According to Caltrans Life-Cycle Benefit/Cost Analysis Model). Considering that emissions/pollutants attainment are not critical for FDOT we exclude consideration of emission-related performance measures and a subsequent cost-benefit analysis.

1. Travel time savings
2. Vehicle operating cost savings
3. Safety benefits (accident cost savings)
4. Emission reductions

1. Travel time savings are calculated as a function of the travel speeds and traffic volumes: (Delay savings can also be considered)
   a. Based on the base and future-year traffic volume projections, future annual average daily traffic (ADT) are estimated, without and with the proposed improvements, assuming a straight-line growth.
   b. Annual ADTs are multiplied by the length of the area affected by the improvement and divided by the travel speed to find the total travel time, without and with the proposed improvements.
   c. Annual travel time savings are multiplied by the value of time and average vehicle occupancy for each mode to convert travel time savings into dollar values.
   d. The dollar value of the travel time savings is discounted to estimate its present value.

2. Vehicle operating cost (VOC) savings (i.e., changes in fuel use, vehicle wear, etc. due to improved speed) are estimated from travel speeds and traffic volumes as follows:
    a. Forecasted annual ADTs are multiplied by the affected segment length to find annual vehicle-miles traveled (VMT) with and without the improvements, as well as their differences (VMT savings).
    b. For each mode, annual VMT savings are multiplied by the fuel consumption (from look-up table, based on an average speed) and the unit fuel cost to find the dollar value for fuel VOC savings.
    c. Annual VMT savings are multiplied by unit non-fuel VOC to find the dollar value of non-fuel VOC savings.
    d. Future annual VOC savings are summed across modes and discounted to obtain their present value.

3. Safety benefits are a function of traffic volumes:
    a. The aggregated accident cost is calculated by multiplying the accident rate by an average user cost for each type of accident and summing the result.
    b. Annual VMT is multiplied by aggregate accident cost to estimate the annual cost of accidents without and with the proposed improvements.
    c. The difference (change in accident cost) is discounted to find the present value of future safety benefits.

4. **Building, Calibrating and Validating Traffic Models**

This chapter describes the model-building process and results of the model calibration and validation processes. The FAU research team has worked on developing, calibrating and validating of the models necessary to execute the general scenarios as defined under the Chapter 3. Chapter 4 includes description of data acquisition and model building for two networks (i) Central Broward County; and (ii) Salt Lake City downtown. The modeling was done to provide feasibility in performing multiresolution evaluations (Macroscopic, Mesoscopic, and Microscopic). Both of the networks were modeled in microscopic (VISSIM) and macroscopic (VISUM) models. Once these models were developed they have been calibrated and validated to accurately resemble the field conditions.

4.1. Network of Salt Lake City

Salt Lake City (SLC) is the capital and the most populous municipality of the state of Utah. SLC lies at the convergence of two cross-country freeways; I-15 running north-south, and I-80, which connects downtown with Salt Lake City International Airport to the west and exits to the east. SLC has a mass public transit that includes a bus system, light rail, and a commuter rail line. The network was modeled in microscopic (VISSIM) and a macroscopic (VISUM) environments. The downtown of SLC was modeled in VISSIM as this is the main area of interest for this research, whereas the entire city was modeled in VISUM. The reason behind that decision is to take into consideration impact of the changes in the evaluations of SLC Central Business District (CBD) scenarios on the metro network level.

4.1.1. Modeling of SLC in microsimulation software

Traffic microsimulation software (VISSIM) will be used extensively to evaluate the scenarios proposed in task 2. SLC CBD network was built in VISSIM because the software enables researchers to properly model intricacies of field traffic operations in this network.

Downtown Salt Lake City is usually defined as the area approximately between South Temple and 400 South Streets in north-south direction and from 500 East to 600 West Streets in east-west direction. The proposed network encompasses the downtown of SLC and majority of its multimodal transportation operations. Modeling of this network contributes to the overall goal of this research to evaluate performance and impact of the complete streets (many streets with multimodal transportation operations are seen as synonyms for complete streets). Figure 10 shows the main streets that were modeled in the downtown of SLC.

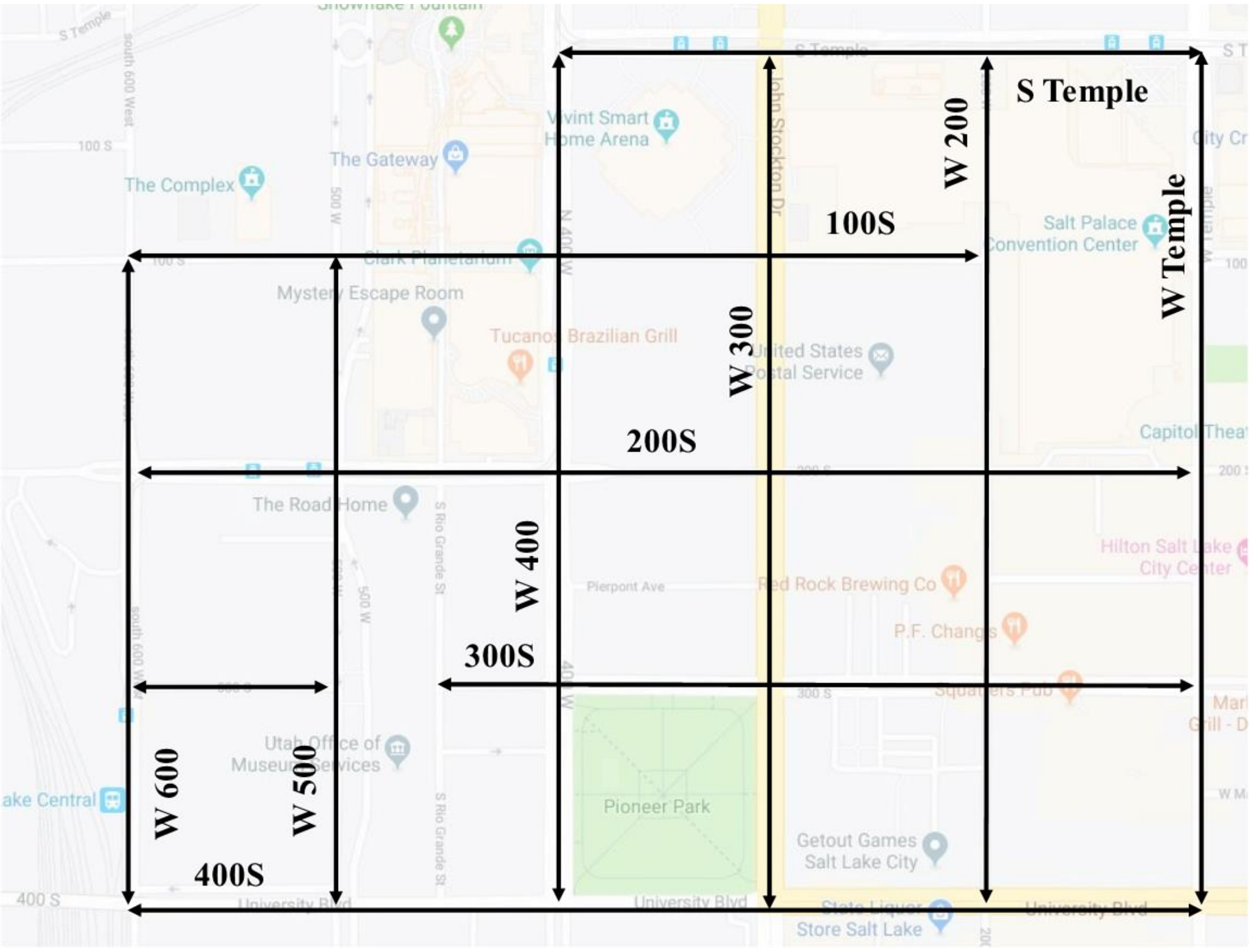


Figure 10: Main streets in the downtown Salt Lake City.

4.1.1.1.Data Collection

The FAU research team has used the data that was collected by another research project which referred to the SLC conditions between September and November of 2015. The utilized data were collected to meet the needs of microsimulation model - its development and analysis. The dataset consists of intersection counts, which include vehicular traffic, pedestrians, and bicyclists. These data were collected in the field for 25 major signalized intersections within the analysis network, for the PM peak period (4:00 PM – 6:00 PM).

In order to calibrate traffic volumes from simulation models, AADT (Annual Average Daily Traffic) data were downloaded from UDOT's website for most of the main streets in the SLC downtown. Table 8 shows such AADT values (veh/day) per predefined segments. Historical travel times (intersection to intersection) were extracted from the field using Bing maps, Google maps, and Waze traffic application. Then, these field travel times were compared to the travel times from simulation models to perform the validation processes.

Table 8: AADT values (veh/day) per segment

Location	AADT
400S (600-300)	33000
400S (600-300)	33000
400S (300-Temple)	29000
400S (300-Temple)	29000
200S (600-300)	13000
200S (600-300)	13000
200S (300-Temple)	17000
200S (300-Temple)	17000
S Temple (400-300)	3500
S Temple (400-300)	3500
S Temple (300-Temple)	10000
S Temple (300-Temple)	10000
400 (200S-S Temple)	14000
400 (200S-S Temple)	14000
300 (400S-S Temple)	18000
300 (400S-S Temple)	18000
200 (400S-200S)	11000
200 (400S-200S)	11000
200 (200S-S Temple)	11000
200 (200S-S Temple)	11000
W Temple (400S-200S)	22000
W Temple (400S-200S)	22000
W Temple (200S-S Temple)	21000
W Temple (200S-S Temple)	21000

The AADT is useful, when K and D factors are known, to calculate the traffic volume on a specific segment of a street for a particular course of time, usually an hour. However, when K and D factors are not readily available they must be computed from the other relevant data. The FAU research team used historical AADT data (provided on the UDOT website) to calculate the K and D factors.

- K factor: is defined as the proportion of annual average daily traffic occurring in an hour.

Since K factors are usually calculated based on the traffic from continuous traffic count stations, data from 112 automatic traffic recorders (ATRs) were downloaded for a year. Usually, the K factor is the proportion of the AADT occurring at the 30th highest hour of traffic from the year's-worth of data and it is also known as “K30”. For that reason, the 30th-highest hour of traffic from the year’s-worth of UDOT’s data was extracted (from each

ATR) and the average K30 factor was found to be 12.9%. Table 9 presents a sample of the considered K30 factors and their average value (for 112 ATRs).

Table 9: A sample of calculated K_{30} factors

Station	**K 30th**
301	10.3 %
302	8.6 %
303	10.8 %
304	31.6 %
305	12.0 %
306	9.9 %
307	11.2 %
308	15.3 %
309	12.4 %
310	13.8 %
n-1	x%
n	y%
Average	**12.9 %**

- D factor: is the proportion of the traffic moving in the peak direction during the design hour. Because the ATR traffic volumes are not given for any of the streets in SLC CBD, the FAU research team has used various ATR data from nearby streets to identify a relevant D factor for the SLC CBD (assuming that the difference in D factors would be insignificant for nearby streets). Twelve hourly samples from ATR stations were taken for each direction (NB, SB, WB, and EB) to calculate an average D factor.

The average of the 12 samples was calculated for each direction as shown in Figure 11. Since the averages for the same hour do not add up to 1, two values which add up to 1 and are closest to the average values were adopted for the time of interest (4:00 PM – 5:00 PM) and (5:00 PM – 6:00 PM) . Table 10 summarizes the values of D factor.

Table 10: D factors per approach.

Direction	4:00 PM – 5:00 PM	5:00 PM – 6:00 PM
NB	0.47	0.49
SB	0.53	0.51
WB	0.55	0.54
EB	0.45	0.46

In Figure 11 below, positive and negative values refer to opposite directions; where negative is for SB or WB, whereas positive represents NB and EB.

	EW	Date\Hour	17:00	18:00
WB	Negative Average		0.517376	0.539015
WB	Negative Average		0.704147	0.675839
WB	Negative Average		0.724525	0.61018
WB	Negative Average		0.51195	0.535946
WB	Negative Average		0.412686	0.464777
WB	Negative Average		0.496584	0.501812
WB	Negative Average		0.479569	0.48449
WB	Negative Average		0.578472	0.537715
WB	Negative Average		0.47862	0.460273
WB	Negative Average		0.465055	0.467197
WB	Negative Average		0.608906	0.584973
WB	Negative Average		0.50323	0.496922
	Average		0.540093	0.529928
		Date\Hour	17:00	18:00
EB	Positive Average		0.482624	0.460985
EB	Positive Average		0.295853	0.324161
EB	Positive Average		0.242141	0.356487
EB	Positive Average		0.455792	0.431796
EB	Positive Average		0.552832	0.50074
EB	Positive Average		0.470083	0.464854
EB	Positive Average		0.487098	0.482177
EB	Positive Average		0.38927	0.430027
EB	Positive Average		0.489122	0.507469
EB	Positive Average		0.500462	0.49832
EB	Positive Average		0.358836	0.382769
EB	Positive Average		0.460288	0.462467
	Average		0.432033	0.441854
		Date\Hour	17:00	18:00

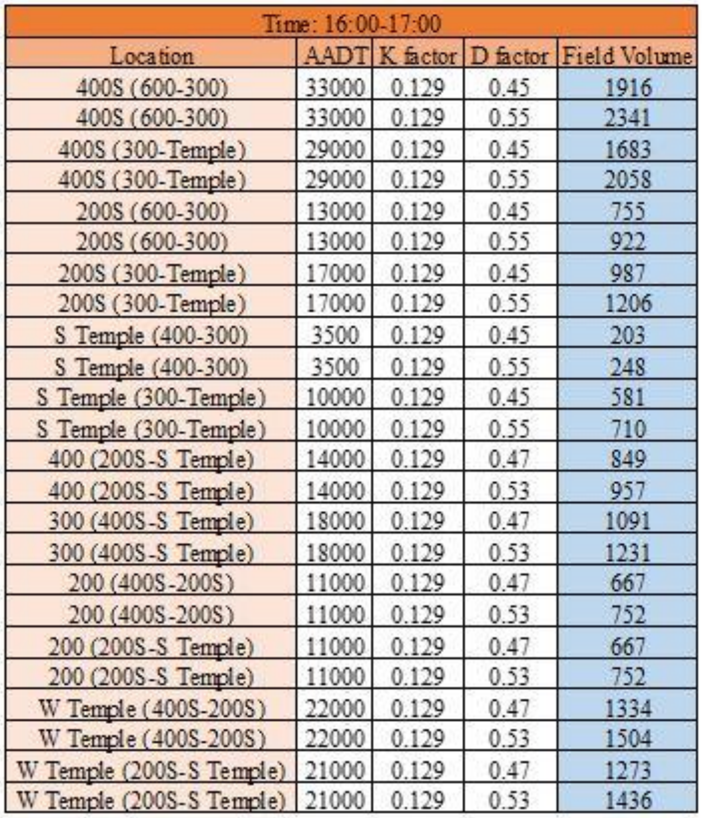
	SN			
SB	Negative Average		0.539084	0.487427
SB	Negative Average		0.541833	0.466614
SB	Negative Average		0.369073	0.429098
SB	Negative Average		0.471046	0.441873
SB	Negative Average		0.55212	0.558871
SB	Negative Average		0.599459	0.566119
SB	Negative Average		0.60018	0.574414
SB	Negative Average		0.340418	0.425109
SB	Negative Average		0.543796	0.484649
SB	Negative Average		0.496037	0.446428
SB	Negative Average		0.588328	0.536416
SB	Negative Average		0.517376	0.539015
	Average		0.513229	0.496336
		Date\Hour	17:00	18:00
NB	Positive Average		0.428658	0.480315
NB	Positive Average		0.42113	0.496349
NB	Positive Average		0.598668	0.538644
NB	Positive Average		0.495621	0.524794
NB	Positive Average		0.414547	0.407795
NB	Positive Average		0.368283	0.401623
NB	Positive Average		0.367562	0.393328
NB	Positive Average		0.626248	0.541558
NB	Positive Average		0.422871	0.482018
NB	Positive Average		0.47063	0.520239
NB	Positive Average		0.411672	0.463584
NB	Positive Average		0.482624	0.460985
	Average		0.459043	0.475936
		Date\Hour	17:00	18:00

Figure 11: Calculating average D factors.

To calculate traffic volume for a particular direction during an hour, Equation 1 was used to find volumes for the segments with known AADTs.

$$Volume\ =\ AADT * D * K \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

Figure 12 shows the results of estimating field traffic volumes from AADTs (by using the Equation 1). It can be seen from the figure that K factor is constant for all segments regardless of the direction, whereas values shown in Table 10 are used for D factor based on the direction of the segment.



Time: 16:00-17:00				
Location	AADT	K factor	D factor	Field Volume
400S (600-300)	33000	0.129	0.45	1916
400S (600-300)	33000	0.129	0.55	2341
400S (300-Temple)	29000	0.129	0.45	1683
400S (300-Temple)	29000	0.129	0.55	2058
200S (600-300)	13000	0.129	0.45	755
200S (600-300)	13000	0.129	0.55	922
200S (300-Temple)	17000	0.129	0.45	987
200S (300-Temple)	17000	0.129	0.55	1206
S Temple (400-300)	3500	0.129	0.45	203
S Temple (400-300)	3500	0.129	0.55	248
S Temple (300-Temple)	10000	0.129	0.45	581
S Temple (300-Temple)	10000	0.129	0.55	710
400 (200S-S Temple)	14000	0.129	0.47	849
400 (200S-S Temple)	14000	0.129	0.53	957
300 (400S-S Temple)	18000	0.129	0.47	1091
300 (400S-S Temple)	18000	0.129	0.53	1231
200 (400S-200S)	11000	0.129	0.47	667
200 (400S-200S)	11000	0.129	0.53	752
200 (200S-S Temple)	11000	0.129	0.47	667
200 (200S-S Temple)	11000	0.129	0.53	752
W Temple (400S-200S)	22000	0.129	0.47	1334
W Temple (400S-200S)	22000	0.129	0.53	1504
W Temple (200S-S Temple)	21000	0.129	0.47	1273
W Temple (200S-S Temple)	21000	0.129	0.53	1436

Time: 17:00-18:00				
Location	AADT	K factor	D factor	Field Volume
400S (600-300)	33000	0.129	0.46	1958
400S (600-300)	33000	0.129	0.54	2299
400S (300-Temple)	29000	0.129	0.46	1721
400S (300-Temple)	29000	0.129	0.54	2020
200S (600-300)	13000	0.129	0.46	771
200S (600-300)	13000	0.129	0.54	906
200S (300-Temple)	17000	0.129	0.46	1009
200S (300-Temple)	17000	0.129	0.54	1184
S Temple (400-300)	3500	0.129	0.46	208
S Temple (400-300)	3500	0.129	0.54	244
S Temple (300-Temple)	10000	0.129	0.46	593
S Temple (300-Temple)	10000	0.129	0.54	697
400 (200S-S Temple)	14000	0.129	0.49	885
400 (200S-S Temple)	14000	0.129	0.51	921
300 (400S-S Temple)	18000	0.129	0.49	1138
300 (400S-S Temple)	18000	0.129	0.51	1184
200 (400S-200S)	11000	0.129	0.49	695
200 (400S-200S)	11000	0.129	0.51	724
200 (200S-S Temple)	11000	0.129	0.49	695
200 (200S-S Temple)	11000	0.129	0.51	724
W Temple (400S-200S)	22000	0.129	0.49	1391
W Temple (400S-200S)	22000	0.129	0.51	1447
W Temple (200S-S Temple)	21000	0.129	0.49	1327
W Temple (200S-S Temple)	21000	0.129	0.51	1382

Figure 12: Field volumes interpolated from AADTs.

4.1.1.2.Calibration and validation processes and results

The processes of model verification, validation and calibration are critical to the credibility and reliability of the model results. Under this section we examine major parameters used in the calibration and validation processes of SLC network in VISSIM.

- Calibration: field volumes estimated from the AADT were compared to the volumes from the micro (VISSIM) and macro (VISUM) simulation models.

Data collection points (elements of VISSIM network infrastructure) were created along the segments where AADT are collected. Data collection measurements, each consisting of multiple data collection points, were created for each segment with AADT. Figure 13 shows each data collection measurement in VISSIM with its corresponding segment from the field.

Data Collection Measurement	Location	AADT
400: SEGMENT 1-1	400S (600-300)	33000
401: SEGMENT 1-2	400S (600-300)	33000
402: SEGMENT 2-1	400S (300-Temple)	29000
403: SEGMENT 2-2	400S (300-Temple)	29000
404: SEGMENT 3-1	200S (600-300)	13000
405: SEGMENT 3-2	200S (600-300)	13000
406: SEGMENT 4-1	200S (300-Temple)	17000
407: SEGMENT 4-2	200S (300-Temple)	17000
408: SEGMENT 5-1	S Temple (400-300)	3500
409: SEGMENT 5-2	S Temple (400-300)	3500
410: SEGMENT 6-1	S Temple (300-Temple)	10000
411: SEGMENT 6-2	S Temple (300-Temple)	10000
412: SEGMENT 7-1	400 (200S-S Temple)	14000
413: SEGMENT 7-2	400 (200S-S Temple)	14000
414: SEGMENT 8-1	300 (400S-S Temple)	18000
415: SEGMENT 8-2	300 (400S-S Temple)	18000
416: SEGMENT 9-1	200 (400S-200S)	11000
417: SEGMENT 9-2	200 (400S-200S)	11000
418: SEGMENT 10-1	200 (200S-S Temple)	11000
419: SEGMENT 10-2	200 (200S-S Temple)	11000
420: SEGMENT 11-1	W Temple (400S-200S)	22000
421: SEGMENT 11-2	W Temple (400S-200S)	22000
422: SEGMENT 12-1	W Temple (200S-S Temple)	21000
423: SEGMENT 12-2	W Temple (200S-S Temple)	21000

Figure 13: AADTs with their corresponding Data Collection Measurements.

The SLC microscopic model was run 5 times to generate stochastic results for a meaningful and reliable calibration. Figure 14 shows the field volumes per segment (estimated from the AADTs) and the traffic volumes from the calibrated (VISSIM) model.

Figure 15 and Figure 16 show the calibration results of the SLC model in VISSIM for the PM peak hours (16:00-17:00) and (17:00-18:00), respectively. The r-square values indicate how closely the modeled traffic volumes match the field data. A higher r-squared value means a more reliable regression model; whereas the closer the regression model is to the ideal Y=X, more properly the simulated values reflect the field conditions. As Figures 15 and 16 show, the regression models and their r-square values document that the simulation results properly reflect the field conditions.

Time: 16:00-17:00		Time: 17:00-18:00	
Field Volume	VISSIM Volume	Field Volume	VISSIM Volume
1916	1800	1958	1812
2341	2253	2299	2171
1683	1656	1721	1757
2058	2168	2020	2139
755	497	771	401
922	727	906	725
987	868	1009	810
1206	1040	1184	1421
203	286	208	264
248	72	244	57
581	552	593	580
710	765	697	804
849	826	885	787
957	896	921	911
1091	1213	1138	1284
1231	1310	1184	1350
667	630	695	767
752	707	724	782
667	771	695	631
752	541	724	614
1334	1279	1391	1456
1504	1872	1447	1809
1273	1029	1327	1367
1436	879	1382	944

Figure 14: Field volumes and corresponding microsimulation (VISSIM) volumes.

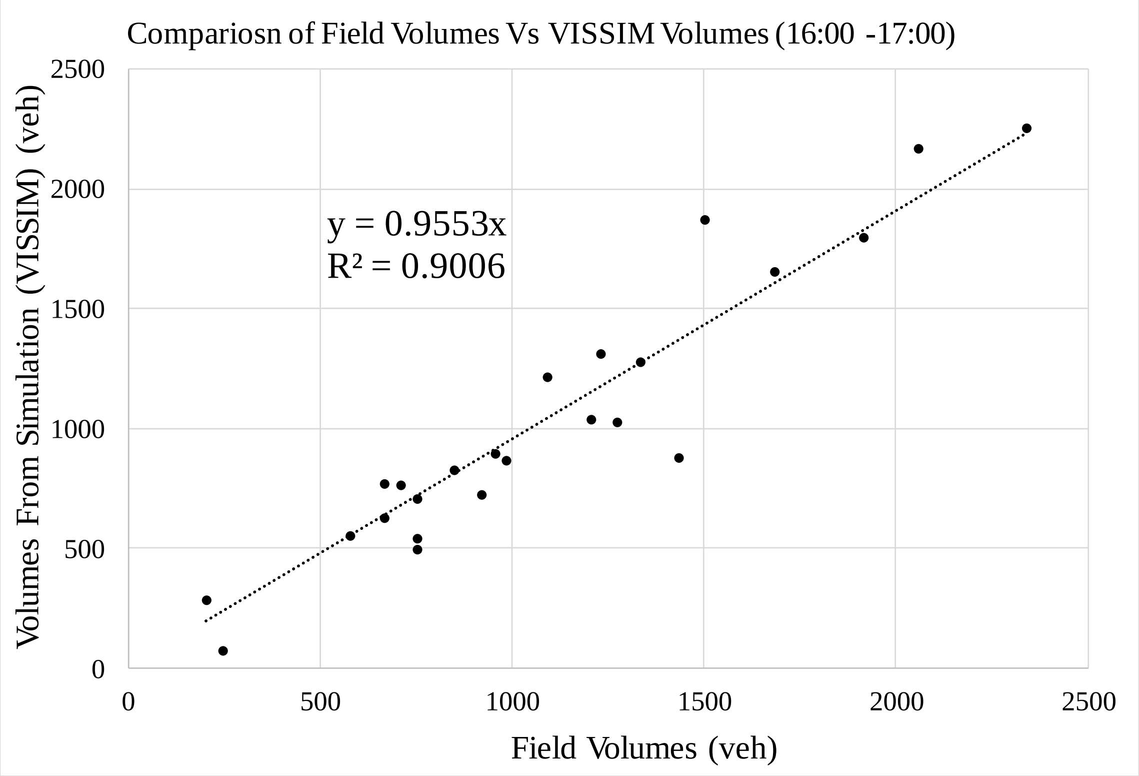


Figure 15: Volume calibration results (microsimulation-SLC) (16:00-17:00).

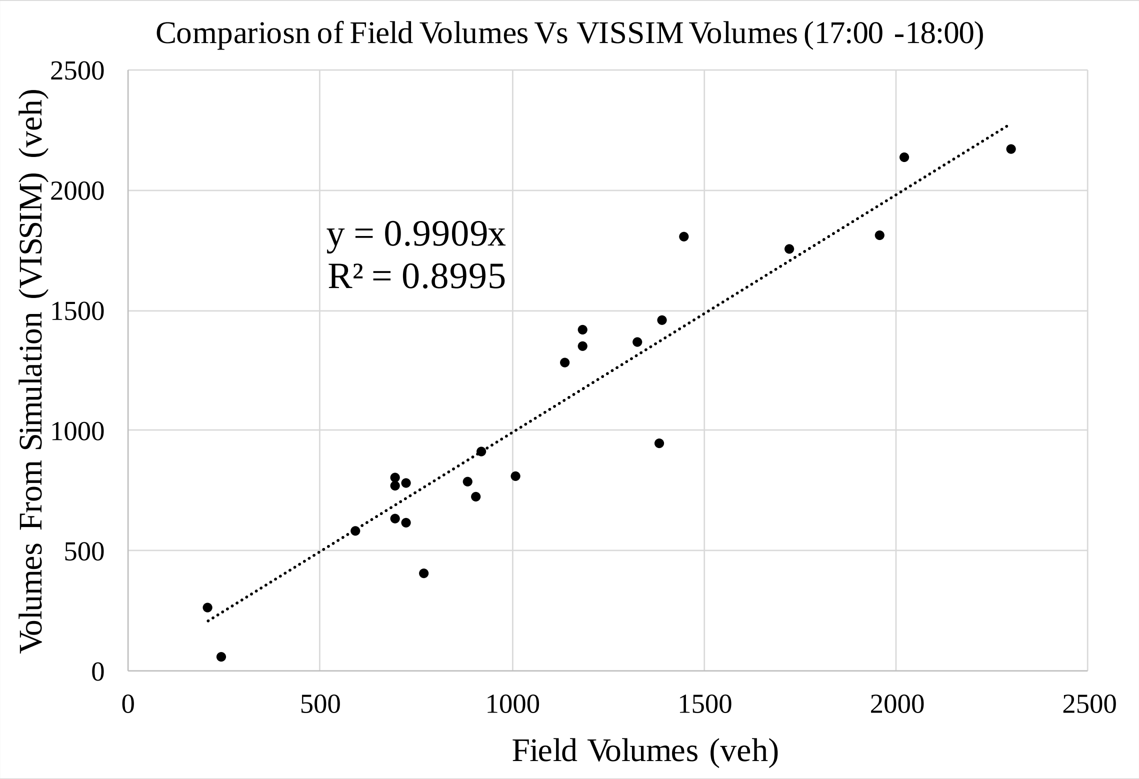


Figure 16: Volume calibration results (microsimulation-SLC) (17:00-18:00).

- Validation: Travel times, measured from the middle of an intersection to the middle of the next intersection, are used in the validation process. Such travel times are retrieved from Bing maps, Google maps, and Waze traffic application and then compared to the travel times extracted from vehicle travel time measurements in the microsimulation (VISSIM).

Vehicle travel time measurements in VISSIM (components of VISSIM modeling infrastructure) were created between each pair of intersections. In total, there are 68 such vehicle travel time measurements, which are used in the validation process. Figure 17 show an example of how travel time measurements are defined in VISSIM.

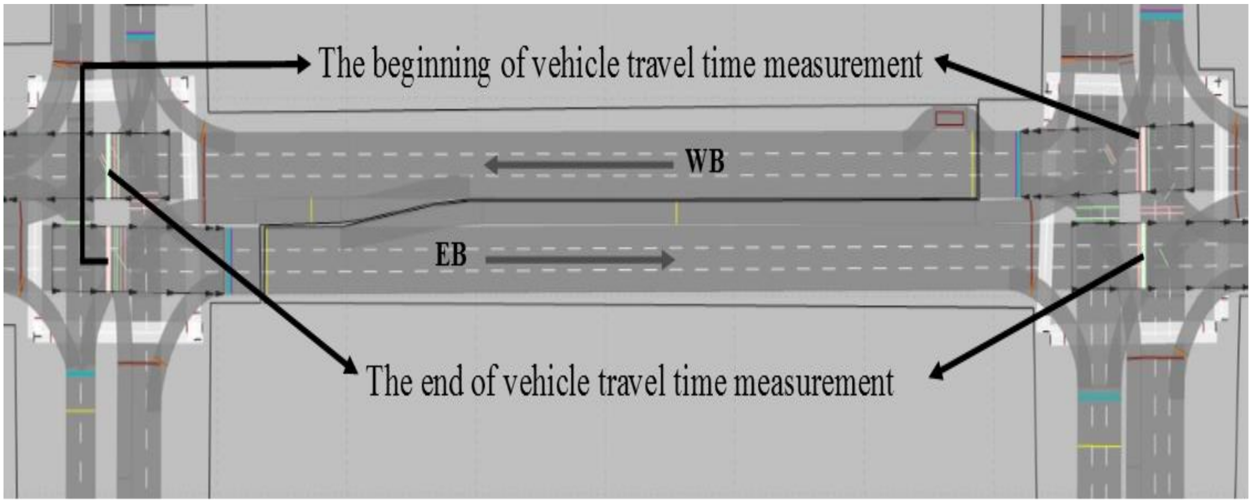


Figure 17: Travel time measurement between a pair of intersections.

The SLC model in VISSIM was run multiple times to generate random results for a reliable validation. Figure 18 and Figure 19 show the validation results of the SLC model in microsimulation for the PM peak period (16:00-17:00) and (17:00-18:00), respectively. As Figures 18 and 19 show, the regression models and their r-square values document that the simulation travel times are close to the travel times measured in the field. It should be noted here that the validation results are not as good as those from the calibration processes. However, this is a very common result of the calibration and validation processes and can be explained by two major reasons: 1. Traffic volumes are traffic characteristic that is usually much easier to match in simulation with the field values than the travel times (e.g. similar volumes can result in very different travel times), and 2. Field travel times were collected from various sources and during temporal intervals which are farther away from the times when the traffic volumes were collected in the field (e.g. while there were historical records of the AADTs, the travel times were collected in recent weeks).

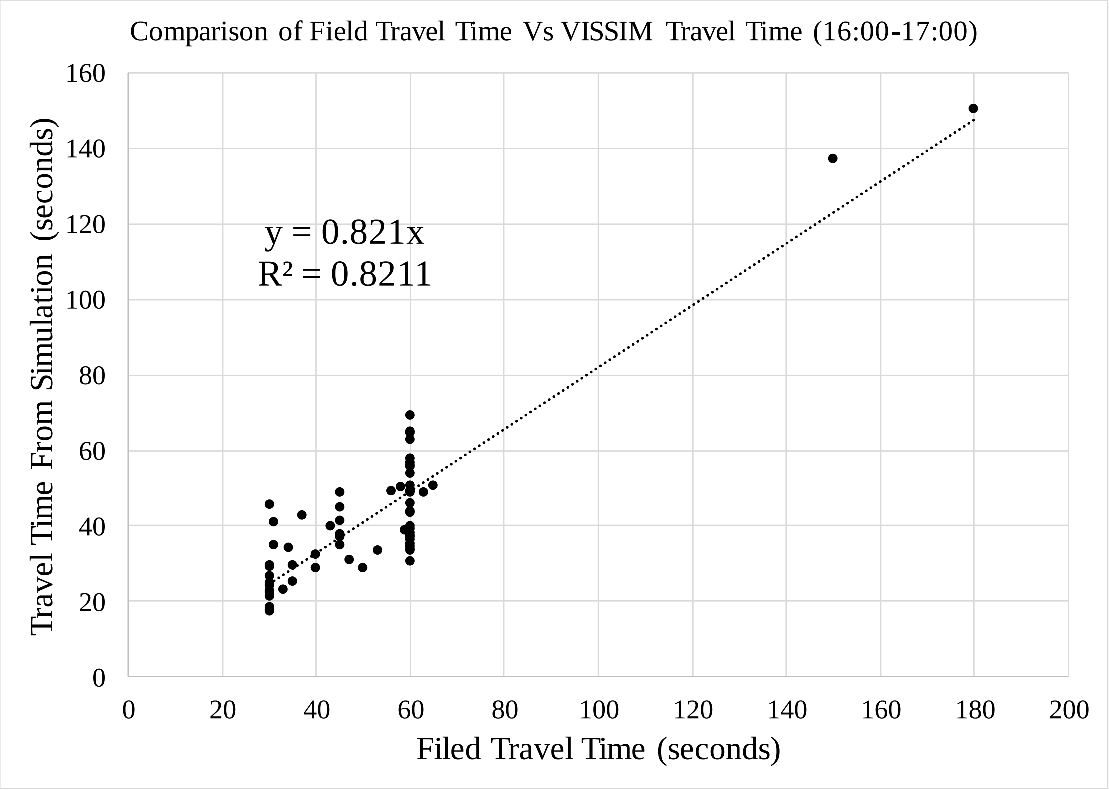


Figure 18: Travel-time validation results (microsimulation-SLC) (16:00-17:00).

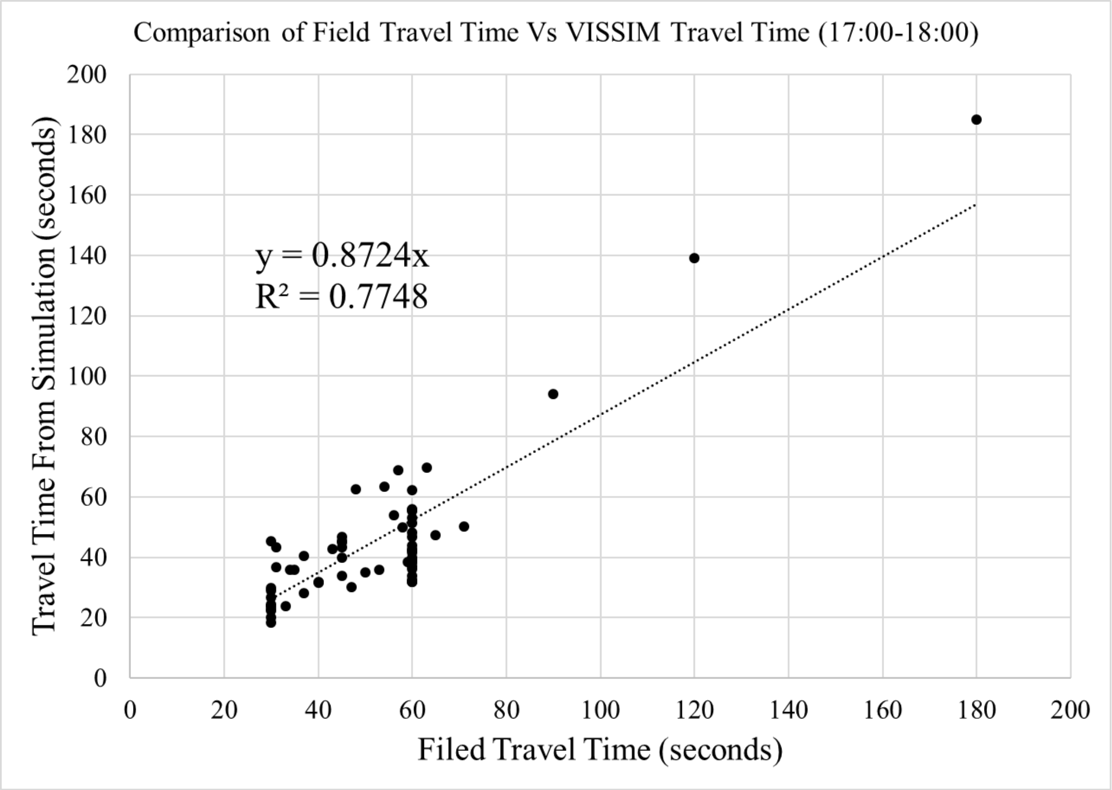


Figure 19: Travel-time validation results (microsimulation-SLC) (17:00-18:00).

4.1.2. Modeling of SLC in VISUM

Traffic macro simulation software (VISUM) is intended for evaluating broad, metro-wide, impacts of the scenarios proposed in task 2. SLC network was built in VISUM because this macro tools is compatible with VISSIM and this interface between micro and macro models will enable the FAU researchers to evaluate Complete Streets in a long-term planning framework, where future transportation demand levels will be considered in the macroscopic network, for relevant scenarios proposed in task 2.

Considering that the macroscopic modeling is based on metropolitan scale, the entire area of Salt Lake City was prepared for modeling. For this purpose the FAU researchers utilized an older VISUM model of the area of interest, which was previously built for another research project in Utah. The old model consisted of 1,350 traffic analysis zones (TAZs) and Origin-destination table for private transportation in 2008 (for a 3-hour PM peak period from 3:00 PM – 6:00 PM).

4.1.2.1.Modification of existing model

The FAU research team has performed a proper consistency check of the CBD area in VISUM and performed necessary modifications, such as: length of links were corrected, missing links were added, number of lanes and turning bays were modified, at each link, to match the current field conditions, etc. The main purpose of this consistency check is to ensure that the macro model is capable of producing truthful results; but also it was important to ensure consistency between micro and macro models. Figure 20 shows the part of the SLC CBD before and after such modifications. Figure 21 shows a position of the SLC CBD area the entire metropolitan network of the SLC region.

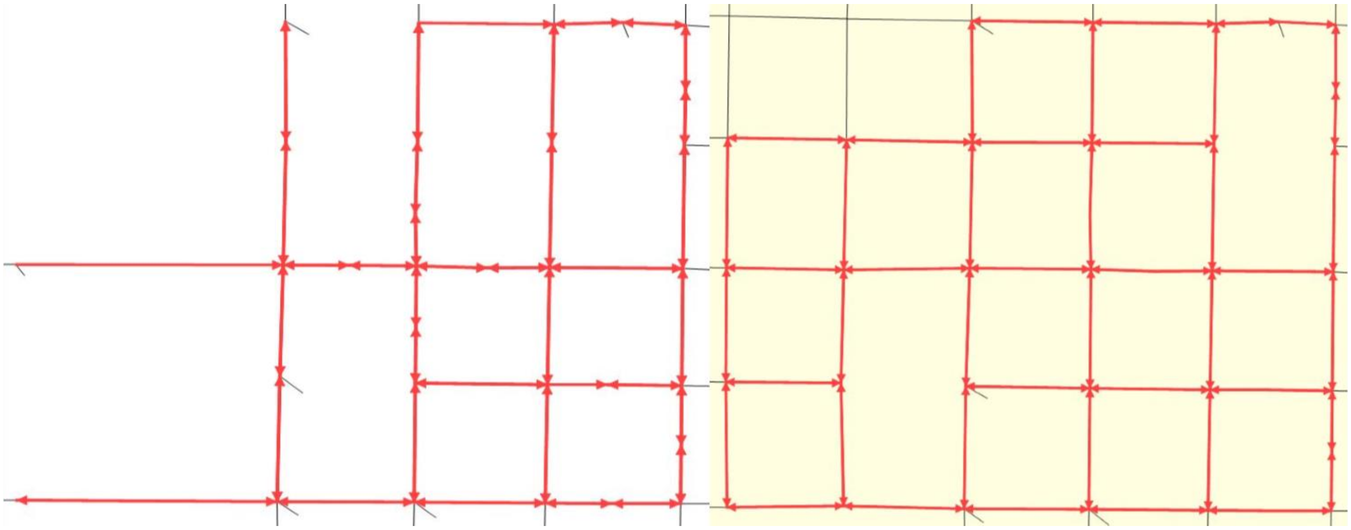


Figure 20: Downtown SLC in macro model (VISUM) before (left) and after (right) editing.

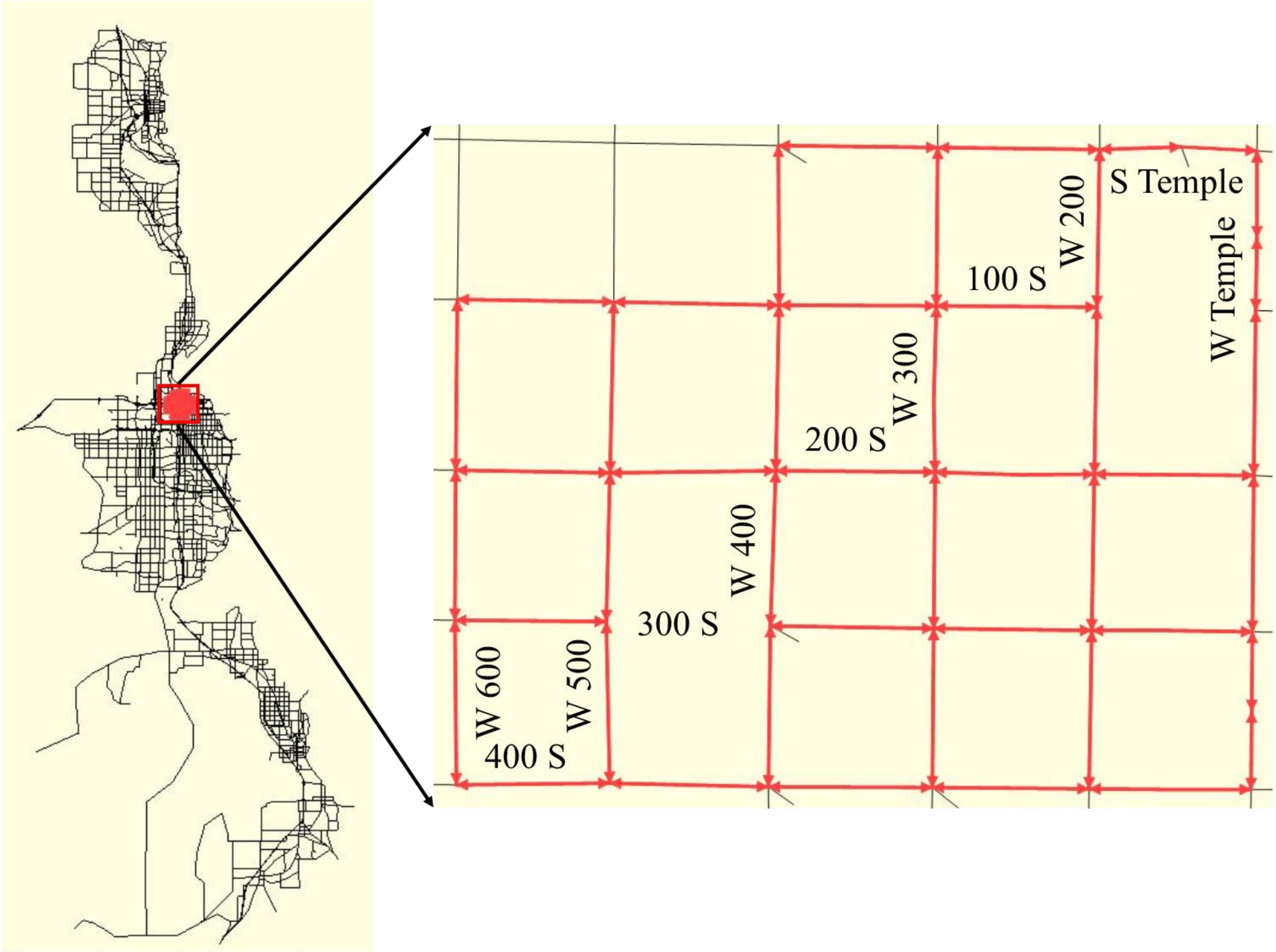
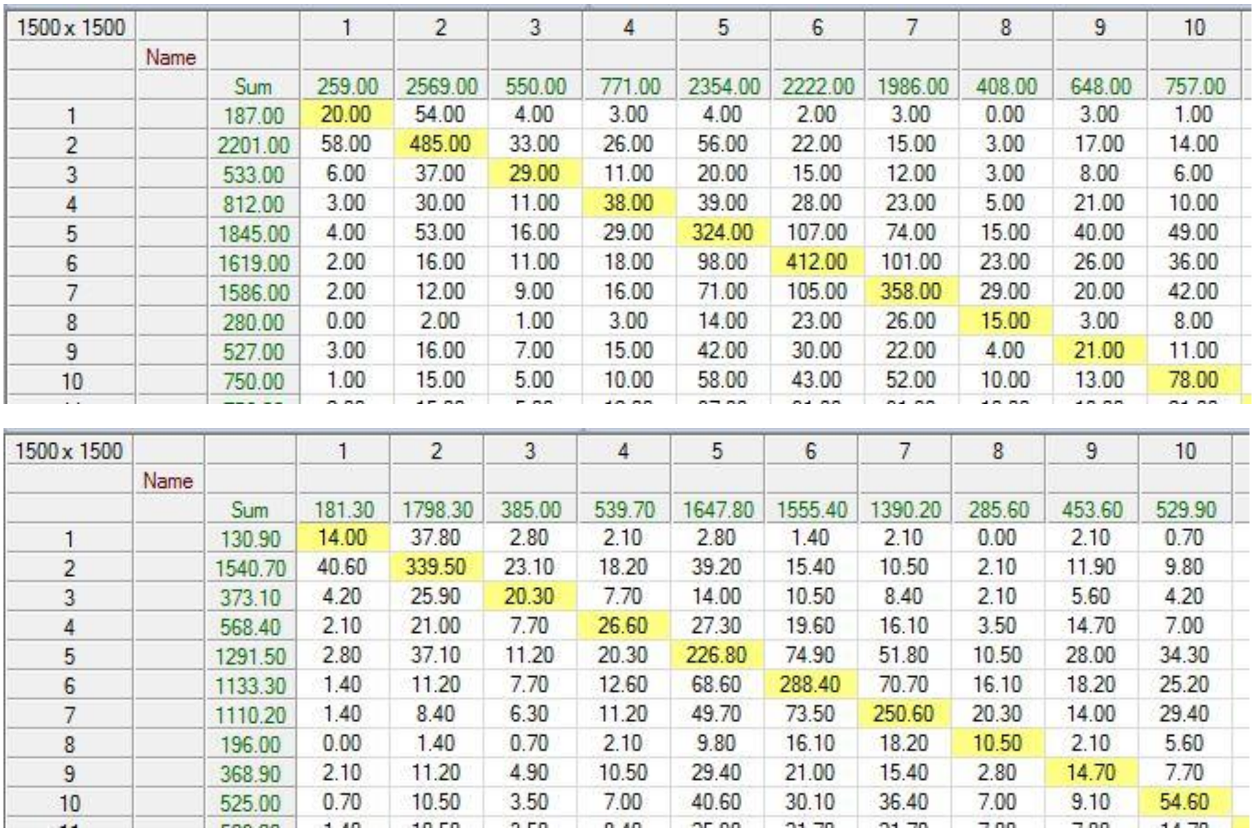


Figure 21: Position of downtown SLC in the entire macro (VISUM) model.

The next step of modifying the old macro model was to apply a fresh set of origin-destination flows, which reflected 2008 data as mentioned before in the section 3.4.2. The purpose of this task was to obtain an OD-matrix which will represent the same 2-hour period which was used for microsimulation modeling, for the year of 2015. The process of modifying the old OD-table was performed in two steps:

- Modifying the OD-table to represent the PM peak period from 4:00 PM – 6:00 PM.

This step was based on a simplistic traffic engineering assumption that ~70% of the 3-hour traffic volume in the OD-table (3:00 PM - 6:00 PM) happens during the desired 2-hour interval (4:00 – 6:00) PM. To accomplish this, each cell in the 1500*1500 matrix, shown in Figure 22, was multiplied by a factor of 0.7 (70%). Figure 22 illustrates a small part of the matrix before and after this multiplication was executed.



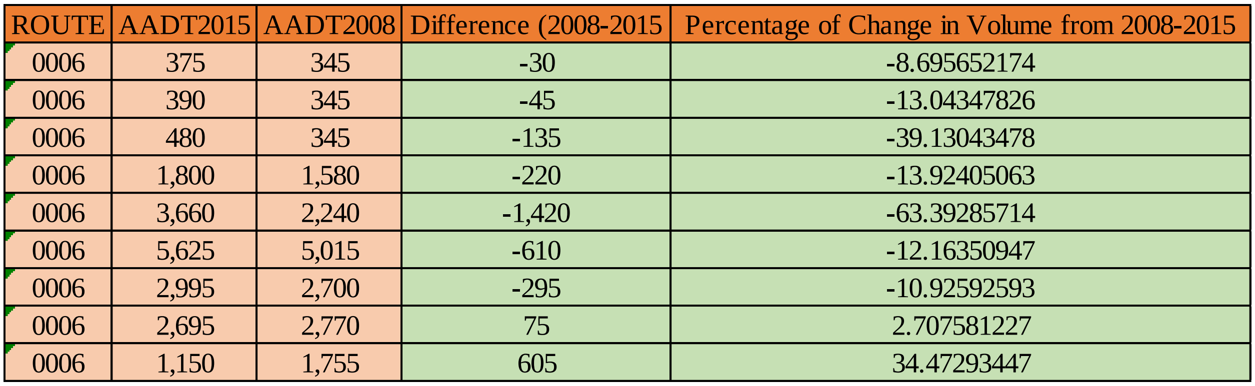
1500 x 1500			1	2	3	4	5	6	7	8	9	10
	Name											
		Sum	259.00	2569.00	550.00	771.00	2354.00	2222.00	1986.00	408.00	648.00	757.00
1		187.00	20.00	54.00	4.00	3.00	4.00	2.00	3.00	0.00	3.00	1.00
2		2201.00	58.00	485.00	33.00	26.00	56.00	22.00	15.00	3.00	17.00	14.00
3		533.00	6.00	37.00	29.00	11.00	20.00	15.00	12.00	3.00	8.00	6.00
4		812.00	3.00	30.00	11.00	38.00	39.00	28.00	23.00	5.00	21.00	10.00
5		1845.00	4.00	53.00	16.00	29.00	324.00	107.00	74.00	15.00	40.00	49.00
6		1619.00	2.00	16.00	11.00	18.00	98.00	412.00	101.00	23.00	26.00	36.00
7		1586.00	2.00	12.00	9.00	16.00	71.00	105.00	358.00	29.00	20.00	42.00
8		280.00	0.00	2.00	1.00	3.00	14.00	23.00	26.00	15.00	3.00	8.00
9		527.00	3.00	16.00	7.00	15.00	42.00	30.00	22.00	4.00	21.00	11.00
10		750.00	1.00	15.00	5.00	10.00	58.00	43.00	52.00	10.00	13.00	78.00

1500 x 1500			1	2	3	4	5	6	7	8	9	10
	Name											
		Sum	181.30	1798.30	385.00	539.70	1647.80	1555.40	1390.20	285.60	453.60	529.90
1		130.90	14.00	37.80	2.80	2.10	2.80	1.40	2.10	0.00	2.10	0.70
2		1540.70	40.60	339.50	23.10	18.20	39.20	15.40	10.50	2.10	11.90	9.80
3		373.10	4.20	25.90	20.30	7.70	14.00	10.50	8.40	2.10	5.60	4.20
4		568.40	2.10	21.00	7.70	26.60	27.30	19.60	16.10	3.50	14.70	7.00
5		1291.50	2.80	37.10	11.20	20.30	226.80	74.90	51.80	10.50	28.00	34.30
6		1133.30	1.40	11.20	7.70	12.60	68.60	288.40	70.70	16.10	18.20	25.20
7		1110.20	1.40	8.40	6.30	11.20	49.70	73.50	250.60	20.30	14.00	29.40
8		196.00	0.00	1.40	0.70	2.10	9.80	16.10	18.20	10.50	2.10	5.60
9		368.90	2.10	11.20	4.90	10.50	29.40	21.00	15.40	2.80	14.70	7.70
10		525.00	0.70	10.50	3.50	7.00	40.60	30.10	36.40	7.00	9.10	54.60

Figure 22: Sections of the matrix before (Top) and after (Bottom) refactoring (0.7).

- Modifying the OD-table to represent 2015 traffic volumes, instead of those from 2008.

The AADT data collected by the ATR stations were used to find a range of factors that represent the change in volume from 2008-2015. Figure 23 shows a very small sample from of 3584 AADT values, which were used to find the targeted factors to convert the 2008 ODs data to 2015 OD data.



ROUTE	AADT2015	AADT2008	Difference (2008-2015	Percentage of Change in Volume from 2008-2015
0006	375	345	-30	-8.695652174
0006	390	345	-45	-13.04347826
0006	480	345	-135	-39.13043478
0006	1,800	1,580	-220	-13.92405063
0006	3,660	2,240	-1,420	-63.39285714
0006	5,625	5,015	-610	-12.16350947
0006	2,995	2,700	-295	-10.92592593
0006	2,695	2,770	75	2.707581227
0006	1,150	1,755	605	34.47293447

Figure 23: Sample of changes in AADTs from 2008-2015.

This modification was performed by subtracting 2015 AADTs from 2018 AADTs, and then dividing the result by the AADT of 2008 and multiplying with a 100%.

Example: By taking the values from row 1 in table given in Figure 1, AADT of 2015 = 375 veh/day; AADT of 2008 = 345 veh/day.

Difference of these two AADTs: (2008-2015) = 345-375= -30 veh/day. The negative value means that the volume has been increased, on that specific route, by 30 vehicles per day.

Percentage of the change in volume is = (-30/345)*100% = -8.7%. This value means that a 2008 volume has been increased by 8.7% by the year of 2015.

In order to find a frequency with which a particular range of AADTs occur, the FAU research team developed a histogram that illustrates how frequently ranges of 20% of changes occur. Figure 24 presents such a histogram of AADT changes in 2008-2015 timeframe, for the routes with ATR stations in SLC. It can be concluded, from Figure 24, which most of the AADT changes are within +/- 20%. Thus, this was adopted as a prevailing traffic change which was applied to the relevant entry corridors in VISUM, which were previously identified. Consequently, new traffic demand would be distributed, through the traffic assignment process, to all of the minor links in the network. Specific changes in traffic demand, to each corridor, were driven by the need to properly calibrate and validation the macro model and bring it to the closest proximity both to the field and micromodel values (as explained in the next subsection).

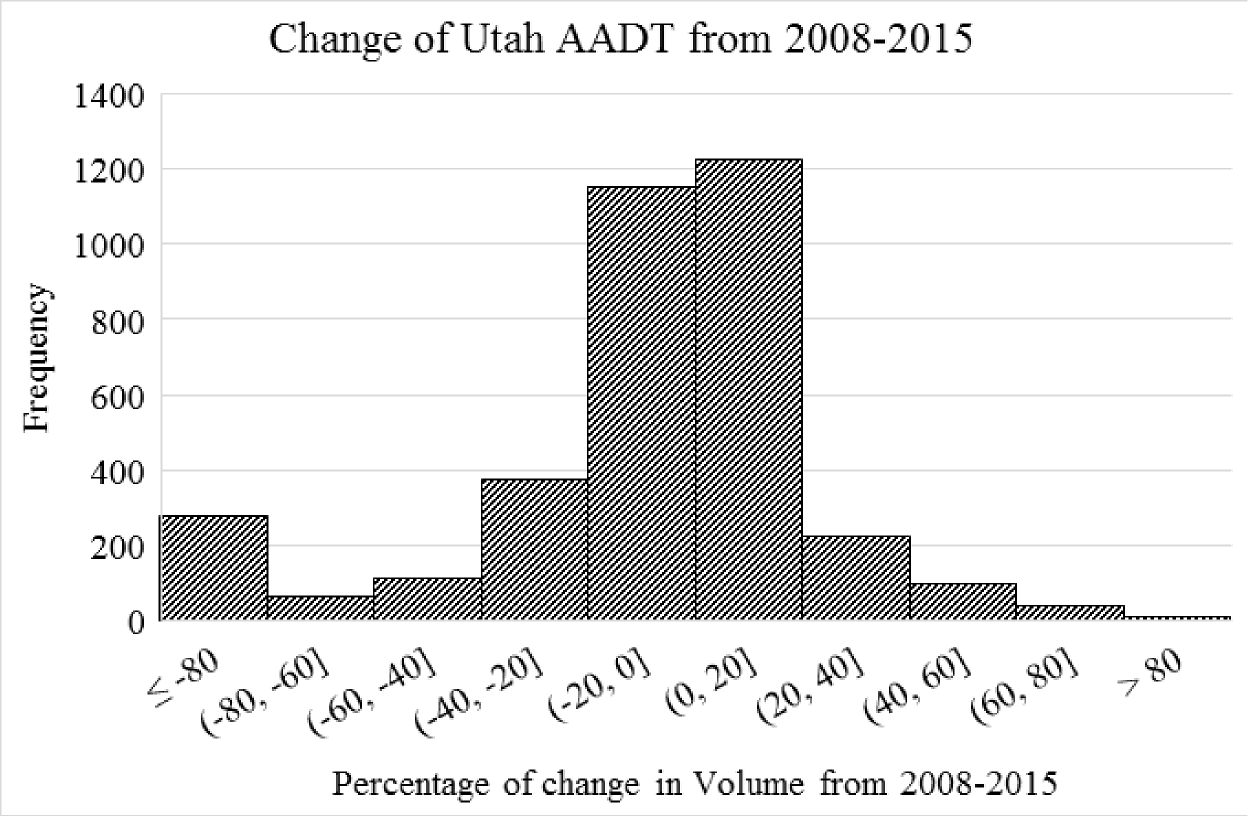


Figure 24: Frequency of AADT changes (given in 20% bins) 2008-2015.

4.1.2.2.Calibration and validation processes and results

The SLC CBD subnetwork shown in Figure 21 was calibrated and validated to match the field conditions. This section covers parameters of the macroscopic model that were used in the calibration and validation processes of SLC CBD network.

- Calibration: Traffic volumes from the field were compared to the traffic volumes from the VISUM, after 2015 OD travel demand has been applied and relevant traffic assignment procedure was executed. Figure 25 shows the results of comparing volumes from the field and VISUM.

- Validation: Travel times, measures between each pair of nodes, are used in the validation process. The same travel times, collected from Google and Bing maps, and Waze application were used to compare to the travel times extracted from macro model, after the traffic assignment was performed.

Data Collection Measurement	Location	16:00-17:00	17:00-18:00	16:00-18:00	16:00-18:00
		Field Volume	Field Volume	Field Volume	VISUM Volume
400: SEGMENT 1-1	400S (600-300)	1916	1958	3874	3435
401: SEGMENT 1-2	400S (600-300)	2341	2299	4640	3524
402: SEGMENT 2-1	400S (300-Temple)	1683	1721	3404	3224
403: SEGMENT 2-2	400S (300-Temple)	2058	2020	4078	4083
404: SEGMENT 3-1	200S (600-300)	755	771	1526	1199
405: SEGMENT 3-2	200S (600-300)	922	906	1828	2302
406: SEGMENT 4-1	200S (300-Temple)	987	1009	1996	2017
407: SEGMENT 4-2	200S (300-Temple)	1206	1184	2390	2187
408: SEGMENT 5-1	S Temple (400-300)	203	208	411	280
409: SEGMENT 5-2	S Temple (400-300)	248	244	492	110
410: SEGMENT 6-1	S Temple (300-Temple)	581	593	1174	1190
411: SEGMENT 6-2	S Temple (300-Temple)	710	697	1406	1415
412: SEGMENT 7-1	400 (200S-S Temple)	849	885	1734	1378
413: SEGMENT 7-2	400 (200S-S Temple)	957	921	1878	1444
414: SEGMENT 8-1	300 (400S-S Temple)	1091	1138	2229	1761
415: SEGMENT 8-2	300 (400S-S Temple)	1231	1184	2415	2522
416: SEGMENT 9-1	200 (400S-200S)	667	695	1362	1185
417: SEGMENT 9-2	200 (400S-200S)	752	724	1476	1522
418: SEGMENT 10-1	200 (200S-S Temple)	667	695	1362	1369
419: SEGMENT 10-2	200 (200S-S Temple)	752	724	1476	1368
420: SEGMENT 11-1	W Temple (400S-200S)	1334	1391	2724	2719
421: SEGMENT 11-2	W Temple (400S-200S)	1504	1447	2952	2950
422: SEGMENT 12-1	W Temple (200S-S Temple)	1273	1327	2601	2081
423: SEGMENT 12-2	W Temple (200S-S Temple)	1436	1382	2817	1771

Figure 25: Field and macro-model (VISUM) volumes.

Figure 26 shows the calibration results of the SLC CBD model in VISUM for the PM peak period (16:00-18:00). As Figure 26 shows, the regression model and r-square value for traffic volumes document that the volumes from VISUM are close to those measured in the field. Similarly, Figure 27 shows the validation results of the SLC CBD model in VISUM for the PM peak period (16:00-18:00). The regression model and r-square value indicate again a relatively close match between the field travel times and those extracted from the macroscopic model once the relevant traffic assignments were executed. Actually, the travel time matches between field and macroscopic data are closer than those of the traffic volumes. There is no logical explanation for this anomaly – this is most likely just a coincidence.

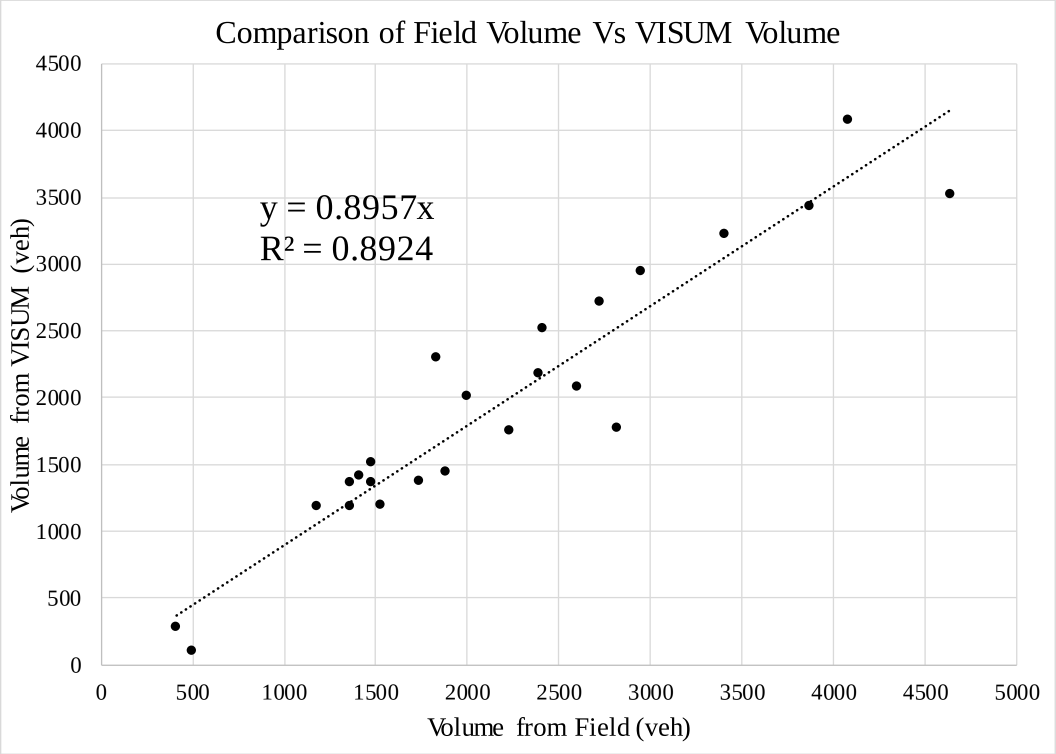


Figure 26: Volume calibration results (macro model-SLC) (16:00-18:00).

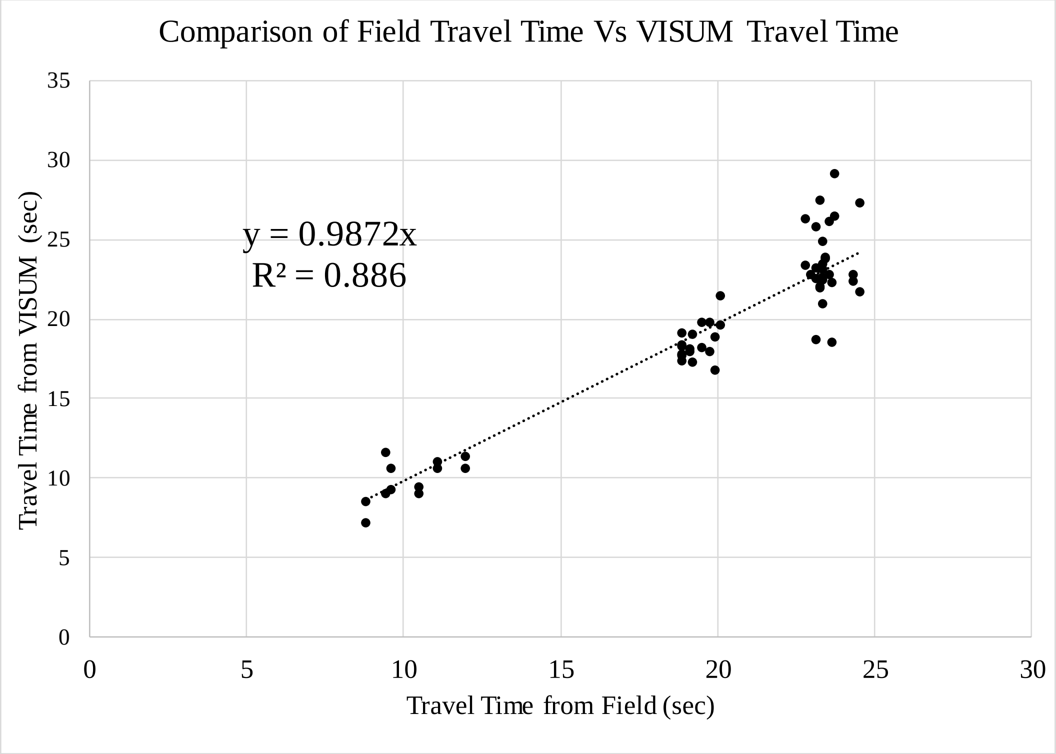


Figure 27: Travel-time validation results (macro model-SLC) (16:00-18:00).

4.2. Network of Central Broward County (CBC)

The Central Broward comprises the unincorporated areas of central Broward County and is bordered by I-95 in the east, the Florida Turnpike and State Road 7 in the west, NW 15 Court on the north side, and the New River on the south side. The total residing population of this unincorporated area is approximately 24,000, but the daytime population increases significantly due to the four major thoroughfares, several schools, and a variety of businesses. The CBC network was modeled both in microscopic and macroscopic models - VISSIM and VISUM, respectively. In order to execute scenarios proposed in task 2, two of the main urban arterials, Sunrise Blvd. and Broward Blvd., were selected for modeling, as separate VISSIM files. On the other hand, the entire Central Broward County network was modeled in VISUM. The reason behind this decision is to ensure that impact of various scenarios (executed on micro levels) is taken in consideration on the entire network level.

4.2.1. Modeling of CBC in VISSIM

Traffic microsimulation software (VISSIM) will be used extensively to evaluate scenarios proposed in task 2. CBC network was built in VISSIM to ensure transferability of the results among various modeling efforts of this project. Two major E-W arterials (Sunrise Blvd and Broward Blvd) were modeled separately to increase accuracy and ease the process of implementing scenarios for Complete Streets.

4.2.1.1.Modeling of Sunrise Boulevard

The FAU research team used a previously built VISSIM model of the entire Central Broward network to extract the corridor of interest - Sunrise Blvd, from State Road 7 to the NE 20th Ave. The remaining part of Sunrise Blvd to the east end of the corridor (from NE 20th Ave to A1A) was built and connected to the existing part as shown in Figure 28. The FAU research team built this additional section of the Sunrise Blvd to precisely match existing field road geometry. In addition, geometry from the previously built model was checked and corrected as needed.

Figure 28: Extraction and expansion of the Sunrise Blvd microsimulation model.

- Vehicle Inputs and Routing Decisions

In the next step of preparation of the CBC micro model, volumes and routing decisions were coded by using balanced 15-minute turning movement counts, which were automatically populated for all major traffic movements on Sunrise Blvd. For this purpose, the FAU research team developed Python scripts, which use consistently organized and filled excel spreadsheets with balanced turning movement counts and volumes as inputs to automatically fill the microscopic model. One should note here that only EB and WB movements were modeled using the turning movement counts balancing sheet. The side street volumes required additional processing, which is explained in following sections.

Considering that historic data of green splits for all of the signalized intersections on Sunrise Blvd was available (downloaded from ATMS.now), it was possible to utilize these data to adjust vehicle inputs and routing decisions of the side-street turning movements to match recorded average green times. The logic behind this approach is that the green time of each phase handling side-street traffic is based on vehicle actuations of the side-street detectors. Considering that relevant green times can be calculated from split history data (as the average value of green time in peak hour for a particular phase on a particular intersection), it is possible to estimate an exact number of vehicles that have utilized those green times. The green split historical data were available for more than a year but data from April 27, 2017 were used as this was the date when the FAU research team performed probe vehicle data collection on the Sunrise Blvd (during an AM peak hour (8:00 AM - 9:00 AM). The same date and time was used as a reference interval for calibration purposes.

In most cases, it was possible to estimate an accurate traffic volumes for left and through movements from the side streets. An estimated turning volume is calculated (as shown in Equation 2) based on the saturation flow/(time gap between vehicles passing through an intersection), cycle length, and number of lanes. The FAU research team used CCTV (Closed-Circuit TeleVision) cameras (where possible) to estimate a reliable value for the saturation flow rate. These estimations were done only for routing decisions of left and through movements. Routing decisions (estimated turning volumes) for right movements were calculated based on the proportions of right turns in the total approach volume, which was information obtained from the volume balancing sheet.

$$Estimated\ Turning\ Volume = \left\{\left[\frac{Green - 12.33s}{tg}\right] + 5\right\} * \frac{3600}{CL} * Nl \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where,

Estimated Turning Volume – volume which has been processed during given green time [veh/h],

Green – green time calculated from split history data [s],

tg – the time gap between two vehicles as they pass over the stop line after green is ON [s],

CL – cycle length [s],

Nl – number of lanes served by a particular phase.

After the side-street routing decisions were calculated by using the abovementioned approach, the vehicle inputs for side streets (total number of vehicles which enter the network from side streets) were calculated as a sum of routing decisions (whose values served to denote both percentage of turning movements and actual turning volumes).

Figure 29 shows a prepared MS Excel Sheet that was utilized to populate the microsimulation model for Sunrise Blvd. This sheet combines balanced turning movement counts for major-street movements and green-time-estimated turning movements for the side streets.

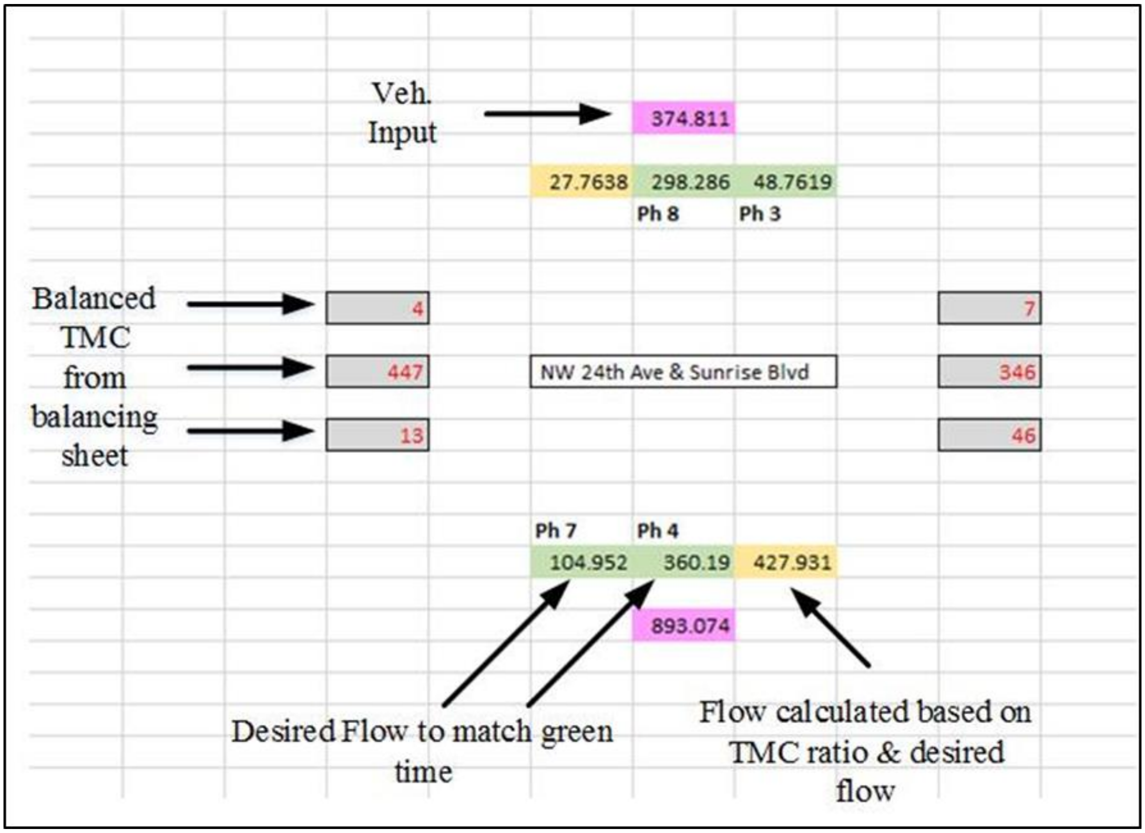


Figure 29: A volume balancing with recalculation of side-street volumes.

- Signal Timings in VISSIM

Signal timings of the Sunrise Blvd model were based on signal timing parameters obtained from FDOT. These timings served as a basis to fill VISSIM RBC's signal timing database but were amended based on the recorded data from the field for April 27, 2017. Based on these field signal timings it was possible to determine which patterns were exactly active on each signalized intersection.

- Adjustment of saturation flows in VISSIM

In order to model realistic behavior of drivers on Sunrise Blvd, the FAU research team modeled saturation flow rates based on field observations (from available (CCTV) cameras). The saturation flow rate defines the number of vehicles that can discharge from an intersection (in this case controlled by a signal), during an hour of green time. Additional parameters, e.g. prevailing traffic speed, share of heavy vehicles, or number of lanes can affect the saturation flow rate. In VISSIM, the FAU research team defined the saturation flow rates by combining the parameters of Wiedeman 74 driving behavior model (additive and multiplicative components of the safety distance were adjusted). These saturation flow rate adjustments ensured that vehicles are passing through intersection with the same efficiency as in the field conditions.

- Calibration and validation processes and results

The model was calibrated by using following field data: (i) Mid-block traffic volumes from Microwave Vehicle Detection System (MVDS); and (ii) Turning movement counts (TMC) (obtained from historic unsynchronized traffic data collection efforts). Once the calibration task was completed, the model was validated through comparisons of Average Green Times, and Travel times obtained both from probe vehicle data and the Regional Integrated Transportation Information System (RITIS). The results of model calibration are summarized in Table 11. One should note that the R^2 values for both calibration and validation were acceptable.

Table 11: Network Model Calibration Results (8:00 AM – 9:00).

Calibration results	MVDS volume	TMC
R^2	0.99	0.95

In addition to summarized results, we provide calibration results in form of multiple graphs to give readers opportunity to better understand our results and match with the field data.

The MVDS volume graph, displayed in Figure 30, shows both EB and WB directional volumes from the field and simulation. As it can be observed from Figure 30, volumes collected on particular day (April 27, 2017) in peak hour (8:00-9:00 A.M.) are highly correlated with the modeled volumes (R^2 value of 0.99).

Turning movement counts calibration results can be observed in Figure 31. The scatter plot shows that even though various turning movement counts were collected through multiple years, the calibration results are quite good (R^2 value of 0.95). Noteworthy, only ratios for the right movements were utilized in volume and routing decisions modeling, while side-street green times and estimated turning volumes were used as primary source of information.

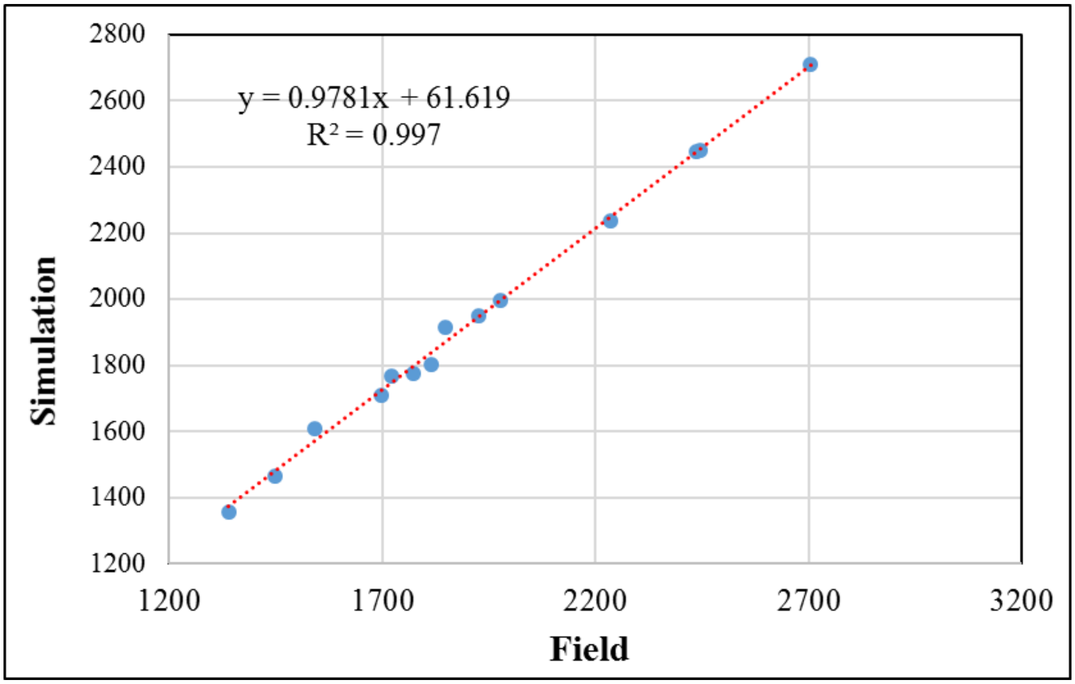


Figure 30: MVDS-Volumes calibration results - Sunrise Blvd.

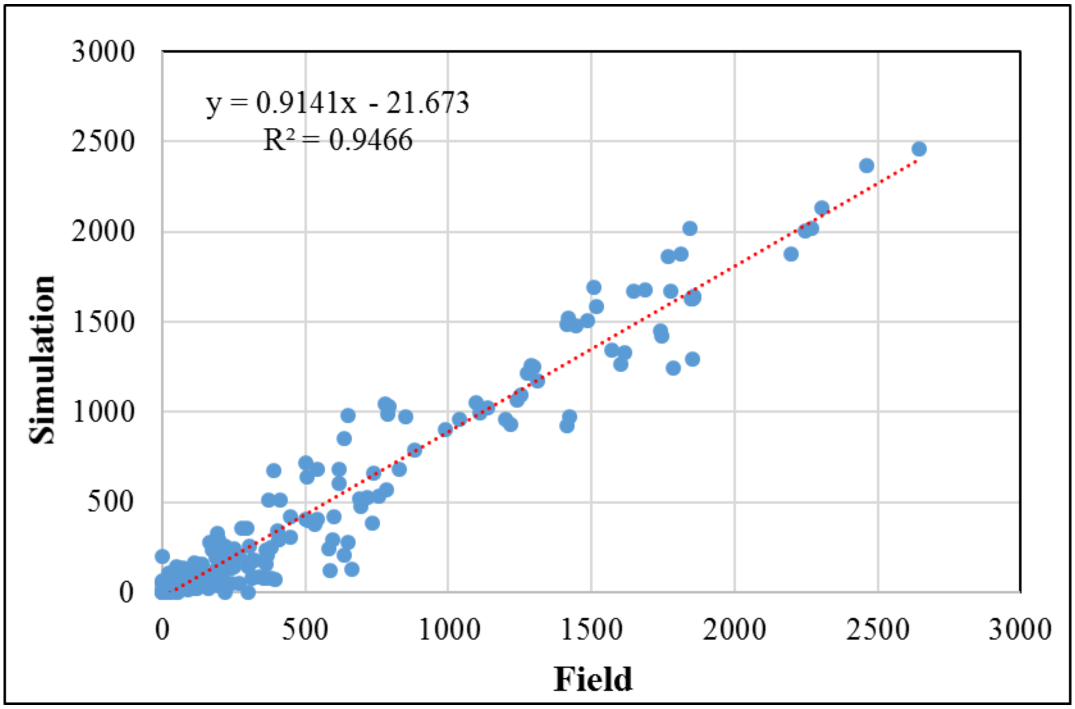


Figure 31: Turning-Movement-Count calibration results - Sunrise Blvd.

The correlation between field green times (calculated from split history data) and green times obtained from VISSIM output file (.lsa file) is utilized for model validation. The results show a R^2 value of around 0.99, as observable in Figure 32. These results mean that almost all of the phases in the model receive nearly the same green time as they got in the field on that particular day (April 27, 2017), which was used as a representative day for calibration purposes. On the x-axis, one can see field green time (in seconds), while the y-axis shows green times in simulation.

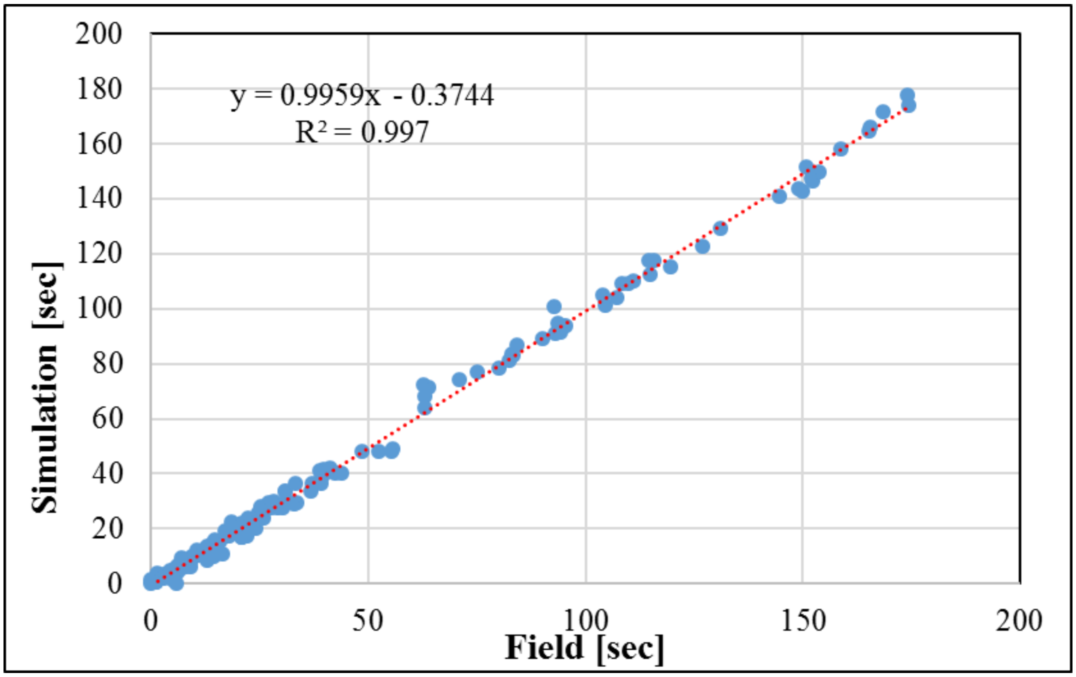


Figure 32: Average-green-time validation results - Sunrise Blvd.

4.2.1.2.Modeling of Broward Boulevard

The Broward Blvd encompasses 19 signalized intersections (with addition of one railroad crossing), from State Road 7 (West side) to Federal Hwy (East side), as shown in Figure 33.

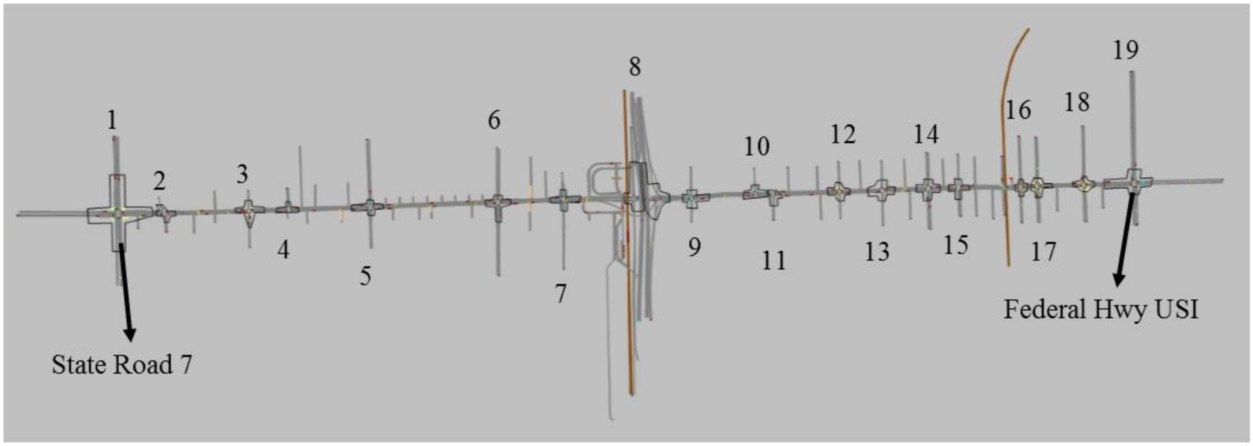


Figure 33: Broward Blvd. microsimulation (Vissim) Model.

- Signal timing plans

The FAU research team used the existing time of day (TOD) signal timing plans at the time of building the model. The TOD signal timing data were provided by Broward County Traffic Engineering Division (BCTED) in two forms: 1. detailed PDF files of signal timings, pattern data and sketches of detectors and signal heads for each intersection from the field, and 2. a Synchro file containing all of the signalized intersections for the entire corridor. Signal timings from the Synchro file for each intersection were compared with values in PDF files and the Synchro file was corrected for minor inconsistencies. Signal timings from Synchro were exported to VISSIM's RBC (Ring Barrier Controller) platform and checked for discrepancies.

- Calibration and validation processes and results

VISSIM model was developed for 18 hours in total, from 6AM until Midnight. Model was calibrated based on a Turning Movement Counts (TMCs) collected by BCTED and Florida Department of Transportation (FDOT). TMCs were available only for peak periods (7AM-9AM, 11AM-1PM and 4PM-6PM) whereas the rest of the traffic flaws were approximated from the traffic counting stations available from FDOT's Florida Traffic Online Interactive Map. VISSIM's traffic inputs and routing decisions were used to properly introduce TMCs and other traffic volumes in the Broward Blvd model. Where it was necessary, manual adjustments of vehicle inputs were made to replicate field conditions correctly.

The calibration process was performed manually, by adjusting speed distributions, implementation of reduced speed areas, desired speed decisions, and basic driving behaviors parameters available in VISSIM. Validation of the model was performed through a comparison of modeled and field travel times, measures between intersection corridor segments. Field travel times were collected by FDOT, using a GPS device, installed in a vehicle. After significant amount of model fine-tuning, both calibration and validation results showed a very close match between outputs from the model and the data collected in the field. The FAU research team has recently minimized the time of the simulation from 18 hours to 1 hour from (8:00 AM – 9:00 AM) in order to keep the consistency between the two models in VISSIM Sunrise Boulevard and Broward Boulevard.

4.2.2. Modeling of CBC in VISUM

CBC model was built in macroscopic simulation (VISUM) to enable researchers to comply with a long-term planning process for urban network infrastructure, where future transportation demands need to be applied in a number of relevant scenarios proposed in task 2.

Considering that the macroscopic modeling should take into account impact of the Complete Street scenarios (applied on corridor levels on Sunrise Blvd and Broward Blvd) on the network level, the entire Central Broward County was modeled in the macroscopic model. The CBC area includes four major E-W urban arterials (Oakland Park Blvd., Sunrise Blvd., Broward Blvd., and Davie Blvd.) which connect the major State Road 7 (441) in the west to the Federal Hwy US1 in the east side of the county. The FAU research team has built, calibrated, and validated the CBC model in VISUM by following the below mentioned steps which are explained later under this section:

- Contact Broward Metropolitan Planning Organization (MPO) to acquire a shape file (.shp) with the traffic analysis zones in Broward County as well as a relevant OD-table.
- Build a geometrical model for Broward County, considering that the old model included only links (no nodes, zones or connectors). Also the previous model (based on the shape files) contained only the main roads while all of the streets inside the Central Broward County had to be created from scratch.
- Connect all of the elements of the VISUM model to ensure that traffic flows function correctly, which is proved by running a successful traffic assignment.
- Perform sub-network generation process in VISUM to cut out the CBC area from the entire Broward County model. By performing this step we ensured that we have a model ready to be calibrated and validated.
- Calibrate and validate two of the major E-W arterials (Sunrise Blvd. & Broward Blvd.) and the macroscopic CBC model. The calibration and validation processes were done by comparing volumes & travel times from simulations with their field counterparts.

4.2.2.1. Acquisition of the CBC shape file and OD tables

The Broward County MPO provided the FAU research team with a shape file that includes 953 TAZs located within the Broward County. A .mat file that includes OD tables for AM peak period (6:00-8:59) was also provided by the MPO.

The shape file was readable by VISUM, as shown in Figure 34, whereas the .MAT file was opened using Cube planning software and the data were manually transferred to VISUM. A resulting VISUM's OD matrix consisted of 953*953 cells, which are partially shown in Figure 35.

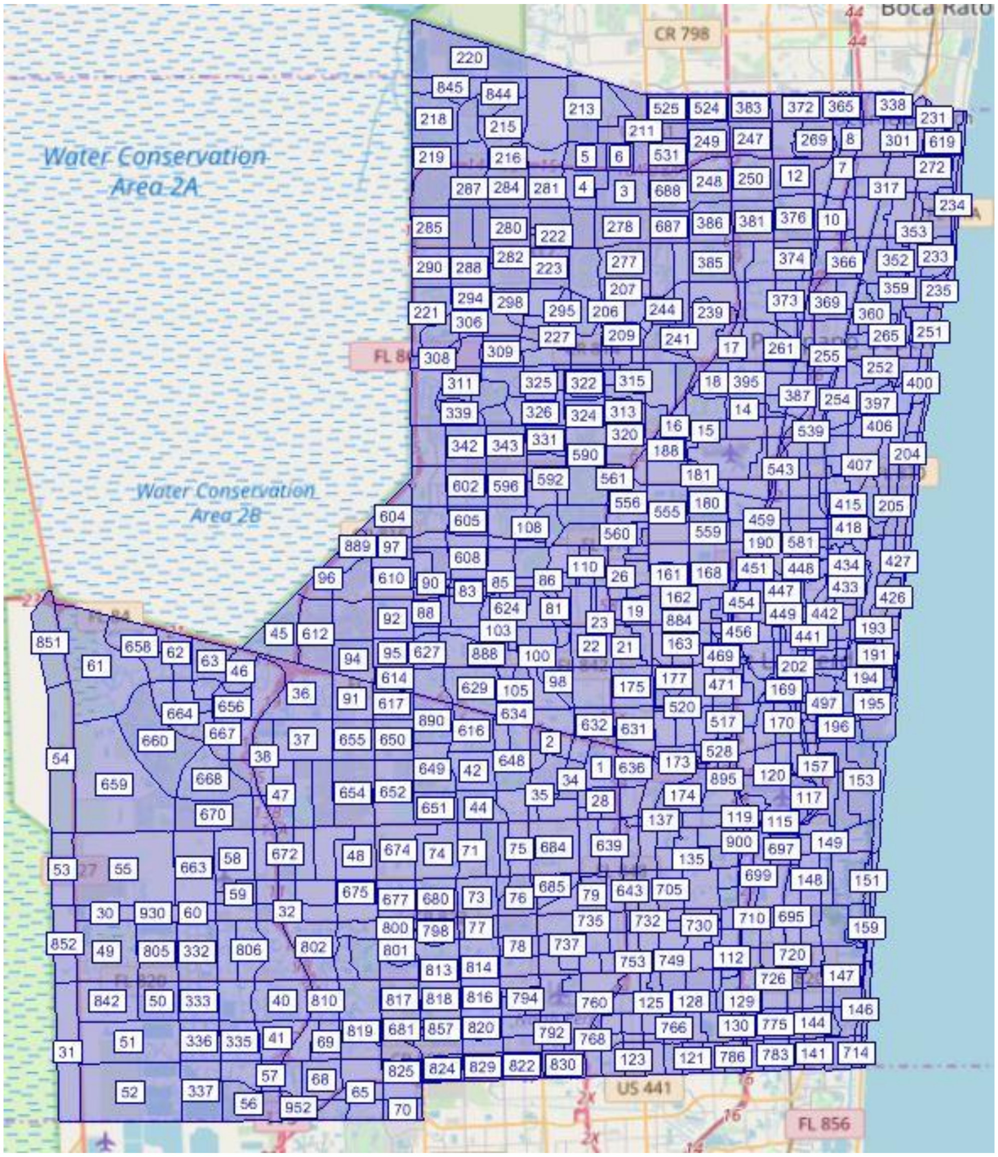
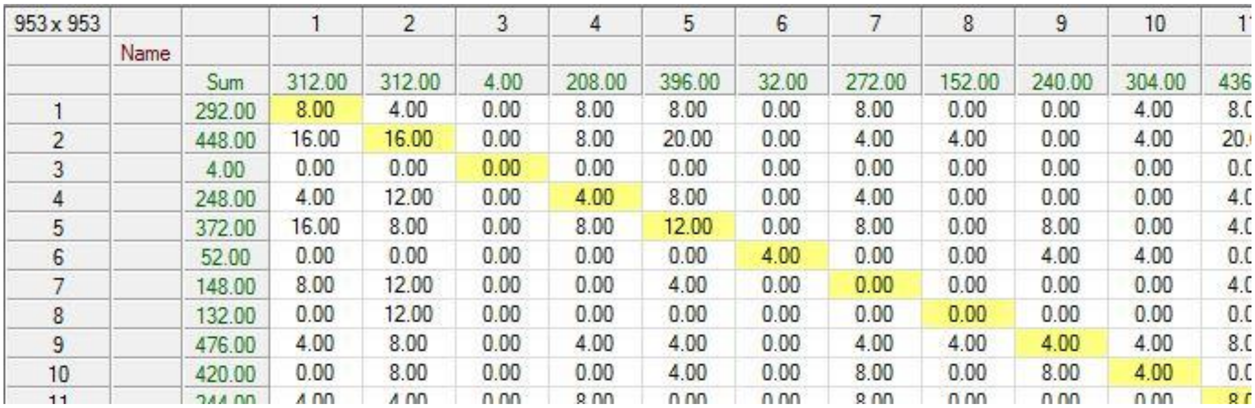


Figure 34: Traffic analysis zones in Broward County.



953 x 953			1	2	3	4	5	6	7	8	9	10	1
	Name												
		Sum	312.00	312.00	4.00	208.00	396.00	32.00	272.00	152.00	240.00	304.00	436
1		292.00	8.00	4.00	0.00	8.00	8.00	0.00	8.00	0.00	0.00	4.00	8.
2		448.00	16.00	16.00	0.00	8.00	20.00	0.00	4.00	4.00	0.00	4.00	20.
3		4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
4		248.00	4.00	12.00	0.00	4.00	8.00	0.00	4.00	0.00	0.00	0.00	4.
5		372.00	16.00	8.00	0.00	8.00	12.00	0.00	8.00	0.00	8.00	0.00	4.
6		52.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	4.00	4.00	0.
7		148.00	8.00	12.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	4.
8		132.00	0.00	12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
9		476.00	4.00	8.00	0.00	4.00	4.00	0.00	4.00	4.00	4.00	4.00	8.
10		420.00	0.00	8.00	0.00	0.00	4.00	0.00	8.00	0.00	8.00	4.00	0.
11		244.00	4.00	4.00	0.00	8.00	0.00	0.00	8.00	0.00	0.00	0.00	8.

Figure 35: A reduced OD-matrix for Broward County.

In order to achieve consistency between the microscopic models in VISSIM (Sunrise and Broward Blvds) and the macroscopic model in VISUM, every cell in the 953*953 matrix was multiplied by a factor to interpolate an appropriate number of trips for a peak hour (8:00 a.m. – 9:00 a.m.) from an OD table developed for a three-hour peak period (6:00 a.m. – 9:00 a.m.). To accomplish this interpolation we utilized a factor of 0.45, which was found after analyzing the entire 2017 traffic data on Sunrise Blvd (in other words ~ 45% of the morning traffic (6:00 a.m. – 9:00 a.m.) occurs during the last hour).

953 x 953			1	2	3	4	5	6	7	8	9	10	1
	Name												
		Sum	140.40	140.40	1.80	93.60	178.20	14.40	122.40	68.40	108.00	136.80	196
1		131.40	3.60	1.80	0.00	3.60	3.60	0.00	3.60	0.00	0.00	1.80	3.
2		201.60	7.20	7.20	0.00	3.60	9.00	0.00	1.80	1.80	0.00	1.80	9.
3		1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
4		111.60	1.80	5.40	0.00	1.80	3.60	0.00	1.80	0.00	0.00	0.00	1.
5		167.40	7.20	3.60	0.00	3.60	5.40	0.00	3.60	0.00	3.60	0.00	1.
6		23.40	0.00	0.00	0.00	0.00	0.00	1.80	0.00	0.00	1.80	1.80	0.
7		66.60	3.60	5.40	0.00	0.00	1.80	0.00	0.00	0.00	0.00	0.00	1.
8		59.40	0.00	5.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
9		214.20	1.80	3.60	0.00	1.80	1.80	0.00	1.80	1.80	1.80	1.80	3.
10		189.00	0.00	3.60	0.00	0.00	1.80	0.00	3.60	0.00	3.60	1.80	0.
11		109.80	1.80	1.80	0.00	3.60	0.00	0.00	3.60	0.00	0.00	0.00	3.

Figure 36: A part of reduced Broward County OD-matrix after refactoring (0.45).

4.2.2.2.Building Model of Broward County in VISUM

The FAU research team has built a macroscopic model of the entire Broward County. The model includes only major roads (similarly to how most of the macroscopic models are built) in the parts of Broward County which are not in the CBC network, whereas all the roads and residential streets in the CBC network are included (see Figure 37). The reason behind this approach is that we wanted to have a model with more details for the CBC network than what is usually available in macroscopic models. This will ensure that whatever Complete Street's effects are created they can be observed and evaluated in detail macro-modeled CBC network. Figure 37 shows the entire Broward County with its major roads modeled in VISUM, as well as the CBC subnetwork with its detailed modeling.

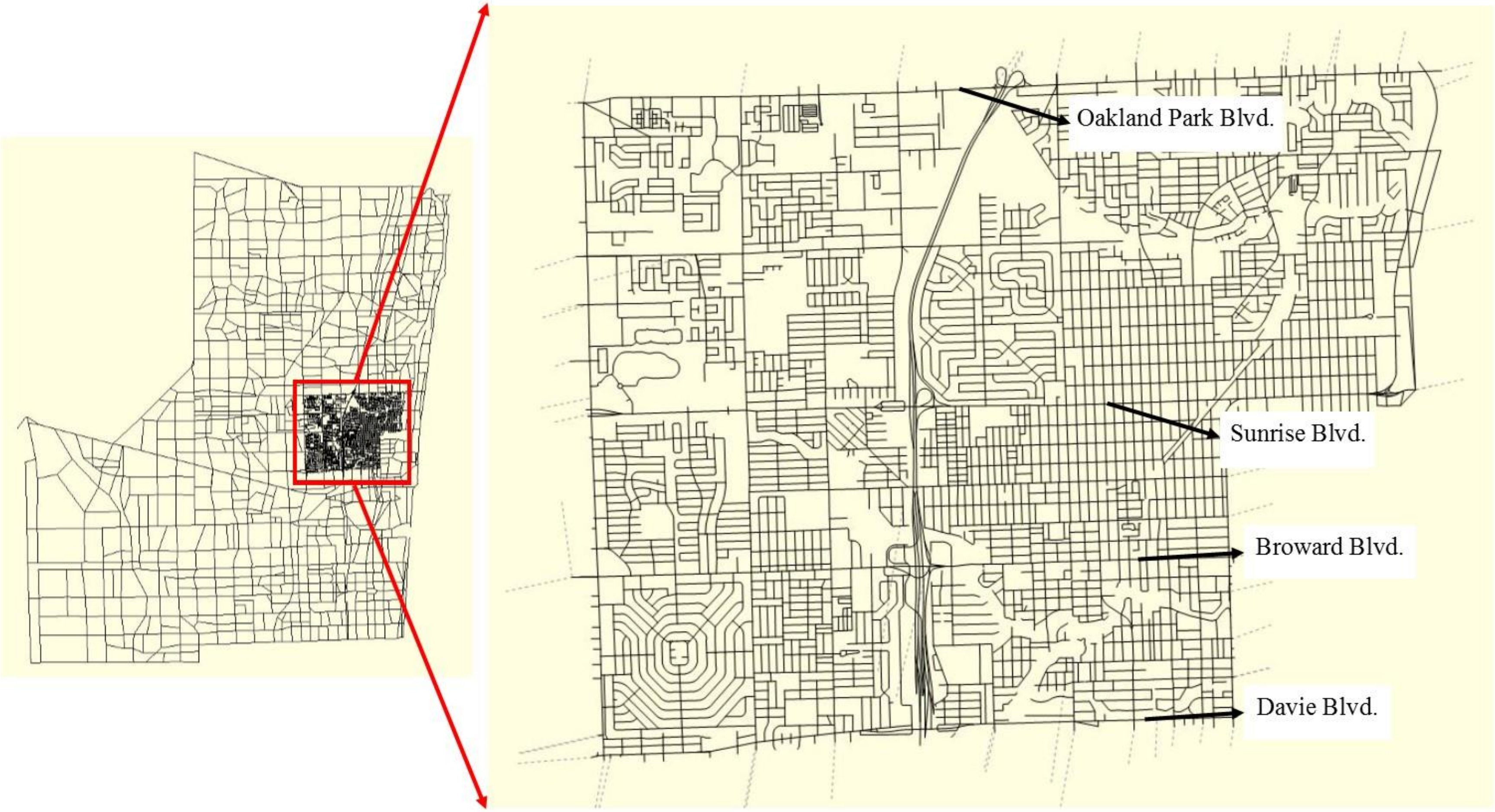


Figure 37: The CBD model (right) in the Broward County (left) road network.

4.2.2.3.Combining TAZs, OD Tables, and Links

Considering that various elements of the macro model were acquired separately and from various sources if was necessary to combine them into a coherent model in order to execute traffic assignments. A shape file that represent TAZs (step 1) was loaded into a file that already contained road links. This step was followed with a manual process of transferring OD trips for an AM peak hour. Figure 38 shows a VISUM model of the Broward County after accomplishing the processes described above.

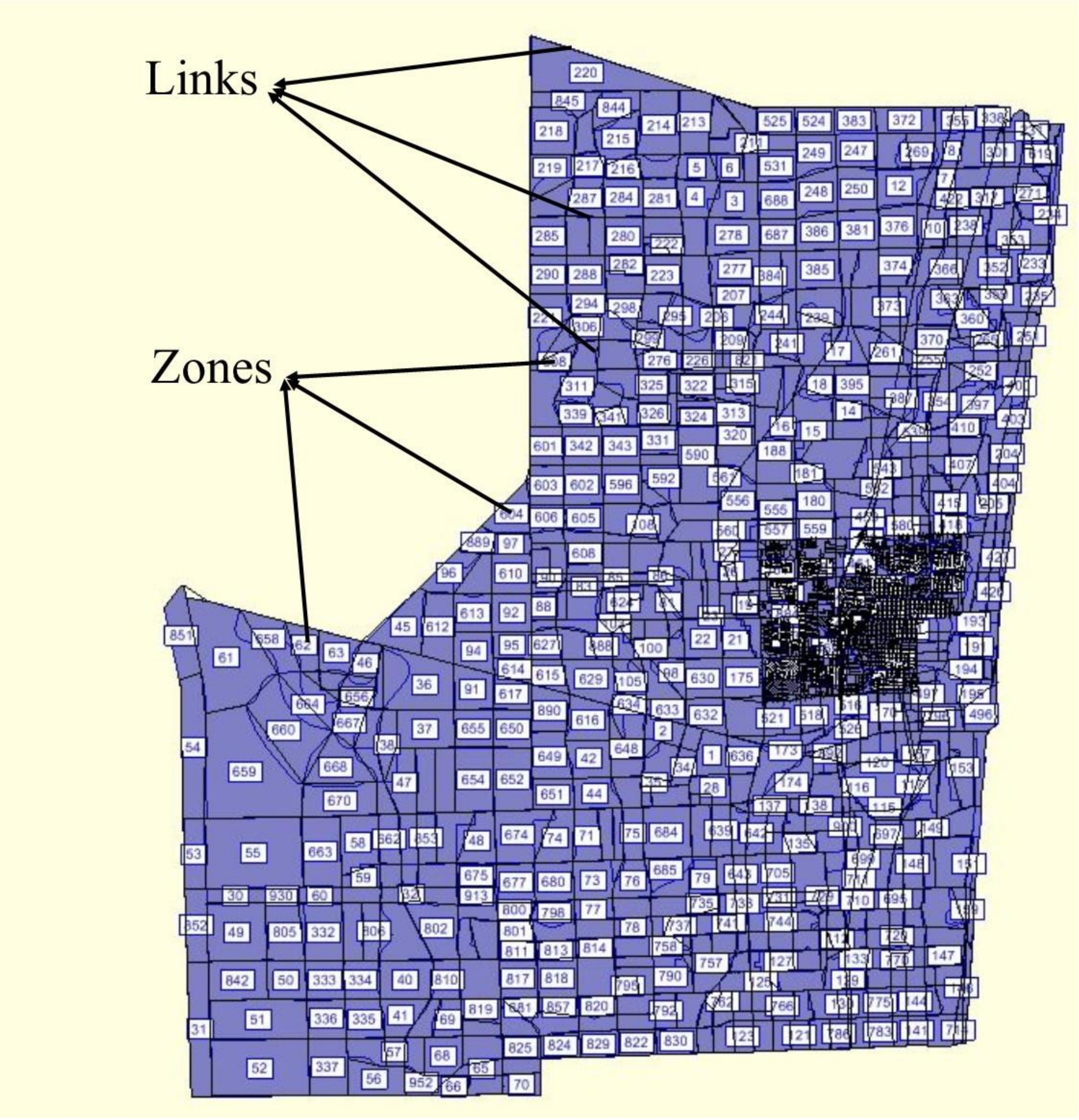


Figure 38: Broward County macro model with 953 OD-Zones and road links.

In the next step (after few iterations requiring few inconsistencies to be fixed), the FAU research team executed traffic assignment to prepare the model for the subnetwork generation process. It is important to note here that subnetwork generation cannot be done without proper traffic assignment as there is no way to synthesize traffic trips/flows from a larger network (with more TAZs) into a smaller subnetwork. Figure 39 shows the results of the traffic assignment execution for the CBC subnetwork of the entire Broward County VISUM model. The thickness of the red line (on a link) represents the intensity of traffic (volume) on the particular link.

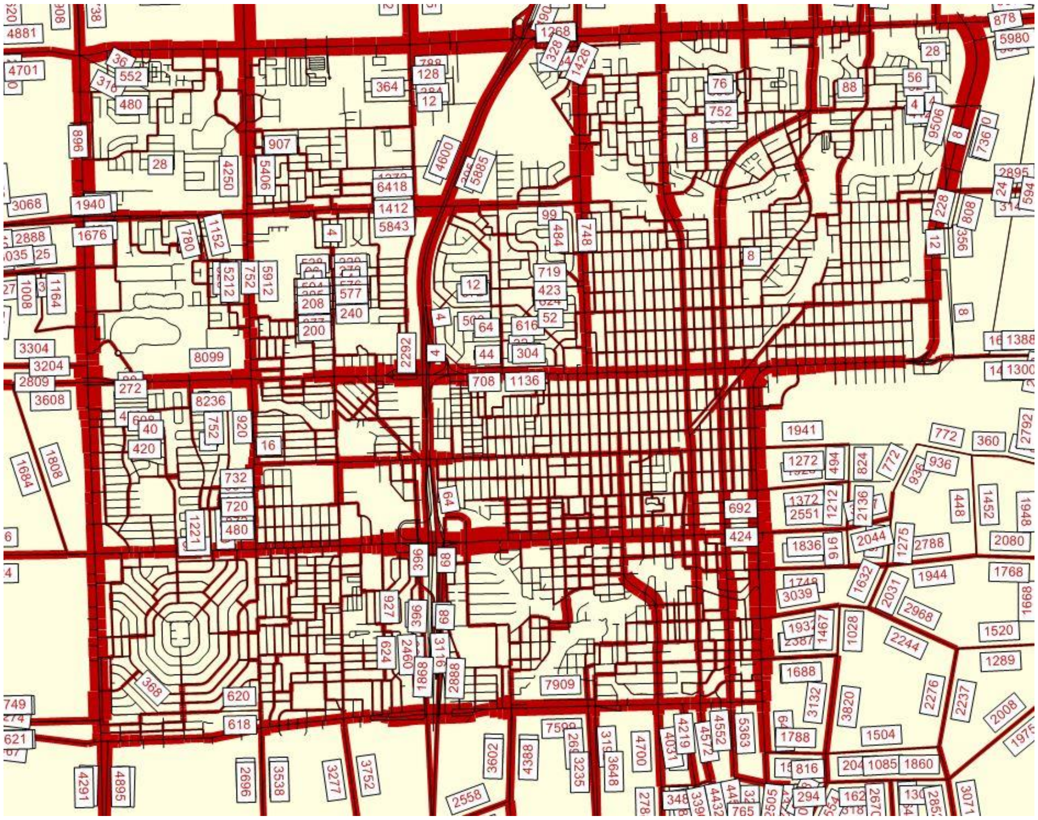


Figure 39: An excerpt of traffic assignment results for the Broward County model.

4.2.2.4. Subnetwork generation

Subnetwork generation is process in VISUM where a subnetwork of the entire mode (together with the associated partial matrices) can be cut out from the entire model in such a way that the OD dependencies of the previous zones are preserved in a set of reduced zones. Generating a subnetwork is done based on specific user-defined rules and many choices (to include and exclude subnetwork generation elements) are available. The FAU research team has performed such a subnetwork generation process to preserve the OD dependencies of the larger model. Many of the previous zones, scattered through the entire Broward County, were replaced by a set of new zones located at the subnetwork entrance points. Figure 40 shows these newly created zones at the subnetwork entrance links.

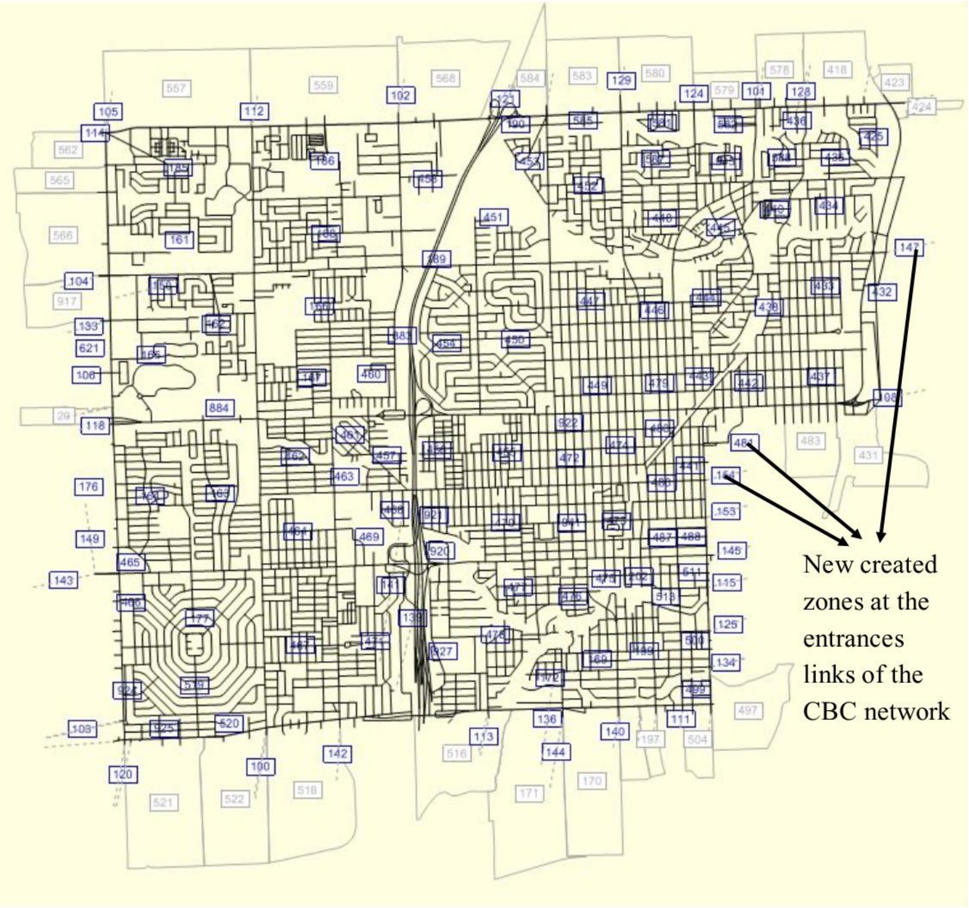


Figure 40: The CBC model after Sub-network generation process.

Once the subnetwork of the CBC was generated, new traffic assignments were executed for the CBC network only in order to facilitate further processes of calibration and validation. Figure 41 shows the results of the traffic assignments executed only on the CBC network. In the following steps the FAU research team concentrated on calibration and validation of the macroscopic model by comparing volumes and travel times from the VISUM model to the volumes and travel times from the microsimulation models.

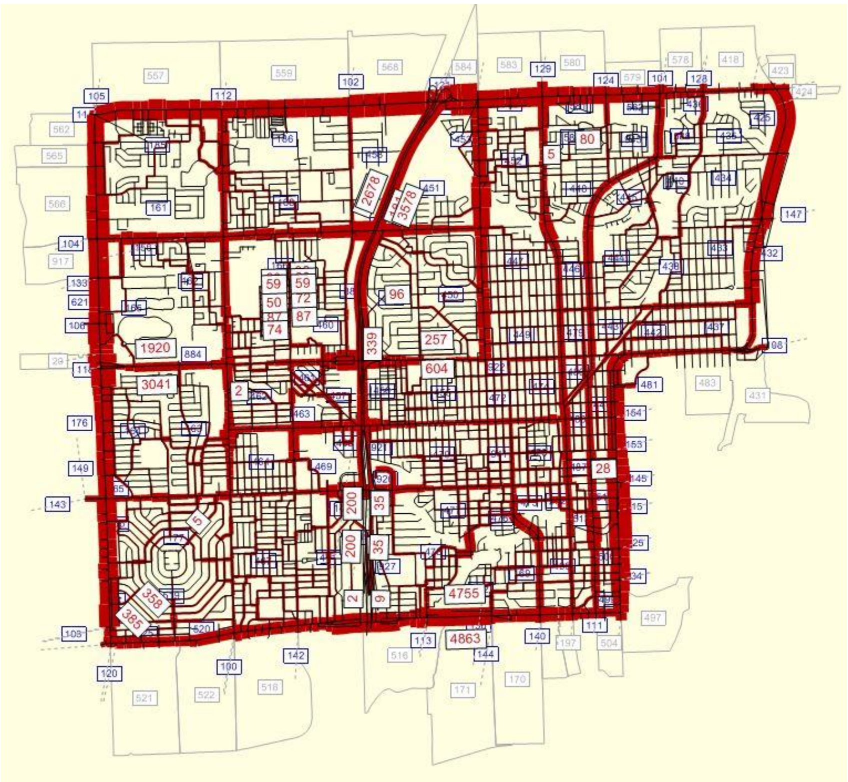


Figure 41: Traffic Assignment results for the CBC network.

4.2.2.5.Calibration and validation processes and results

The Broward Blvd. and Sunrise Blvd. arterials were already calibrated and validated to match the field data. This section covers steps which were used to calibrate and validate the CBC network in VISUM.

- Calibration: volumes from the models in VISSIM were compared to the volumes from the VISUM after execution of the traffic assignment.

- Validation: Travel times between pairs of intersections are used in the validation process. Travel times obtained from VISSIM models were compared to the travel times extracted from traffic assignments in VISUM.

Figure 42 shows the calibration results of the CBC model in VISUM for the AM peak period (8:00-9:00). Relatively strong regression model and a high r-square value show that the match between macroscopic and microscopic volumes is quite strong.

Similarly, travel times extracted from the CBC network in VISUM were compared to the travel times from macroscopic models. Figure 43 shows the validation results of the SLC model in VISUM for the AM peak period (8:00-9:00). The model have been validated relatively well, with the regression model of Y=0.93X and the r-square value around 0.87. The validation results indicate that the macroscopic CBC model is acceptably validated.

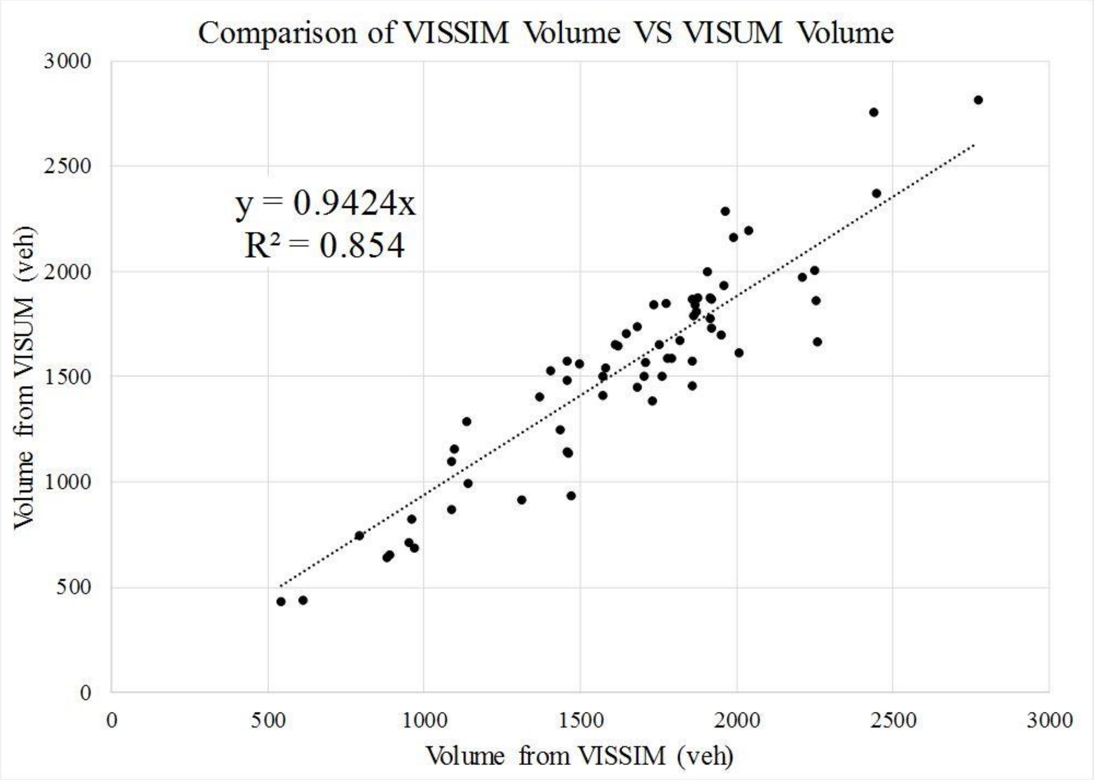


Figure 42: Volume calibration results (macro-model – CBC) (8:00-9:00).

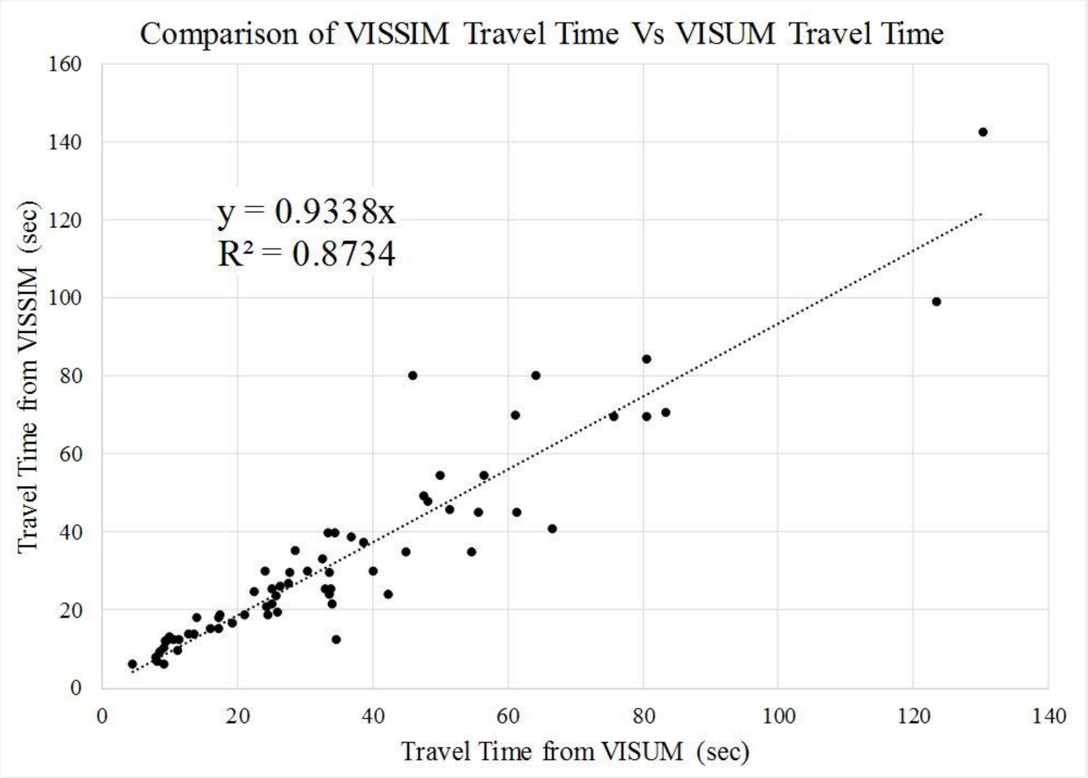


Figure 43: Travel-time validation results (macro-model – CBC) (8:00-9:00).

5. Model Simulation and Results

This chapter describes the model simulation and results of the Salt Lake City (SLC) Central Business District (CBD) network. The FAU research team analyzed three different scenarios in the SLC CBD network. The analysis focused on the microscopic and mesoscopic performance in efficiency and safety. The three different scenarios are detailed as follows:

- Existing SLC CBD – baseline or current field conditions including all of the existing multi-modal amenities including pedestrian and bicycle facilities, Light-Rail Transit, bus lines, etc. There is no alteration of traffic flows or road geometry.
- Partial SLC CBD – which represent a 'half-way' scenario between the two extremes from above. In this case, transit signal priority (TSP) is given to signalized intersections with significant transit demand but the road geometry and passenger car demand and volumes have not been changed.
- Complete SLC CBD – where every street in the CBD is made to be a Complete Street from multi-modal perspective; thus giving pedestrians, bicyclists, public transit riders, and motorists an equal access to any parts of the CBD. In this case, streetcar approach is undertaken where demand and volumes of passenger cars have been reduced along with alteration in road geometry.

5.1 Performance Measures (Key Performance Indicators):

Following performance measures, given in Table 12 are identified as the key parameters for the model simulation. The FAU research team has taken into consideration, when selecting these performance measures, needs of both macroscopic modeling for a long-term planning and the microscopic modeling for a realistic account of traffic operations. Table 12 summarizes how the performance measures can be retrieved from various types of simulation models.

Table 12: Performance measures for efficiency, safety, and environment aspects

Aspect Simulation Model	Efficiency	Safety
Macroscopic	1- Total vehicle-miles [mile] 2- Total travel time [sec/veh] 3- Vehicle hours of delay	Number of accidents
Mesoscopic	1- Delay per node 2- Travel time 3- Speed	Type of conflict and the quantity of each type (SSAM)

Microscopic	1- Delay per node 2- Travel time 3- Speed	Type of conflict and the quantity of each type (SSAM)

The following section provides details for each performance measure based on the resolution of a simulation model:

5.1.1 Macroscopic Performance Measures:

Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. Macroscopic models have considerably fewer demanding computer requirements than microscopic models. They do not, however, have the ability to analyze transportation improvements in as much detail as the microscopic models.

Efficiency:

Total vehicle-miles or vehicle miles of travel (VMT), total travel time, and vehicle hours of delay (VHD) will be calculated for the simulated network using a transportation planning software such as VISUM.

Safety:

Number of accidents and analyze them can be done using the customized GIS-based modules in transportation planning software (e.g. Add-on module “SAF” in VISUM), to geo-locate and analyze safety blackspots and individual accidents.

5.1.2 Mesoscopic Performance Measures:

Mesoscopic simulation models combine the properties of both microscopic (discussed below) and macroscopic simulation models. As in microscopic models, the mesoscopic models’ unit of traffic flow is the individual vehicle. Their movement, however, follows the approach of the macroscopic models and is governed by the average speed on the travel link. Mesoscopic model travel simulation takes place on an aggregate level and does not consider dynamic speed/volume relationships. As such, mesoscopic models provide less fidelity than the microsimulation tools, but are superior to the typical planning analysis techniques.

Efficiency:

Delay per node, which is a modeling component (geographic boundary) that must be defined based on the shape of a field intersection. Travel times & speeds are available in similar options as in microscopic simulation, e.g. by node, link, and individual vehicles. Such information can be retrieved from traffic simulation software such as VISSIM

Safety:

For safety outputs from microsimulation models the FAU research team will utilize vehicular trajectories (e.g. from VISSIM) which will be post-processed by the Surrogate Safety Assessment Model (SSAM) of the Federal Highway Administration Research and Technology of the U.S. Department of Transportation. SSAM provides an opportunity to estimate number of conflicts (near trajectory misses) for three types of conflict (Rear-end, Crossing, and Lane-change)

5.1.3 Microscopic Performance Measures:

Microscopic models simulate the movement of individual vehicles based on car-following and lane-changing theories. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network over small time intervals (e.g., 1 second or a fraction of a second). Typically, upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulations runs that can be completed.

Efficiency:

Delay per node or link. Travel times & speeds are available for different scales, e.g. node, link, and individual vehicle.

Safety:

Similarly to mesoscopic simulations, vehicular trajectories is exported to the SSAM which will process the data and output frequencies for each type of the conflict types (Rear-end, Crossing, and Lane-change). It should be noted that pedestrian trajectories can also be used but it will be crucial to model risk-prone pedestrian behavior.

5.2 Salt Lake City (SLC) network preliminary simulation results:

The SLC CBD network was modeled in VISSIM to perform the microscopic and mesoscopic analyses for both efficiency and safety. All three scenarios (existing, partial, and complete) were considered for comparison.

5.2.1 Efficiency of various complete street scenarios

Efficiency performance metrics such as delay, travel time, and speed are compared and analyzed in the following:

5.2.1.1 Vehicle delay and person delay

Table 13: Delay Comparison among the three scenarios

Delay	**Existing** **SLC CBD**	**Partial** **SLC CBD**	**Complete** **SLC CBD**
Average Vehicle Delay: Overall	2.3 (sec/veh)	1.8 (sec/veh)	4.5 (sec/veh)
Average Vehicle Delay: Transit	15 (sec/veh)	12 (sec/veh)	7.7 (sec/veh)
Average Vehicle Delay: Passenger Cars	4.6 (sec/veh)	4.4 (sec/veh)	8.4 (sec/veh)
Average Person Delay: Overall	0.5 (sec/person)	0.4 (sec/person)	0.39 (sec/person)
Average Person Delay: Transit	0.4 (sec/person)	0.3 (sec/person)	0.19(sec/person)
Average Person Delay: Passenger Cars	3.8 (sec/person)	3.7 (sec/person)	7 (sec/person)

Table 13 represents the delay comparison among the three scenarios. Overall, simulation results show that the partial complete street scenario reduces both the vehicle delay and the person delay. More specifically, delay for both passenger cars and transit vehicles would reduce under the partial complete street scenario. This could be explained by the fact that signal priority intended for transit vehicles reduces the amount of the number of stops and the amount of time stopped at signalized intersections on major arterial streets, for both the transit vehicles and passenger cars traveling on the major arterials. Thus leading to lower overall vehicle delay and person delays. On the other hand, the complete scenario reduces the vehicle delay for transit but increases the vehicle delay for passenger cars and thereby increases the overall vehicle delay. However, since transit vehicles accommodate greater number of passengers, the reduction in vehicle delay of transit can outweigh the increase in vehicle delay in passenger cars when account for passenger delay. Nevertheless, the complete scenario for complete street could significantly penalize passenger cars as changes in road geometry to enhance safety pedestrians and cyclists and efficiency of transit vehicles could dramstrically reduce roadway capacities for passenger cars.

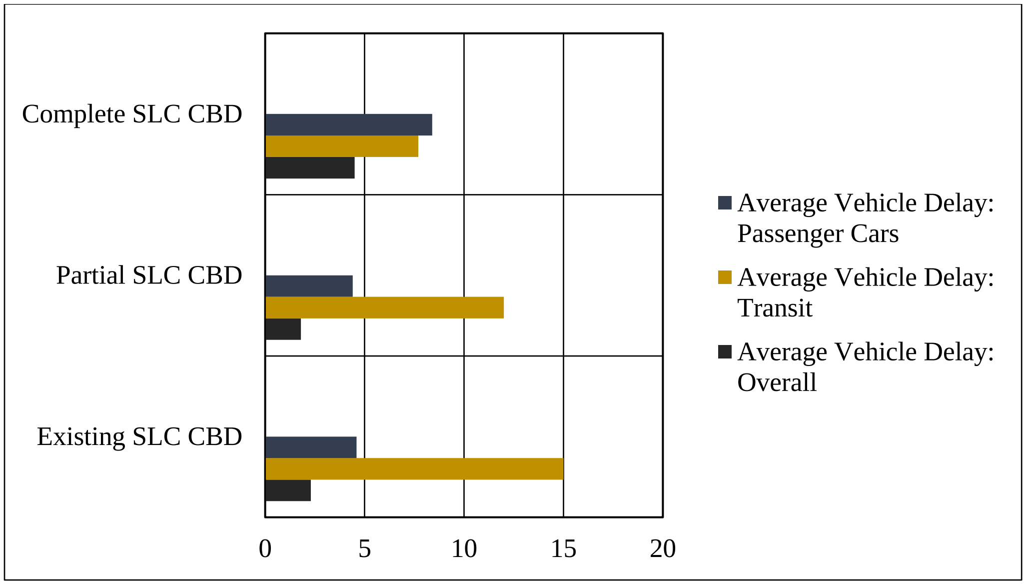


Figure 44: Average vehicle delay comparison among the three scenarios (sec/veh)

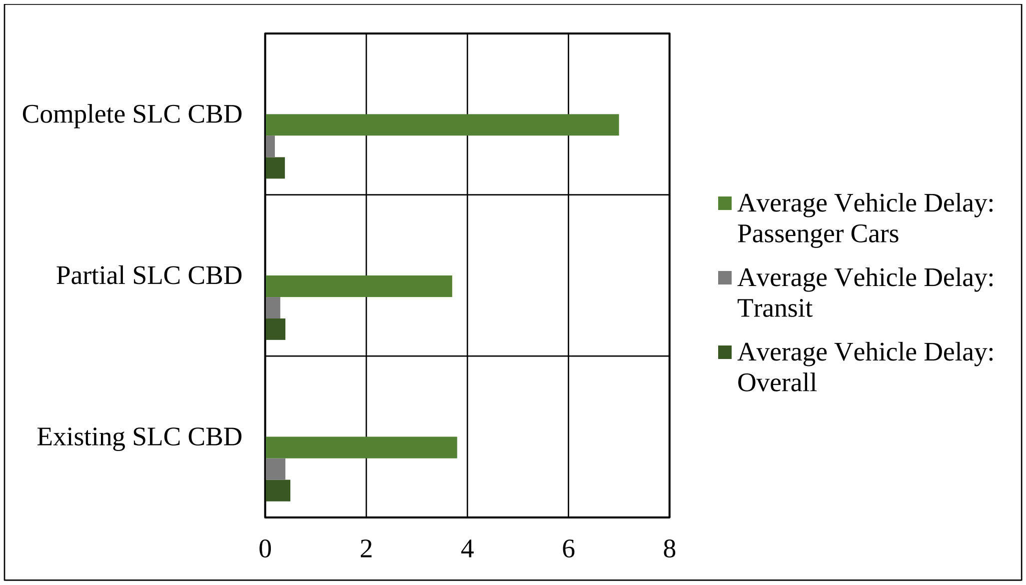


Figure 45: Average person delay comparison among the three scenarios (sec/person)

5.2.1.2 Vehicle travel time

Table 14: Vehicle travel time comparison

Travel Time Per Vehicle	**Existing** **SLC CBD**	**Partial** **SLC CBD**	**Complete** **SLC CBD**
Average Vehicle Travel Time: Overall	$1.03 * 10^{-5}$ (sec/vehicle/distance)	$8.6 * 10^{-6}$ (sec/vehicle/distance)	$6.15 * 10^{-5}$ (sec/vehicle/distance)
Average Vehicle Travel Time: Transit	$4.44 * 10^{-4}$ (sec/vehicle/distance)	$3.75 * 10^{-4}$ (sec/vehicle/distance)	$2.07 * 10^{-3}$ (sec/vehicle/distance)
Average Vehicle Travel Time: Passenger Cars	$2.56 * 10^{-5}$ (sec/vehicle/distance)	$2.57 * 10^{-5}$ (sec/vehicle/distance)	$1.67 * 10^{-4}$ (sec/vehicle/distance)

Vehicle travel time comparison is shown in table 14 or all three cases simulated in VISSIM. Table 14 shows that the partial complete street scenario reduces average overall travel time and significantly reduces the average transit travel time. However, the complete scenario increases the average overall travel time, the average transit travel time, and the average passenger car travel time. Such observation is consistent with the delay comparison shown in the previous table and figures, where the complete street scenario increases the overall and passenger car vehicle delay but the partial complete street scenario decreases the overall and passenger car vehicle delay in addition to the transit vehicle delay.

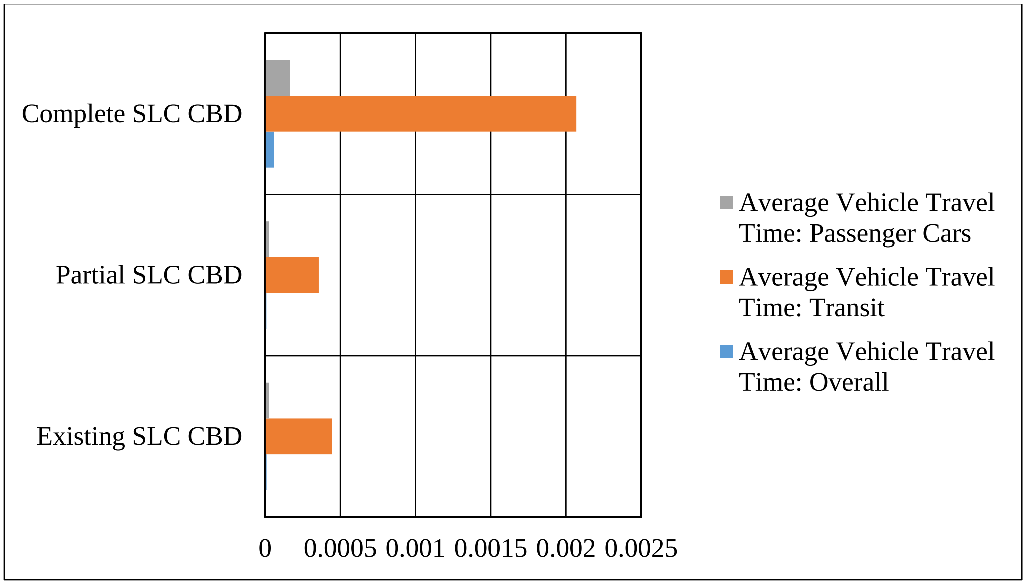


Figure 46: Vehicle travel time comparison (sec/vehicle/distance)

5.2.1.3 Vehicle speed

Table 15: Speed Comparison

Average Speed Per Vehicle	**Existing SLC CBD**	**Partial SLC CBD**	**Complete SLC CBD**
Average Speed: Overall	14 mph	14.5 mph	13.3 mph
Average Speed: Transit	12.7 mph	15.1 mph	15.8 mph
Average Speed: Passenger Cars	15.7 mph	15.1 mph	5.34 mph

Vehicle speed is compared in table 15 with the cases taken into account. The above table clearly represents that speeds of both transit and passenger cars have increased in the partial complete street scenario, but the average speed of passenger cars decreased significantly in the complete scenario, which lead to a decrease in overall average speed despite the improvement in average speed of transit.

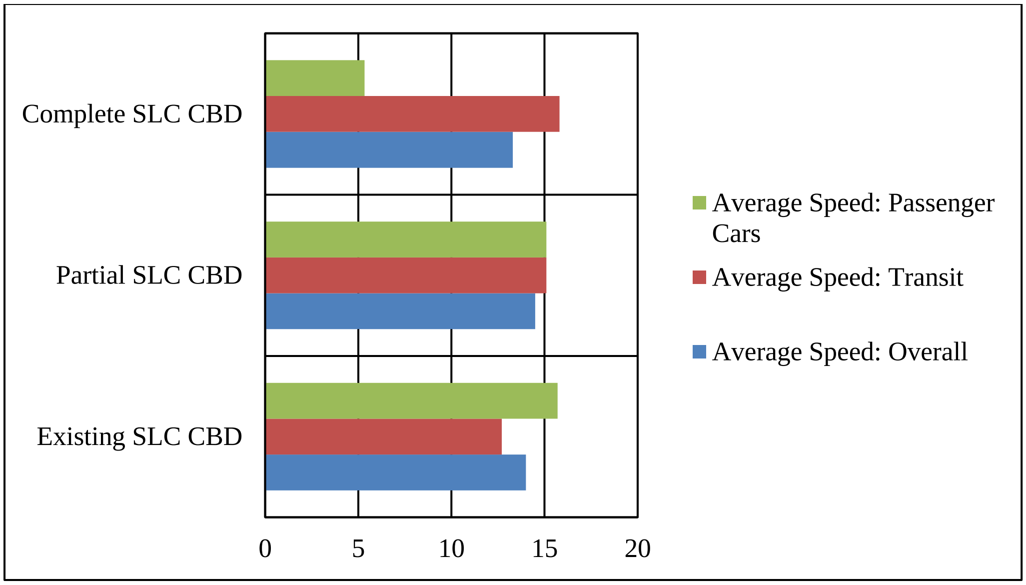


Figure 47: Speed Comparison in mph

5.2.2 Safety of various complete street scenarios

The safety performance of various complete street scenarios is analyzed using the Surrogate Safety Assessment Model (SSAM). SSAM is a technique combining microsimulation and automated conflict analysis to analyze the frequency and character of narrowly averted vehicle-to-vehicle collisions in traffic. This enables us to assess the safety of traffic facilities without waiting for a statistically above-normal number of crashes and injuries to actually occur.

To assess the performance of complete street scenarios with SSAM, the scenario is modeled in simulation models and then simulated with desired traffic conditions (typically simulating several replications with different random number seeds). Each simulation run results in a corresponding trajectory file, referred to as a TRJ file corresponding to the .trj filename extension. Then, SSAM is used as a post-processor to analyze the batch of TRJ files.

5.2.2.1 Existing condition

The results obtained from the SSAM analysis for the existing condition are shown below.

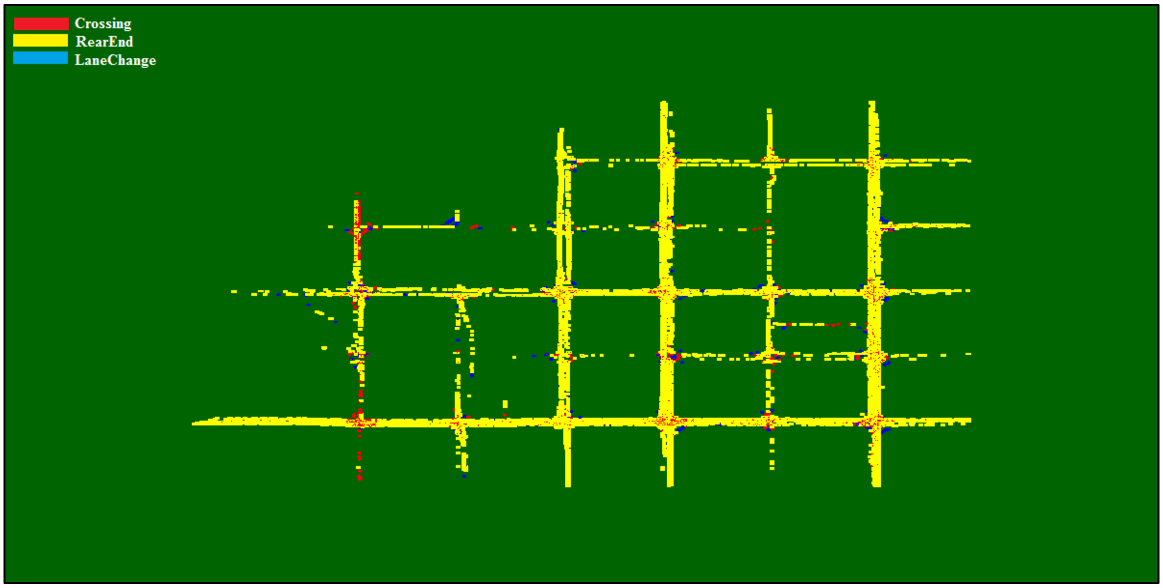


Figure 48: Conflict points for the existing condition

Different types of color codes are used to display conflicts. Here, red color is for crossing conflict, the yellow color is for rear end conflict, and blue color is for lane change conflict. From the map, it is understandable that yellow color, i.e. rear end conflict is most are all over the place. Then, the red color is the second most part of the map. And the blue color is in fewer places. So it is cleared that rear end conflict is the main reason for severe traffic conditions at the existing condition.

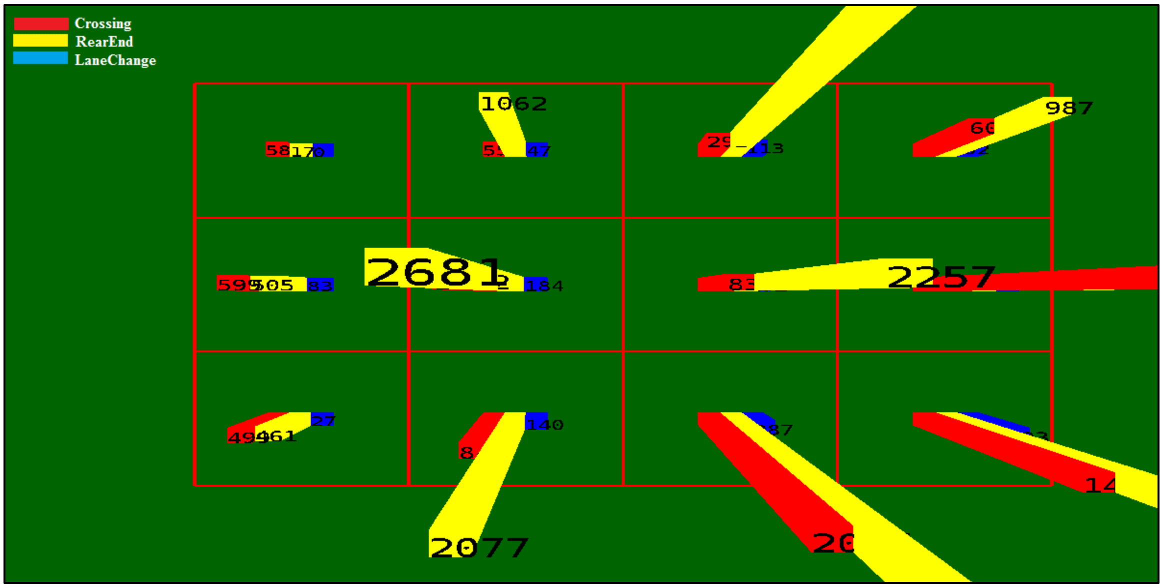


Figure 49: Comparison of conflict cases for the existing condition

Despite the abovementioned results in figure 54, three cases of conflict are compared with the bar chart in figure 55. The same color code is also used here as like before. From the bar chart, it is also seen that the yellow bar is the largest at almost every grid, the red bar is the second largest, and the blue bar is only a negligible portion at every segment. Although red bar is the second largest, it is very small in comparison to the yellow bar. So, it is concluded that the number of conflict due to lane change and crossing is very small with respect to rear end in the existing condition.

5.2.2.2 Partial SLC CBD complete street scenario

The following observations have been made (shown in the figure below).

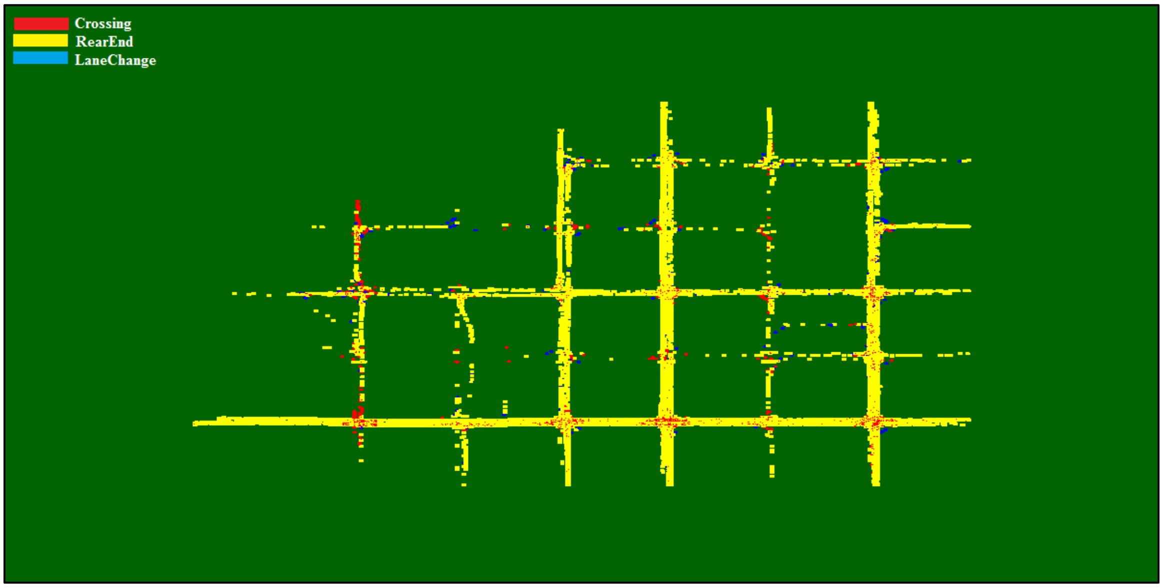


Figure 50: Conflict points for the partial SLC CBD complete street scenario

The color code used in the existing condition is also applied for the partial complete street scenario. Similar to the existing condition, figure 56 shows the results for the partial complete street scenario, it is easily noticeable that the maximum part of the total area is covered by yellow color i.e. rear end conflict. Some portion has red color i.e. crossing conflict, but it is too much less than the rear end conflict. Blue color i.e. lane change conflict has a negligible amount in the area. Therefore, the partial complete street scenario will experience traffic severity for rear end conflict in most of the parts.

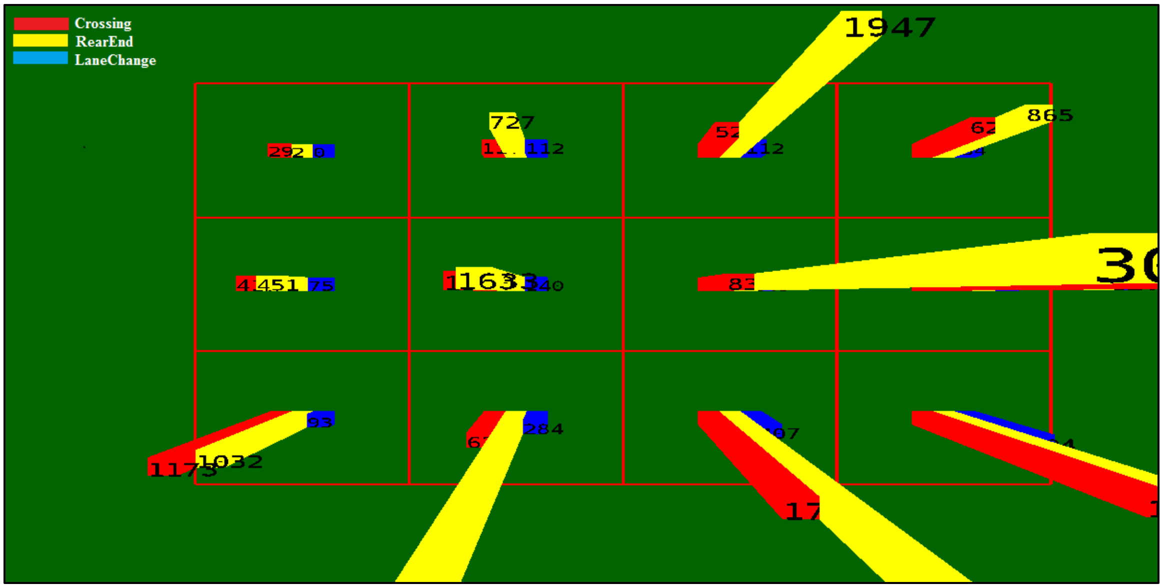


Figure 51: Comparison of conflict cases for the partial SLC CBD complete street scenario

The bar chart in figure 57 is showing the comparison of three conflict cases for the partial complete street scenario with the same color code as like as the existing condition. The above chart displays that in almost every grid segment, the yellow bar has the peak value which states that rear end conflict will cause the most traffic hazards. Red bar i.e. crossing, and blue bar i.e. lane change is responsible for some scale extent. It is summarized that the total number of conflict is the highest due to the rear end; on the other hand lowest conflict is for the lane change.

5.2.2.3 Complete SLC CBD complete street scenario

From the SSAM analysis for the complete SLC CBD scenario, the following results have been obtained (shown in the figure below).

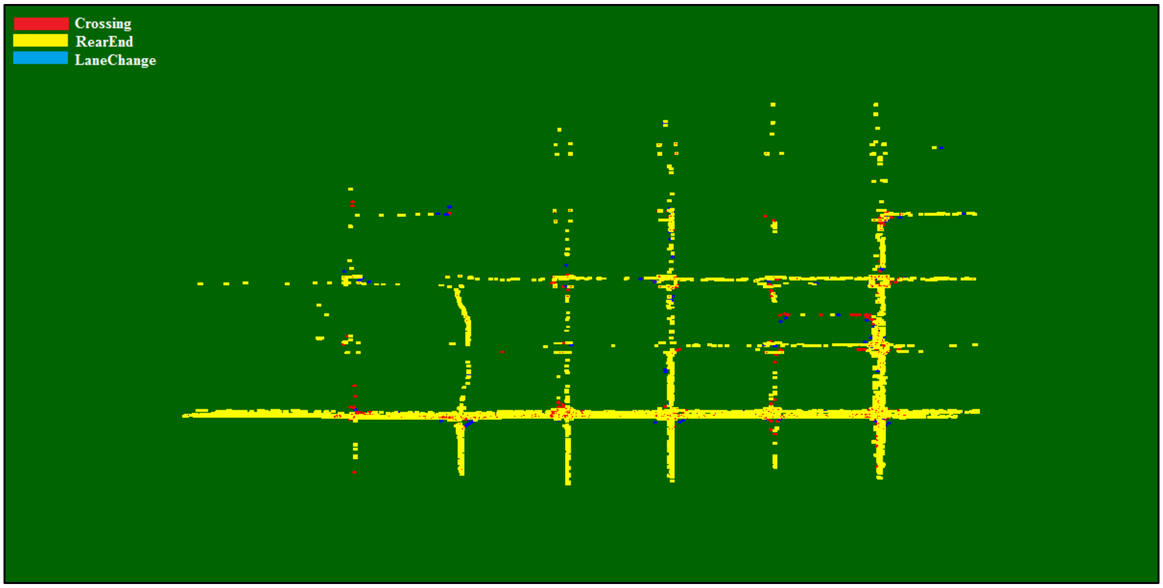


Figure 52: Conflicts points for the complete SLC CBD complete street scenario

The map in figure 58 is according to the color code shown previously. The map illustrates that the maximum area will experience adverse traffic conditions due to rear end i.e. yellow color. Crossing i.e. red color will also affect some portion of traffic but very small in comparison to the rear end. Lane change i.e. blue color is in the minimal portion of the coverage.

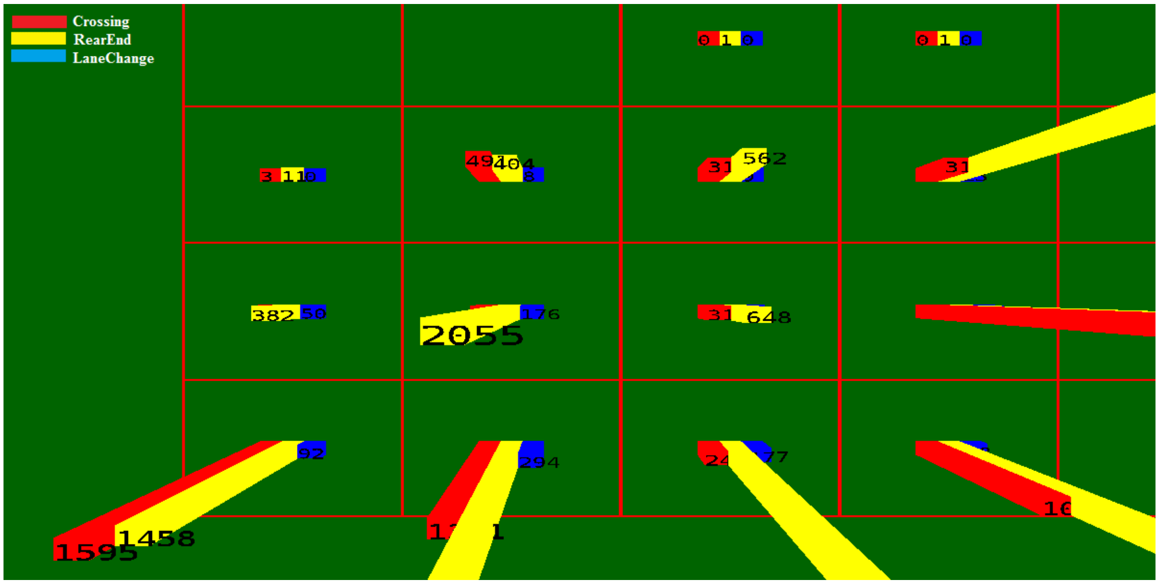


Figure 53: Comparison of conflict cases for the complete SLC CBD complete street scenario

Comparison of the conflict cases i.e. crossing, rear end, and lane change in the figure 59 for complete street scenario shows the almost same effect like as existing condition and partial complete street scenario. Yellow color bar has the highest value in the entire region. Red and blue color bar covers some small portion. So, the above results notice that rear end is main reason for the maximum number of conflict, while the others are less.

5.2.2.4 Comparison of results among the three scenarios

Table 16: Comparison of conflict

Conflict	**Existing SLC CBD**	**Partial SLC CBD**	**Complete SLC CBD**
Crossing	15398	13532	8285
Rear end	60195	41580	30691
Lane change	2259	3430	1144
Total	77852	58542	40120

Table 16 represents that maximum number of conflicts has occurred at the existing condition and complete street scenario is the smallest of all. Partial complete street scenario has experienced moderate number of conflicts in almost all cases except the lane change conflict. The entire scenarios represent that rear end is the main reason for the highest number of conflict and for the lane change; lowest number of conflict has been observed. So, it can be mentioned that in case of conflict consideration, existing condition is in highest traffic severity, while partial complete street scenario and complete street scenario are some less than that.

Table 17: Comparison of conflict per vehicle

Conflict	**Existing SLC CBD**	**Partial SLC CBD**	**Complete SLC CBD**
Crossing	2.175	1.685	6.768
Rear end	8.503	5.179	25.074
Lane change	0.319	0.427	0.935
Total	10.997	7.29	32.778

Comparison of conflict per vehicle indicates that although complete street scenario has the lowest number of conflicts, but for all the cases of conflict per vehicle, this scenario possesses the maximum value. And the conflict per vehicle for the partial complete street scenario is very much negligible in comparison to the other two scenarios. For the complete street scenario, conflict per vehicle due to crossing and rear end is much higher than the other two scenarios. But for lane change conflict, there is no significant difference between three scenarios.

5.3 Macroscopic Analysis:

The Central Broward County and the Salt Lake City network were modeled in Aimsun to perform the macroscopic, microscopic, and mesoscopic analyses for both efficiency and safety. All three scenarios (existing, partial, and complete) were considered for comparison.

5.3.1 Efficiency of various complete street scenarios

Efficiency performance metrics such as delay, travel time, and speed are compared and analyzed using the meso and microsimulation results. System performance measures from the macrosimulation such as vehicle miles traveled (VMT), total travel time, and speed are used to establish the comparison between the existing condition and the complete street scenario.

5.3.1.1 Vehicle Travel Time

From the macrosimulation total travel time for the system was obtained. Total travel time refers to the summation of the time of all trips generated in a specific time period. Travel time correlates with the level of congestion and specific characteristics of the corridors.

Table 18: Vehicle Travel comparison for both Central Broward County (CBC) and Salt Lake City (SLC)

Performance Measure	**CBC**		**SLC**		**Difference (%)**	
	Baseline	**Complete Street**	**Baseline**	**Complete Street**	**CBC**	**SLC**
Total travel time	414798	345960	278013	279505	-16.60	+0.54

For the analyzed network of Central Broward County (CBC), the value in the overall travel duration decreased by 16.6%. in relative terms, a decrease of 16.6% in a one-hour trip means the reduction on 10 minutes. The decrease in travel time seen in the previously shown table could be translated into better conditions for the users at a system level. The difference in travel time is related to the increase in speed at systemic level mentioned above with other performance measures. In case of SLC, there is a slight increase of travel time by 0.54% compared to the baseline condition.

5.3.1.2 Vehicle speed

Overall vehicle speed is also calculated in the macrosimulation and it is provided for the entire system. The computation adds up the travel times and divides it by the length of the trips generated in the simulation. The following table shows the results from the macrosimulation for the portion of the network considered in the simulation.

Table 19: Vehicle Speed comparison for Central Broward County (CBC) and Salt Lake City (SLC)

Performance Measure	**CBC**		**SLC**		**Difference (%)**	
	Baseline	**Complete Street**	**Baseline**	**Complete Street**	**CBC**	**SLC**
Vehicle speed (kmph)	35.56	42.32	38.37	38.19	+19	-0.47

The overall increase in the speed for CBC network suggests that the changes derived from the implementation of the complete street configuration improves mobility in the big picture. Higher speeds are related to less congestion and one of the key performance measures to assess the condition is overall speed from the vehicles. For the latter case, the difference in change is negligible and it can be concluded that, there was no change of vehicle speed from macro perspective in SLC.

5.3.1.3 Total vehicle kilometers

Total vehicle miles or vehicle miles traveled is a commonly used performance metric to assess traffic demand, in this case, it helps to understand the effects of changes produced by the implementation of the complete street configuration. Total vehicle miles are defined as the summation of all the trajectories from vehicles in the study zone, in this case, the summation is made by the simulation program.

Total vehicle miles is also correlated to accessibility, when the accessibility improves in certain area, people tend to reduce the use of vehicles to reach their destination place which at the same time helps improving the system due to less congested roads. The following table shows the results from the macrosimulation for Central Broward County. As commented before, the network comprises a selection of the network provided which contains Sunrise Boulevard and Broward Boulevard.

Table 20: Total Vehicle kilometers comparison for Central Broward County (CBC) and Salt Lake City (SLC)

Performance Measure	**CBC**		**SLC**		**Difference (%)**	
	Baseline	**Complete Street**	**Baseline**	**Complete Street**	**CBC**	**SLC**
Total vehicle kilometers	245868.23	244451.35	177809	177887	-1.00	+0.04

From the above table, can be seen that the number of vehicle miles traveled decreases in about 1% when comparing the existing and the complete street scenarios in CBC. On the other hand, a minor increase of +.04% total vehicle miles was observed after implementing complete street in SLC. In this regard, the contribution of the project does not seem to be too relevant, however, when considering that vehicle miles is not only a measure of demand but implicitly correlates to congestion, it can be described as a positive step.

5.4 Mesoscopic Analysis:

5.4.1 Efficiency of various complete street scenarios

Efficiency performance metrics such as delay, travel time, and speed are compared and analyzed in the following:

5.4.1.1 Vehicle delay and person delay

Table 21: Delay Comparison for Broward and Sunrise Blvd.

Delay (sec/veh/distance)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Delay Time - Bus/Truck	293.89	270.27	40.46	39.48
Delay Time - Car	254.29	253.78	199.34	198.79
Passenger car equivalent delay	292.74	269.79	93.11	92.93
% change of passenger delay	-8.51		-0.20	

For the Broward County, delay time for buses got significantly improved with the implementation of TSP in Broward Blvd. Car scenario also got improved slightly. Considering a factor of 40 passengers in bus and 1.2 in cars, there is a reduction of around 8.5% passenger car equivalent delay time after implementing TSP. Similar scenario was observed in Sunrise Blvd too, but the delay time for trucks did not go down significantly with FSP. Overall, there was a minor reduction of passenger car equivalent delay after the implementation of FSP.

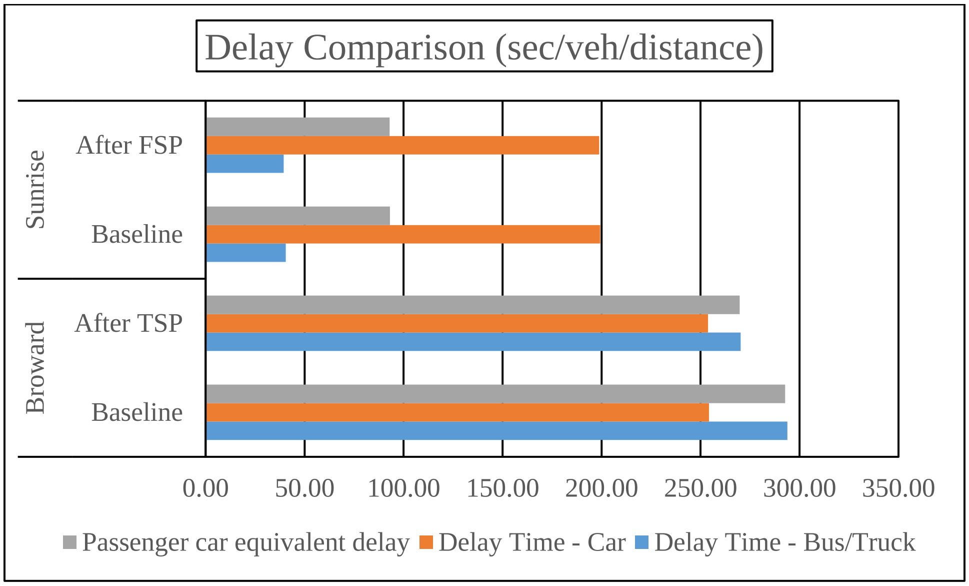


Figure 54: Comparison of delay metrics for the Broward county

Table 22: Delay Comparison for SLC

Delay (sec/veh/distance)	**SLC**	
	Baseline	**After TSP**
Delay Time - Bus	147.93	142.47
Delay Time - Car	234.29	239.39
Passenger car equivalent delay	150.45	145.29
% change of passenger delay	-3.55	

In SLC, the system-wide delay got reduced for transit vehicle but it got increased slightly for the passenger cars as buses were moving along the major corridors which had an impact on the passenger cars on the cross streets. However, considering the same factor for passenger car equivalency, overall scenario got improved with a reduction of around 3.5% delay time.

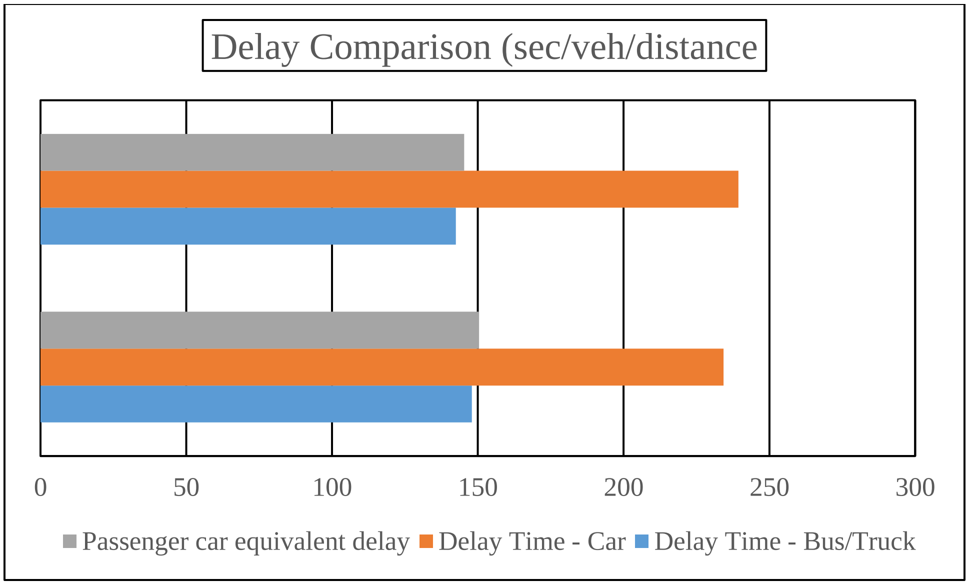


Figure 55: Comparison of delay metrics for the SLC

5.4.1.2 Total distance travelled

Table 23: Total distance travelled comparison for Broward and Sunrise Blvd.

Total Distance Travelled (km)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Total Distance Travelled - Bus/Truck	117.91	107.50	2698.92	2756.95
Total Distance Travelled - Car	29076.99	29139.47	20130.86	20205.41
Passenger car equivalent distance travelled	961.38	953.09	8509.57	8573.10
% change of passenger distance travelled	-0.87		0.74	

In Broward Blvd, total distance travelled by bus has been decreased with the implementation of TSP. However, for passenger cars, the distance travelled got increased. Opposite scenarios were observed for Sunrise Blvd. The cases were endorsed by passenger car equivalent distance travelled. Overall, there was a reduction of around 0.87% passenger distance travelled for Broward Blvd and an increase of 0.74% distance travelled for Sunrise Blvd.

Table 24: Total distance travelled comparison for SLC

Total Distance Travelled (km)	**SLC**	
	Baseline	**After TSP**
Total Distance Travelled - Bus	550.85	574.72
Total Distance Travelled - Car	15568.88	15440.92
Passenger car equivalent distance travelled	988.27	1007.72
% change of passenger distance travelled	1.93	

Percentage change of passenger distance travelled got increased by around 2% with the implementation of TSP in SLC. This is endorsed by the increase of total distance travelled by bus. However, total distance travelled by car got reduced in the process.

5.4.1.3 Vehicle travel time

Table 25: Vehicle travel time comparison for Broward and Sunrise Blvd.

Travel Time (sec/veh/distance)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Travel Time – Bus/Truck	411.92	388.21	100.28	99.33
Travel Time – Car	312.92	312.40	258.91	258.42
Passenger car equivalent travel time	409.04	386.00	153.16	152.36
% change of passenger travel time	-5.97		-0.52	

Travel time for both bus and truck got reduced after signal priority in Broward and Sunrise Blvd. respectively. However, the travel time for car was almost same in both the scenarios, i.e. TSP/FSP did not have any effect on the travel time for car. In addition, passenger distance travelled got lowered by around 6% and 0.5% for Broward and Sunrise Blvd. respectively.

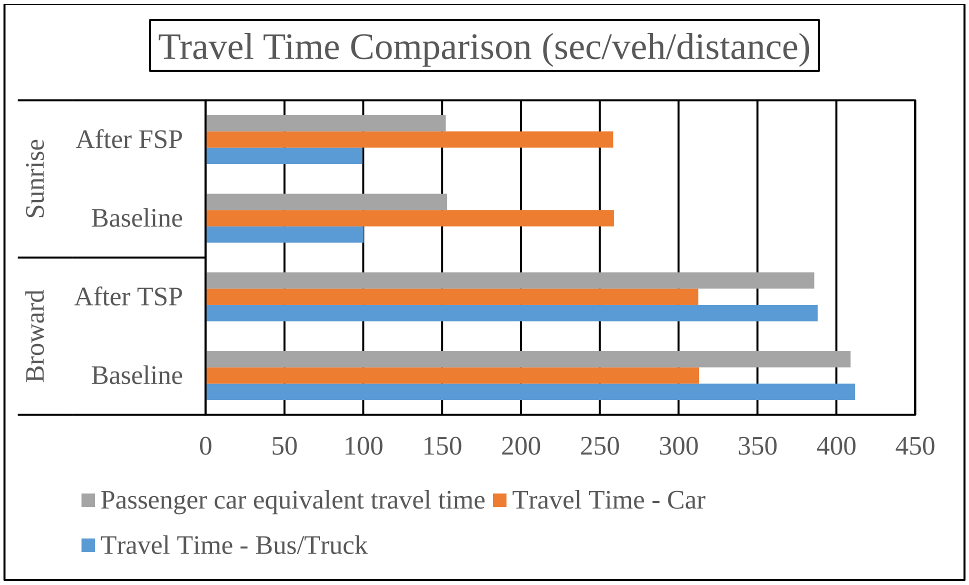


Figure 56: Comparison of vehicle travel time metrics for Broward and Sunrise Blvd.

Table 26: Vehicle travel time comparison for the SLC

Travel Time (sec/veh/distance)	**SLC**	
	Baseline	**After TSP**
Travel Time - Bus	261.4	255.97
Travel Time - Car	307.28	312.29
Passenger car equivalent travel time	262.74	257.61
% change of passenger travel time	-1.99	

After applying TSP in SLC, the travel time for bus got reduced, but the travel time for car got increased. Overall, passenger car equivalent travel time scenario became better after the implementation of TSP. As a result, percentage change of passenger travel time got lowered after TSP.

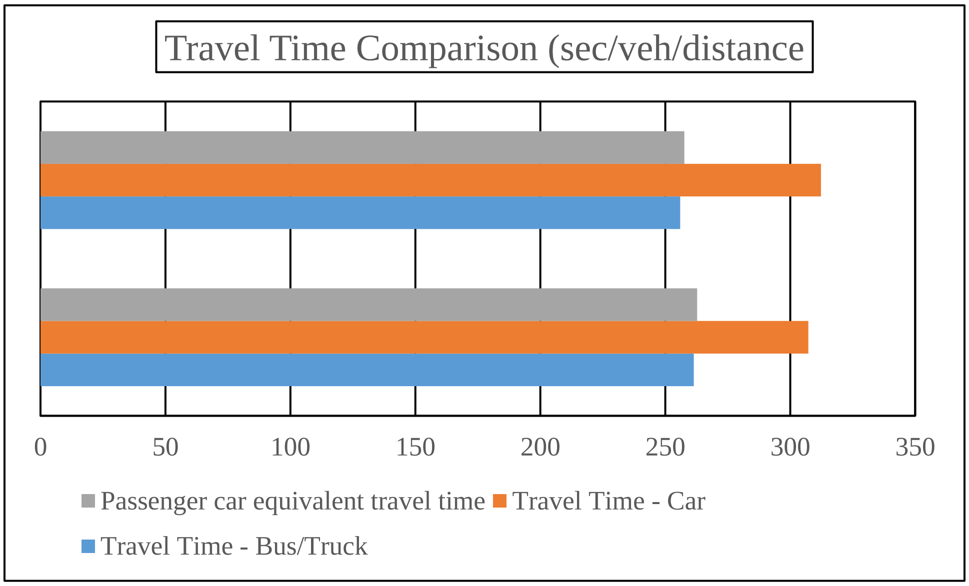


Figure 57: Comparison of vehicle travel time metrics for the SLC

5.4.1.4 Vehicle speed comparison

Table 27: Vehicle speed comparison for Broward and Sunrise Blvd.

Vehicle speed (kmph)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Speed - Bus/Truck	9.72	10.45	36.13	36.41
Speed - Car	28.93	28.96	37.93	37.97

The speed of bus and trucks got increased after implementation of TSP and FSP in Broward and Sunrise Blvd. respectively. Similar scenario is observed for cars in both the cases.

Table 28: Vehicle speed comparison for the SLC

Vehicle speed (kmph)	**SLC**	
	Baseline	**After TSP**
Speed - Bus	17.1	17.52
Speed - Car	20.29	20.31

TSP improves the speed for both bus and car in SLC. Similar results are obtained like the Broward County.

5.4.2 Safety of various complete street scenarios

The safety performance measures i.e. lane changes (#/km), standard deviation of speed are taken into consideration.

5.4.2.1 Lane Changes

Table 29: Vehicle lane change comparison among the scenarios for Broward and Sunrise Blvd.

Lane Changes (#/km)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Number of Lane Changes - Bus/Truck	1.39	1.28	10.85	11.92
Number of Lane Changes - Car	290.95	291.79	117.45	118.45

Number of lane changes for bus got decreased with TSP in Broward Blvd. However, there is a slight increase in number of lane changes for car. However, number of lane changes for both truck and car got increased in Sunrise Blvd after the implementation of FSP.

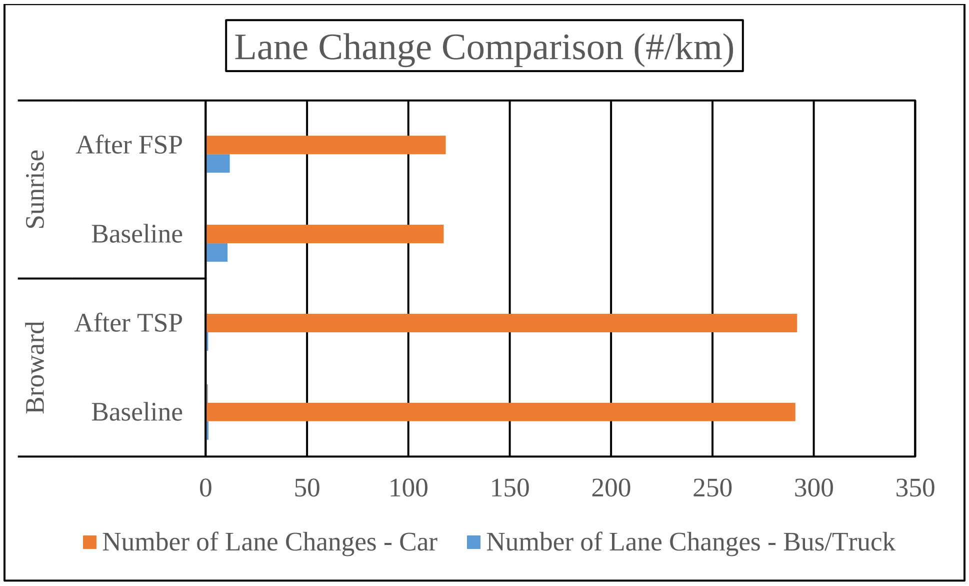


Figure 58: Comparison of lane change metrics for Broward and Sunrise Blvd.

But SLC scenario got improved after TSP in terms of number of lane changes. For bus scenario, there was a reduction in number of lane changes whereas the car scenario remained the same.

Table 30: Vehicle lane change comparison among the scenarios for the SLC

Lane Changes (#/km)	**SLC**	
	Baseline	**After TSP**
Number of Lane Changes - Bus	2.99	2.9
Number of Lane Changes - Car	92.03	92.03

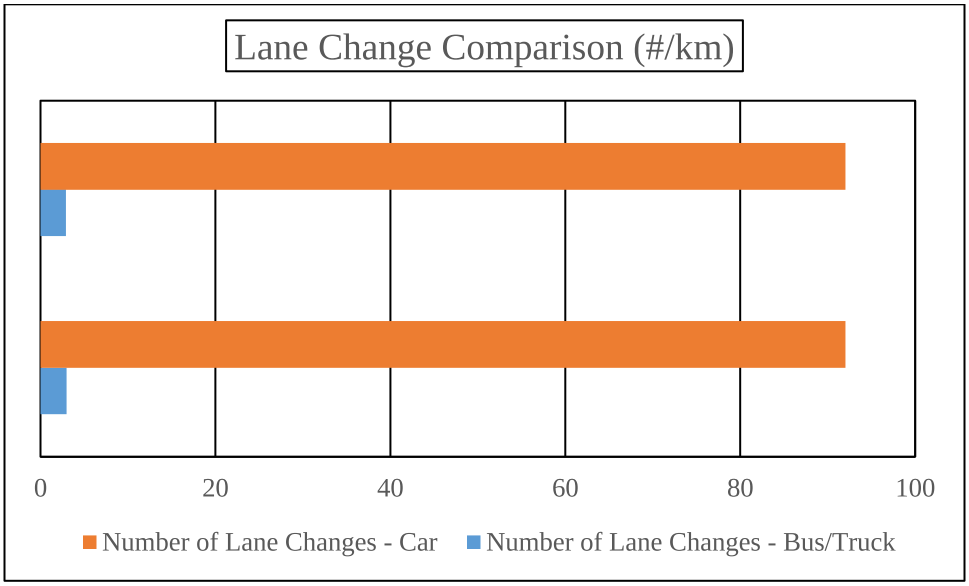


Figure 59: Comparison of lane change metrics for the SLC

5.5 Microscopic Analysis:

5.5.1 Efficiency of various complete street scenarios

Efficiency performance metrics such as delay, travel time, and speed are compared and analyzed in the following:

5.5.1.1 Vehicle delay and person delay

The following table shows the delay comparison for Broward and Sunrise Blvd. considering the baseline scenarios and after the implementation of TSP for Broward and FSP for Sunrise. In general, it is found that due to TSP, and FSP, some improvements happened for the % change of passenger delay. For Broward, and Sunrise, they are reduced by 1.50%, and 1.51% respectively.

Table 31: Delay Comparison among the scenarios for Broward and Sunrise Blvd

Delay (sec/veh/distance)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Delay Time - Bus/Truck	222.95	219.59	120.68	117.70
Delay Time - Car	265.26	263.73	275.13	270.79
Passenger car equivalent delay	224.18	220.88	66.89	65.90
% change of passenger delay	-1.50		-1.51	

In the figure shown below, all types of delay i.e. Delay Time - Bus/Truck, Delay Time – Car, Passenger car equivalent delay are compared. For the Broward Blvd., Delay Time - Bus/Truck got reduced from 222.95 sec/veh/distance to 219.59 sec/veh/distance. In case of Sunrise that also became less after the FSP. Delay Time – Car follows a decreasing trend i.e. 0.6%, 1.8% for Broward, and Sunrise respectively. Finally, Passenger car equivalent delay, applying factors for car, truck, and bus, follows the same.

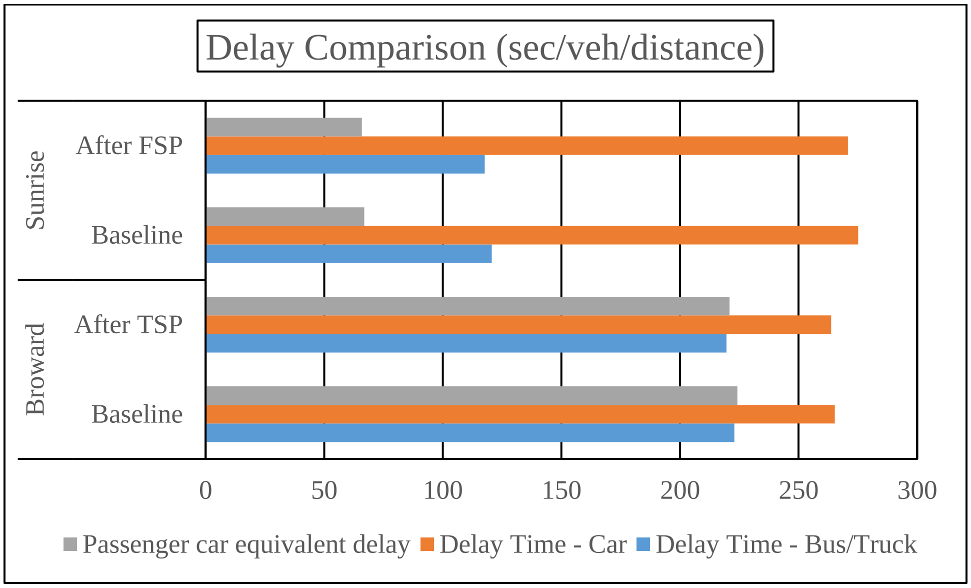


Figure 60: Comparison of delay metrics for the Broward county

In the Table 13, delay comparison among the scenarios for SLC is shown. For the SLC, TSP has been applied. It is seen that % change of passenger delay got reduced by around 10%. Also, correlating this, Delay Time – Bus, and Delay Time – Car followed a downward trend. Applying the factors for car, truck, and bus, Passenger car equivalent delay was calculated, which is 188.02 sec/veh/distance for the baseline, and 171.09 sec/veh/distance for the case implementing TSP.

Table 32: Delay Comparison among the scenarios for SLC

Delay (sec/veh/distance)	**SLC**	
	Baseline	**After TSP**
Delay Time - Bus	185.74	165.99
Delay Time - Car	264.05	341.08
Passenger car equivalent delay	188.02	171.09
% change of passenger delay	-9.90	

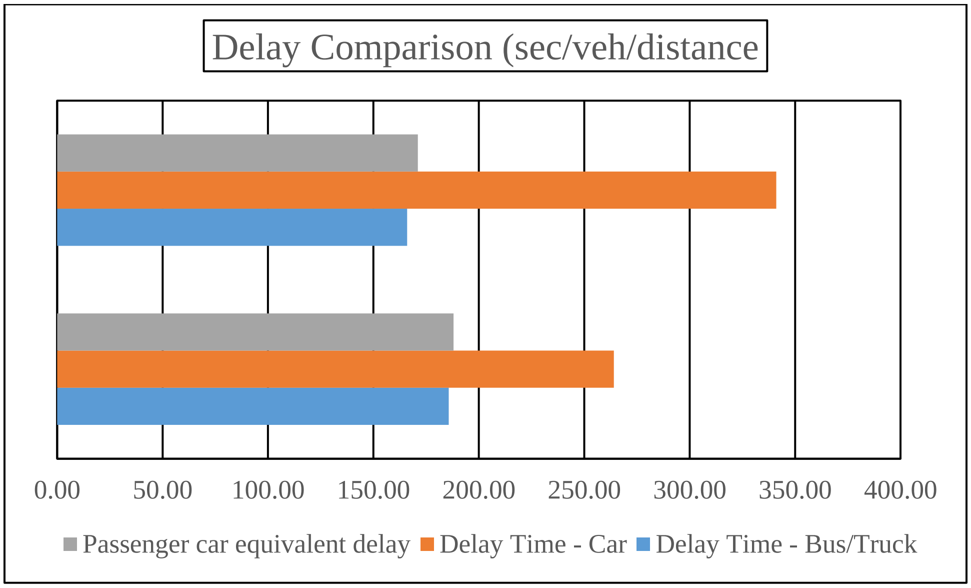


Figure 61: Comparison of delay metrics for the SLC

Figure 53 shows the comparison of delay metrics for the SLC using the bar. It is cleared that all those items for the measurement of delay metrics reduced due to the TSP implementation.

5.5.1.2 Vehicle total distance travelled

Vehicle travel time comparison is presented in the figure below. For this purpose, like as before, baseline scenario and after the implementation of TSP, and FSP for Broward Blvd. and Sunrise Blvd. respectively are considered.

Table 33: Vehicle total distance travelled comparison among the scenarios for Broward and Sunrise Blvd.

Total Distance Travelled (km)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Total Distance Travelled - Bus/Truck	103.59	96.61	2692.79	2629.91
Total Distance Travelled - Car	35004.24	34993.89	19446.20	19845.81
Passenger car equivalent distance travelled	1120.11	1113.04	13861.73	14107.18
% change of passenger distance travelled	-0.64		1.74	

The above table shows that overall, % change of passenger distance travelled is reduced a little for the Broward, and a bit increment in Sunrise case. It is 0.64%, and 1.74% respectively. Total Distance Travelled - Bus/Truck, Total Distance Travelled – Car, and Passenger car equivalent distance travelled parameters endorse that. Implying factors for the car, bus, and truck, Passenger car equivalent distance travelled reduced from 1120.11 km to 1113.04 km for the Broward Blvd., and increased from 13861.73 km to 14107.18 km for the Sunrise Blvd.

Table 34: Vehicle total distance travelled comparison among the scenarios for SLC

Total Distance Travelled (km)	**SLC**	
	Baseline	**After TSP**
Total Distance Travelled - Bus	522.74	586.17
Total Distance Travelled - Car	17112.77	15370.35
Passenger car equivalent distance travelled	1005.94	1016.78
% change of passenger distance travelled	1.07	

For the SLC network, vehicle total distance travelled parameters increased by some margin from the baseline scenario to after the TSP implementation. 1.07 % change of passenger distance travelled is observed. Passenger car equivalent distance travelled is changed from 1005.94 km to 1016.78 km. Endorsing those, it is found that Total Distance Travelled – Bus, and Total Distance Travelled – Car increased by 12%, and 10% respectively.

5.5.1.3 Vehicle travel time

Table 35: Vehicle travel time comparison among the scenarios for Broward and Sunrise Blvd.

Travel Time (sec/veh/distance)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Travel Time - Bus/Truck	389.97	382.12	134.86	129.60
Travel Time - Car	323.35	321.81	1259.45	1255.63
Passenger car equivalent travel time	388.03	380.36	884.59	880.28
% change of passenger distance travelled	-2.02		-0.49	

Vehicle travel time comparison among the scenarios for Broward and Sunrise Blvd. is shown in the Table 14. It is noticed that travel time parameters reduced for both the Broward and Sunrise Blvd. after the TSP, and FSP respectively. Overall, % change of passenger distance travelled is 2.02% reduction for the Broward, and 0.49% decrement for the Sunrise Blvd.

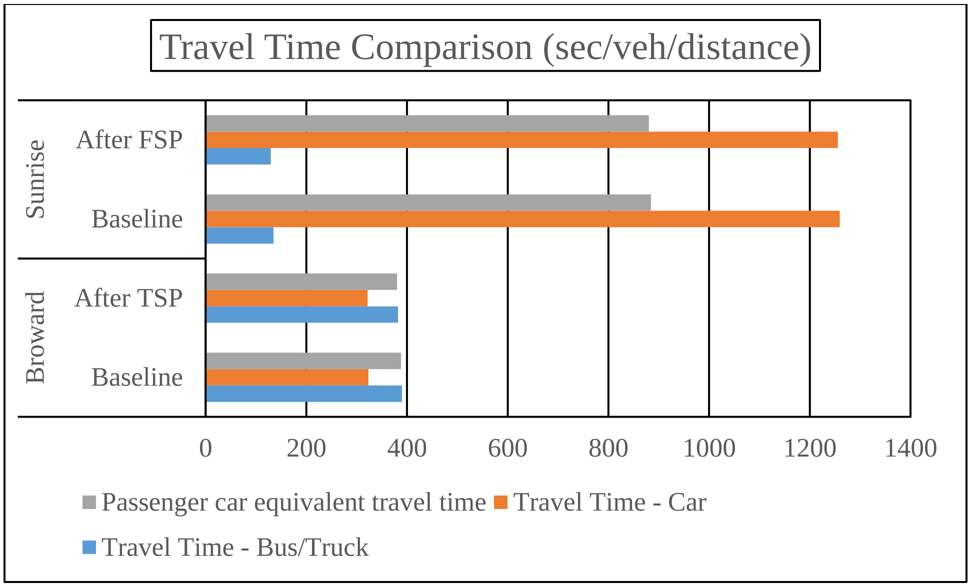


Figure 62: Comparison of vehicle travel time metrics for Broward and Sunrise Blvd.

Comparison of vehicle travel time metrics for the SLC shown in the figure 53, represents that Travel Time - Bus/Truck increased for Broward after the TSP i.e. around 2%, and for the Sunrise, it got increased i.e. around 4%. Considering Travel Time – Car, it is reduced for both the Broward, and Sunrise Blvd, i.e. 0.47%, and 0.30% respectively. And, finally, Passenger car equivalent travel time for the Broward Blvd. changed from 388.03 sec/veh/distance to 380.36 sec/veh/distance, for the Sunrise, it got a downward trend of 884.59 sec/veh/distance to 880.28 sec/veh/distance.

Table 36: Vehicle travel time comparison among the scenarios for SLC

Travel Time (sec/veh/distance)	**SLC**	
	Baseline	**After TSP**
Travel Time - Bus	319.45	295.89
Travel Time - Car	337.15	414.12
Passenger car equivalent travel time	319.97	299.33
% change of passenger distance travelled	-6.89	

Vehicle travel time comparison among the scenarios for SLC network is shown in the Table 14, and Figure 53. It is correlated with the above descriptions that travel time metrics reduced after the TSP in the SLC. Overall, 6.89 % change of passenger distance travelled is found due to the TSP implementation.

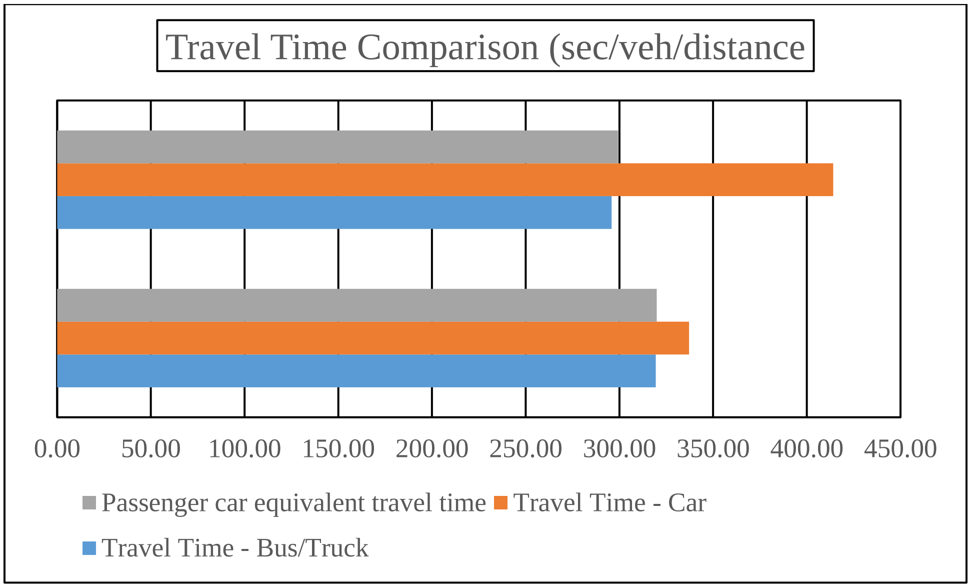


Figure 63: Comparison of vehicle travel time metrics for the SLC

Observing the bar chart above, it is seen that Travel Time – Bus, and Passenger car equivalent travel time parameters reduced. These are around 7.50%, and 6.50%. Only Travel Time – Car got increased i.e. 23%. Due to the implication of factors for Bus, car, Passenger car equivalent travel time got reduced.

5.5.1.4 Vehicle speed

Vehicle speed is compared in the following table 14, and 15 for the Broward, Sunrise, and SLC. From the Table 14, it is seen that Speed - Bus/Truck got an increasing trend for both the Broward, and Sunrise Blvd. Although, Speed – Car got higher due to the TSP at Broward, but due to the FSP at Sunrise, there is a little reduction from 29.92 kmph to 29.64 kmph.

Table 37: Vehicle speed comparison among the scenarios for Broward and Sunrise Blvd.

Vehicle speed (kmph)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Speed - Bus/Truck	9.92	10.13	20.61	20.99
Speed - Car	25.12	25.20	29.92	29.64

Table 38: Vehicle speed comparison among the scenarios for SLC

Vehicle speed (kmph)	**SLC**	
	Baseline	**After TSP**
Speed - Bus/Truck	13.13	15.35
Speed - Car	16.07	14.25

Table 14 shows the comparison of vehicle speed for SLC implying both baseline, and TSP. It is correlated with the Broward county network. Speed - Bus/Truck has found an increasing trend, while Speed – Car has reduced from 16.07 kmph to 14.25 kmph.

5.5.2 Safety of various scenarios

The safety performance measures i.e. lane changes (#/km), and standard deviation of speed are taken into consideration.

5.5.2.1 Lane changes

This part of the study is focused on the safety measures. Firstly, considering the lane change for the Broward and Sunrise Blvd. in both the baseline and after the TSP, and FSP. Overall, it is clearly noticed that the number of lane changes got reduced due to the priority.

Table 39: Vehicle lane change comparison among the scenarios for Broward and Sunrise Blvd.

Lane Changes (#/km)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After FSP**
Number of Lane Changes - Bus/Truck	1.83	1.7	56.61	52.6
Number of Lane Changes - Car	902.28	899.79	468.03	477.48

Table 14 represents that Number of Lane Changes - Bus/Truck got reduced for both of the Broward, and Sunrise Blvd. Also Figure 53 shows them in bar chart.

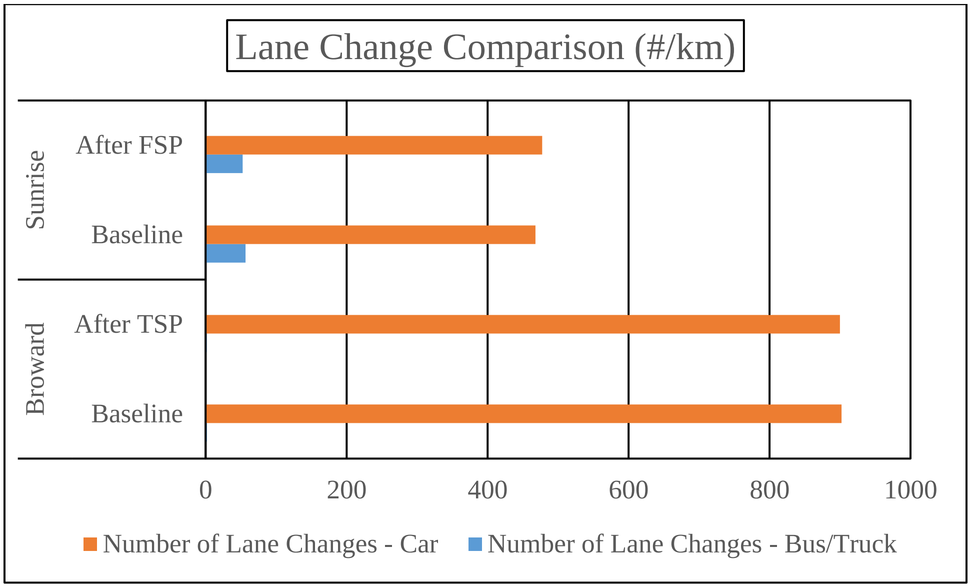


Figure 64: Comparison of lane change metrics for Broward and Sunrise Blvd.

From the bar chart shown above, it is seen that Number of Lane Changes - Bus/Truck is very much negligible with respect to the Number of Lane Changes – Car. For the Broward, Number of Lane Changes - Bus/Truck changed from 1.83 #/km to 1.7 #/km, and for the Sunrise it has changed from 56.61 #/km to 52.6 #/km. In case of Number of Lane Changes – Car, for the Broward, it got a downward trend from 902.28 #/km to 899.79 #/km, while in Sunrise it increased a little bit from 468.03 #/km to 477.48 #/km.

Table 40: Vehicle lane change comparison among the scenarios for SLC

Lane Changes (#/km)	**Broward**	
	Baseline	**After TSP**
Number of Lane Changes - Bus/Truck	10.72	12.3
Number of Lane Changes - Car	397.63	345.43

For the SLC, considering the lane change parameters, overall, thy got reduced. Like as the previous analysis Number of Lane Changes - Bus/Truck is very less comparing to the Number of Lane Changes – Car.

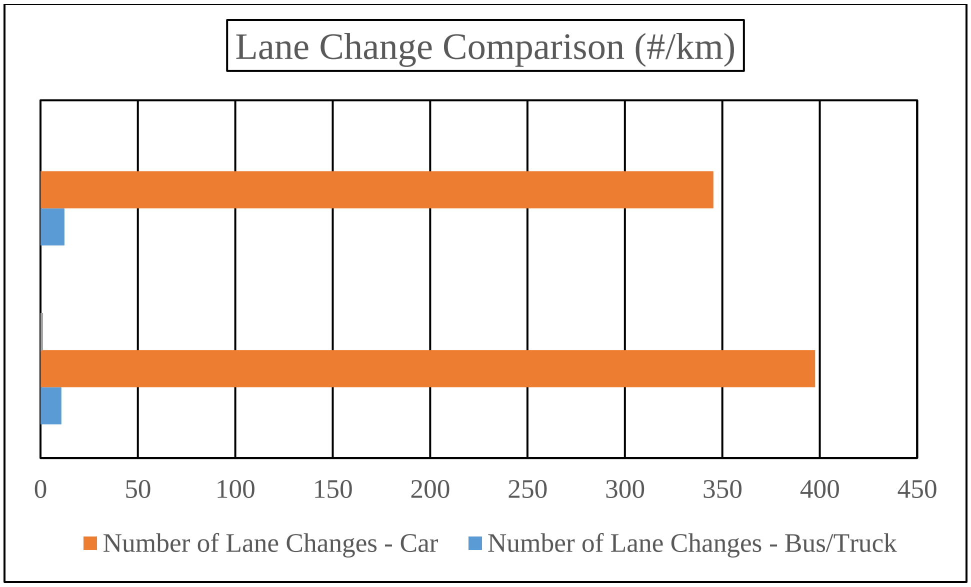


Figure 65: Comparison of lane change metrics for SLC.

Figure 53 shows the bar chart representation for the lane change parameters of the SLC network. In Number of Lane Changes - Bus/Truck, there is a little increase, but for Number of Lane Changes – Car, implementing the TSP, it got decreased tremendously i.e. 397.63 #/km to 345.43 #/km.

5.5.2.2 Standard deviation of speed

This part is taken into consideration the standard deviation of speed. Table 14 represents the comparison for the standard deviation of speed. It is seen that for Bus/Truck, significant reduction in the deviation i.e. 0.64 to 0.55 for Broward, and 0.30 to 0.28 for Sunrise. There is some change noticed for the Car.

Table 41: Vehicle's standard deviation of speed comparison among the scenarios for Broward and Sunrise Blvd.

Standard Deviation of Speed (kmph)	**Broward**		**Sunrise**	
	Baseline	**After TSP**	**Baseline**	**After TSP**
Bus/Truck	0.64	0.55	0.30	0.28
Car	0.2	0.25	0.16	0.15

Table 14 represents the comparison for the standard deviation of speed of SLC network. It is noticed that some amount of increment is for the Bus/Truck due to the implementation of TSP, while for Car, it got reduced from 0.24 to 0.22.

Table 42: Vehicle’s standard deviation of speed comparison among the scenarios for SLC

Standard Deviation of Speed (kmph)	**Broward**	
	Baseline	**After TSP**
Bus/Truck	0.47	0.77
Car	0.24	0.22

5.6 Conclusion and recommendation

An existing condition, a partial complete street scenario (TSP in this case) and a full complete street scenario (Streetcar in this case) were considered for SLC network. The difference between the partial complete street scenarios is that it has been enhanced with TSP but does not include other complete street features such as reduction in number of lanes, lower speed limits, etc.

After VISSIM simulation for all the scenarios, it has been found that for partial complete street scenario, delay has reduced for almost all parameters i.e. total delay, car delay, and person delay car; while these increased in the complete street scenario. Also, vehicle travel comparison indicates partial complete street scenario has the lowest value for maximum parameters (total travel time and car travel time). Only for bus travel time, complete street scenario has the smallest one. In addition, speed of vehicle increased in partial complete street scenario compared to the existing condition and complete street scenario for almost all parameter except the average speed of bus. This clearly justifies the partial complete street scenario as a better option than existing condition and complete street scenario.

Safety performance metrics from the SSAM analysis i.e. crossing conflict, rear end conflict, and lane change conflict show that despite the smallest number of conflict points in the complete street scenario, it has the greatest number of conflicts per vehicle. Therefore, a complete street scenario would make traffic safety less favorable than the existing condition and complete street scenario. Comparing between existing condition and partial complete street scenario, it has been observed that partial complete street scenario not only has the smaller number of conflicts but also fewer conflicts per vehicle. So, it is a clear that partial complete street scenario is the best option considering the efficiency and safety parameters.

This was further confirmed by the analysis of the macroscopic network performance. In addition, another case study was performed using two corridors (Broward Blvd. and Sunrise Blvd.) that are part of the Central Broward County network. This also confirmed that the partial complete street scenario was effective in enhancing efficiency and safety. Finally, we recommend future analyses to include long term route choice and travel behavior changes that could arise from complete street designs on one or a few key corridors within a network.

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